Lecture Notes in Mechanical Engineering

Rakesh Kumar Phanden
K. Mathiyazhagan
Ravinder Kumar
J. Paulo Davim *Editors*

Advances in Industrial and Production Engineering

Select Proceedings of FLAME 2020

Springer

Lecture Notes in Mechanical Engineering

Lecture Notes in Mechanical Engineering (LNME) publishes the latest developments in Mechanical Engineering—quickly, informally and with high quality. Original research reported in proceedings and post-proceedings represents the core of LNME. Volumes published in LNME embrace all aspects, subfields and new challenges of mechanical engineering. Topics in the series include:

- Engineering Design
- Machinery and Machine Elements
- Mechanical Structures and Stress Analysis
- Automotive Engineering
- Engine Technology
- Aerospace Technology and Astronautics
- Nanotechnology and Microengineering
- Control, Robotics, Mechatronics
- MEMS
- Theoretical and Applied Mechanics
- Dynamical Systems, Control
- Fluid Mechanics
- Engineering Thermodynamics, Heat and Mass Transfer
- Manufacturing
- Precision Engineering, Instrumentation, Measurement
- Materials Engineering
- Tribology and Surface Technology

To submit a proposal or request further information, please contact the Springer Editor of your location:

China: Dr. Mengchu Huang at mengchu.huang@springer.com
India: Priya Vyas at priya.vyas@springer.com
Rest of Asia, Australia, New Zealand: Swati Meherishi at swati.meherishi@springer.com
All other countries: Dr. Leontina Di Cecco at Leontina.dicecco@springer.com

To submit a proposal for a monograph, please check our Springer Tracts in Mechanical Engineering at http://www.springer.com/series/11693 or contact Leontina.dicecco@springer.com

Indexed by SCOPUS. All books published in the series are submitted for consideration in Web of Science.

More information about this series at http://www.springer.com/series/11236

Rakesh Kumar Phanden · K. Mathiyazhagan ·
Ravinder Kumar · J. Paulo Davim
Editors

Advances in Industrial and Production Engineering

Select Proceedings of FLAME 2020

Springer

Editors
Rakesh Kumar Phanden
Department of Mechanical Engineering
Amity School of Engineering and Technology
Noida, Uttar Pradesh, India

K. Mathiyazhagan
Department of Mechanical Engineering
Amity School of Engineering and Technology
Noida, Uttar Pradesh, India

Ravinder Kumar
Department of Mechanical Engineering
Amity School of Engineering and Technology
Noida, Uttar Pradesh, India

J. Paulo Davim
Department of Mechanical Engineering
University of Aveiro, Campus Santiago
Aveiro, Portugal

ISSN 2195-4356 ISSN 2195-4364 (electronic)
Lecture Notes in Mechanical Engineering
ISBN 978-981-33-4319-1 ISBN 978-981-33-4320-7 (eBook)
https://doi.org/10.1007/978-981-33-4320-7

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

This book brings together the collection of cutting-edge research articles on industrial and production engineering from the Second International Conference on Future Learning Aspects for Mechanical Engineering (FLAME), which was organized by Amity University, Noida, Uttar Pradesh, India, from August 5 to 7, 2020. Owing to pandemic COVID 19 this conference was held virtually. The primary mission of this conference was to lay a platform that brings together academicians, scientists, and researchers across the globe to share their scientific ideas and vision in the areas of thermal, design, industrial, production, and interdisciplinary areas of mechanical engineering. FLAME 2020 played a key role to set up a bridge between academia and industry.

The conference hosted almost 600 participants to exchange scientific ideas. During 3 days of the conference, researchers from academics and industries presented the most recent cutting-edge discoveries, went through various scientific brainstorming sessions, and exchanged ideas on practical socioeconomic problems. This conference also provided a scope to establish a network for joint collaboration between academia and industry. Major emphasis was focused on the recent developments and innovations in various fields of mechanical engineering through plenary and keynote lectures.

In particular, this volume discusses different topics of industrial and production engineering in eighty eight chapters such as sustainable manufacturing processes, logistics, Industry 4.0 practices, circular economy, lean six sigma, agile manufacturing, additive manufacturing, IoT and Big Data in manufacturing, 3D printing, simulation, manufacturing management and automation, surface roughness, multi-objective optimization and modelling for production processes, developments in casting, welding, machining, and machine tools. The contents of this book will be useful for researchers as well as industry professionals.

We would like to acknowledge all the participants who have contributed to this volume. We also deeply express our gratitude for the generous support provided by Amity University, Noida. We also thank the publishers and every staff of the department and institute who have directly or indirectly helped to accomplish this goal. Finally, we would also like to express our gratitude to Respected Founder

President, Amity University, Dr. Ashok K. Chauhan, for providing all kinds of support and this book is not complete without his blessings.

Noida, India — Dr. Rakesh Kumar Phanden
Noida, India — Dr. K. Mathiyazhagan
Noida, India — Dr. Ravinder Kumar
Aveiro, Portugal — Prof. J. Paulo Davim
October 2020

Contents

About the Editors

Rakesh Kumar Phanden completed his graduation in Mechanical Engineering from U.P. Technical University, Lucknow, India, and post-graduation in Integrated Product Design and Manufacturing from the Department of Mechanical Engineering, G.J.U. of Science and Technology, Hisar, India. He completed his Ph.D. in Mechanical Engineering from the National Institute of Technology, Kurukshetra, India, in 2013. He is postdoctorate from Cranfield University, UK. He is currently working in the Department of Mechanical Engineering at the Amity University, Uttar Pradesh, India. He has 18 years of teaching experience at private and government institutes and universities. He has contributed more than 45 papers at the national/international levels. He has published and edited a book on *Integration of Process Planning and Scheduling: Approaches and Algorithms* in CRC Press and worked as a Guest Editor of a *Special Issue on Advancements in Modern Machining Methods* in *the International Journal of Machining and Machinability of Materials*. He is serving as an editorial board member for many international journals. He is an active reviewer in many international journals of repute. His current areas of interest include flexible manufacturing systems, production scheduling, integration of process planning and scheduling, product design and manufacturing, digital twin and threads, nature-inspired algorithms, discrete simulation.

Dr. K. Mathiyazhagan is working as an Associate Professor in the Department of Mechanical Engineering, Amity University, Noida, UP, India. He is an Associate Editor of Environment, Development and Sustainability, Springer, with an impact factor of 2.1 and editing special issues in *International Journal of Physical Distribution and Logistics Management* (Emerald, IF: 4.7, ABDC: A), *International Journal of Logistics Management* (IJLM, IF: 3.3, ABDC: A) and *Sustainability journals*. His publications are in IJPE, IJPR, PPC, IEEE TEM, JCP, RCR, IJAMT, etc. Also, he is an editorial member in more than five international journals. Recently, one of his papers was awarded as Excellence Citation Award by Emerald Publisher Ltd. Presently, he is editing two books in Elsevier and one in Springer. Also, he is a visiting faculty in the University of Rome Tor Vergata, Italy. He is an active reviewer of more than 30 reputed international journals in Elsevier, Springer, Emerald and Taylor & Francis. Dr. K. Mathiyazhagan received the best reviewer certificate from reputed journals. He supervised more than 10 undergraduate and 3 postgraduate and 1 Ph.D. scholar. His research interest is in Green Supply Chain Management; Sustainable Supply Chain Management; Multi-Criteria Decision Making; Third Party Logistic Provider; Sustainable Lean Manufacturing, Public Distribution System; Lean Six Sigma. He is having more than 10 years of research and teaching experience.

Dr. Ravinder Kumar is working as an Associate Professor in Mechanical Engineering, Amity University, Noida, India. His research interest is in Operation Management, SCM of SMEs, Industry 4.0 and Sustainable manufacturing. He did his Ph.D. from the Faculty of Technology, University of Delhi, in 2014. He is having more than 15 years of teaching and research experience. His thesis was on "Coordination and Responsiveness issues of Supply Chain management in Indian SMEs". His M.E. was in Production Engineering from the Department of Mechanical and Production Engineering, Delhi College of Engineering, University of Delhi, in 2007 and B.E. in Mechanical Engineering from the Department of Mechanical Engineering, M.D. University, Rohtak with (Hons.).

He is an active reviewer of various Journals, namely *International Journal of Technology Management*—Inderscience, *Journal of Quality in Maintenance Engineering*—Emerald, *Journal of Modelling in Management*—Emerald, *Benchmarking: An International Journal*—Emerald. He has published more than 20 research papers published in peer-reviewed international journals and 10 Papers in National Journal as well as around 15 Research papers presented in the International Conferences. He has published a Book Chapter (Scopus Index) in the Handbook of Research on Social and Organizational Dynamics in the Digital Era. IGI Global. He has reviewed a book on *Engineering Drawing* by I. K. International Publishing House Pvt. Ltd., New Delhi.

J. Paulo Davim received his Ph.D. degree in Mechanical Engineering in 1997, M.Sc. degree in Mechanical Engineering (materials and manufacturing processes) in 1991, Mechanical Engineering degree (5 years) in 1986 from the University of Porto (FEUP), the Aggregate title (Full Habilitation) from the University of Coimbra in 2005 and the D.Sc. from London Metropolitan University in 2013. He is a Senior Chartered Engineer by the Portuguese Institution of Engineers with an MBA and Specialist title in Engineering and Industrial Management. He is also an Eur Ing by FEANI-Brussels and Fellow (FIET) by IET-London. Currently, he is a Professor at the Department of Mechanical Engineering of the University of Aveiro, Portugal. He has more than 30 years of teaching and research experience in Manufacturing, Materials, Mechanical and Industrial Engineering, with special emphasis in Machining & Tribology. He has also interest in Management, Engineering Education and Higher Education for Sustainability. He has guided large numbers of postdoc, Ph.D. and master’s students as well as has coordinated and participated in several financed research projects. He has received several scientific awards. He has worked as evaluator of projects for ERC-European Research Council and other international research agencies as well as examiner of Ph.D. thesis for many universities in different countries. He is the Editor-in-Chief of several international journals, Guest Editor of journals, book editor, book series editor and

Scientific Advisory for many international journals and conferences. Presently, he is an Editorial Board member of 30 international journals and acts as a reviewer for more than 100 prestigious Web of Science journals. In addition, he has also published as editor (and co-editor) for more than 100 books and as author (and co-author) for more than 10 books, 80 book chapters and 400 articles in journals and conferences (more than 250 articles in journals indexed in Web of Science core collection/h-index 50+/7500+ citations, SCOPUS/h-index 56+/10500+ citations, Google Scholar/h-index 71+/16500+).

An Explorative Analysis of IoT Applications in Cold Chain Logistics

Marina Marinelli, Mukund Janardhanan, and Nicos Koumi

Abstract This research aims to investigate the main operational challenges of sensitive products (e.g., food, drugs) and propose a framework for the enhancement of the quality and efficiency of the respective logistics process. Four semi-structured interviews were conducted with senior executives of a Cypriot company, which specializes in the provision of Warehousing and Distribution logistics services, in order to obtain insight regarding the company's processes, monitoring systems and difficulties. Based on the interview findings and the literature's suggestions, an IoT platform is introduced with the aim to achieve real-time monitoring of the products' and vehicle's temperature and humidity as well as other transportation parameters, including the vehicle's position. The platform provides real-time, easily accessible information making use of appropriate technologies and applications, such as the Radio Frequency Identification (RFID) tags, Wireless Sensor Network (WSN) and cloud computing. The proposed platform is beneficial for companies involved in cold-chain logistics (CCL), and it leads to operations typified by much higher efficiency levels while increasing the satisfaction level of the end consumers.

Keywords Cloud · Cold chain · IoT · Logistics · Temperature monitoring

1 Introduction

With the rapid growth of the world population, reaching nowadays nearly 7 billion people and over 9 billion by 2050, the need for goods to be transported worldwide increased exponentially. As by now, millions of tons of goods are being produced in factories, transported through any possible ways, stored in warehouses and distributed all around the world [1]. Consequently, in order for the products to reach the customer without suffering any loss or damage on their way to the final destination, logistics are introduced. The term logistics is generally used to refer to the process of coordinating and moving resources—people, materials, inventory and equipment.

M. Marinelli · M. Janardhanan (✉) · N. Koumi
School of Engineering, University of Leicester, Leicester LE17RH, UK
e-mail: mj251@le.ac.uk

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_1

Nonetheless, there are foods and drugs which need special treatment because of the temperature and humidity conditions that are required to be met during their transportation process. Therefore, to ensure that the abovementioned products will maintain their temperature and subsequently avoid possible damages or be compromised throughout their transportation, businesses in different industries such as pharmaceutical, medical and food industries, rely on the Cold Chain. The Cold Chain involves the transportation of temperature-sensitive products along a supply chain through thermal and refrigerated packing methods and the logistical planning to protect the integrity of these shipments [2]. A number of researches based on the impact of temperature on the product's quality and shelf-life have been conducted [3–5] and the findings suggest that the relationship between temperature and quality is crucial and thus, the advancement of the quality and safety monitoring of the cold chain logistics (CCL) procedure is of significant importance [6]. In this context, ensuring the continuity of the cold chain between the producer and the final consumer is a key quality requirement as well as a major challenge. This research aims to investigate the main operational challenges of the cold chain and propose a framework for the enhancement of the quality and efficiency of the respective logistics process. The paper highlights useful industrial practices regarding the use of Internet of Things (IoT) technology in sensitive product logistics, contributing to the improvement of operational efficiency of similar processes.

2 Literature Review

A cold chain makes sure that the product's quality and integrity is maintained through temperature and humidity control [7–9]. In addition, the cold chain is aiming to protect the integrity of the Temperature-Sensitive and Perishable Products (TSPP), starting from the production and processing stage to the transportation stages, which include handling, loading and storage, and last to the customer's own storage [2]. A cold chain without the appropriate and effective management can lead to several quality and safety issues. Consequently, suitable equipment, along with the proper handling and control of information, are necessary so as to maintain the quality and integrity of the TSPP [8, 9]. However, monitoring and controlling the temperature of the products throughout the cold chain is also the hardest management task [6, 10].

Various researchers have previously worked on the Cold Chain Management (CCM), that is, the mechanisms aiming at maintaining the proper temperature for the products and more specifically at minimizing the temperature fluctuations during transit [8, 11, 12]. In a study conducted by Mattoli et al. [13] a Flexible Tag Datalogger (FTD) was designed and developed to improve the logistics of food and goods during their transportation, storage and vending. The sensors placed on wine bottles were transmitting temperature, humidity and light data to a smartphone using infrared communication through an integrated port. However, the authors concluded that the FTD was not able to provide reliable parameter monitoring as the memory of the device was insufficient. Ruiz-Garcia et al. [14] also studied the performance of

ZigBee-based wireless sensor nodes for real-time monitoring of fruit transportation and storage and concluded that this is a promising solution. Moreover, another study by Ruiz-Garcia et al. [15] looked at the performance of ZigBee nodes on tracking a refrigerator that carried vegetables from Spain to France. The gathered information regarding the temperature, humidity, opening of doors and refrigerator vehicle's stops led to the conclusion that this type of nodes has great potential. Furthermore, the renowned technology of Radio Frequency Identification (RFID) was successfully used by Trebar et al. [16] to develop a temperature monitoring solution for the fish supply chain which, once the delivery was completed, could make the relevant data available to be checked on the mobile RFID reader. The data could also be stored in a database and be presented on the web. Another study conducted by Chandra and Lee [17] combined an Arduino WSN with Xively sensors in a cloud-based application developed to monitor the CCL using the Internet of Things (IoT), the latest and most hyped concept in the Information Technology world, based on the vision of physical objects being networked through a worldwide infrastructure, allowing anyone and anything to connect anytime, no matter where they are [18]. The authors [17] concluded that there are numerous benefits in the integration of WSN infrastructure into the cloud, including the reduction of power consumption and the increase of the network lifetime, as the integration releases the devices from running heavy algorithms and programs.

3 Methodology

Several previous literature studies, relevant to the specific topic of this paper, were gathered and examined regarding advanced logistics methods for capturing and monitoring temperature data, throughout the cold chain process. Obtaining already existing information associated with the topic of study allows for improvements in the initial reflections and of identified concepts [19]. This benefits the researchers as it can be used as a framework for further organizations and the expansion of the specific topic [20]. Complementarily, a case study strategy, was adopted to view the topic from multiple perspectives and in a real-life situation [21]. The organization used for the collection of primary data relevant to the operational details of Cold chain logistics is a Cypriot-based company that specializes in the provision of Warehousing and Distribution logistics services. They have large warehousing facilities, approximately 200 vehicles, they do more than 2,500,000 pickings annually, they distribute 100,000 pallets every year and lastly, they are equipped with the latest Information Technology (IT) systems.

In general, there are three possible interview methods, structured, semi-structured and unstructured interviews. The best way to gather significant information about a specific topic is to use semi-structured or unstructured interviews in order to obtain relevant information about the exploratory study [22]. This research paper is grounded on semi-structured interviews, with the participating interviewees been well-informed and able to deliver facts, real-life examples and answer queries on the research topic [23]. Four face-to-face interviews with executives with more than 20 years of experience in logistics were conducted in June 2019. In order to identify the participants who had the necessary characteristics in order to take part in the interviews, this research used the purposive sampling method [24]. The purposive sampling method uses individuals with increased knowledge and experience in leading and managerial positions in the logistics business as they could decisively generate useful information regarding the purpose of the research study.

The interview agenda was mainly about the company and the logistics process that they follow and the issues that they face, along with topics regarding management, planning, and coordination within the company. The interviewees also had the opportunity to express their views and beliefs through the use of open-ended questions and follow-up questions emerging from the discussion, as the semi-structured method allows for [19, 25]. Concluding, as all four of the interviewees gave similar answers to the questions and no new surprising topics were risen from their responses, the data collection reached a saturation point and was deemed as efficiently completed [19, 23]. The responses, along with a combination of technologies well tested in the literature, were then used by the researchers as a basis for the development of an improved IoT-supported framework for the introduction of a CCL process of higher efficiency.

4 Results and Analysis

4.1 Interview Results

During the interviews, useful information was collected related to specific and real-life situations. Regarding how the logistics process works, the interviewees mentioned that when the ship or the plane is near the port or the airport, respectively, a refrigerated vehicle is informed by a phone call in order to load the products into the vehicle without delays. Following the vehicle's departure from the port/airport, the warehouse gets informed about the arrival of those products along with their characteristics of size, and their required needs, for instance, their storing temperature and therefore the warehouse is prepared to receive and store products appropriately. Regarding temperature monitoring, the current system is based on the use of sensors located at different positions inside the vehicle as well as barcodes attached to products, able to provide temperature data following scanning.

All four interviewees were asked about the issues that they face during the process. The main issue unanimously reported was about the quantities of damaged products not suitable for customer use which result from inefficient monitoring of the transportation process as far temperature deviations or possible major vibrations are concerned. Issues associated with delays are also common in the pickup and the delivery to a certain destination when a refrigerator vehicle or even the warehouse is not correctly informed regarding the products' arriving time, size and quantity and, therefore, are not ready or prepared to handle appropriately the products due to possible misunderstandings or misuse of information flow between the company's personnel. Taking into account the respective financial losses, the interviewees agreed that it is imperative to introduce a system able to constantly provide them real-time data reflecting the shipment's condition and location throughout the whole transportation process.

4.2 Proposed Framework Based on the Case Study

Based on the interview findings and the technology solutions previously tested in the literature, this paper introduces an IoT cloud-based platform for products that need constant temperature control during transportation. First of all, the proposed framework aims at providing constant monitoring of the product condition by gathering, transmitting and analyzing temperature data in real-time. The data is provided by wireless sensors that are placed at multiple positions inside the refrigerated vehicles to monitor for humidity and temperature changes. For instance, a sensor can be installed on the door of the refrigerated vehicle in order to indicate when the door is open. Besides temperature and humidity fluctuation, product quality can be also affected by gases, such as oxygen and carbon dioxide emissions [26]. These elements can be monitored again with gas sensors to make sure they are at the required levels. Product data is also monitored and sustained in a cloud-based IoT platform, which enables constant availability and provides for backup and reduced risk of data loss.

The above is achieved with the use of RFID tags attached to the sensitive products so as to send each product's data during their transit to the Micro Control Unit (MCU). Then the MCU continues to send the products' data and their location to the cloud-based IoT platform by the use of a GPRS data transmission unit and a Zigbee coordinator, which has the lowest cost and highest battery life compared to Wi-Fi and Bluetooth [27]. Further to the above, a camera can be installed inside the refrigerated vehicle to monitor with real-time video any undesirable movement of the shipment. In addition, by using a GPS receiver module, the refrigerated vehicle's position can be tracked by combining a GPS module with an onboard computer. As the vehicle's position is getting tracked during transportation, notification messages can be produced and sent to the users when the vehicle takes an unexpected route. For instance, if a shipment is delayed, long queues generated by refrigerator vehicles can be prevented because the platform can inform the driver of the exact time to arrive at the collection point. The refrigerator vehicle paths can also be optimized by minimizing the traveling time and distance.

The above features can be grouped into four modules; the context module, the network module, the server module and the application module (Fig. 1). The context module includes sensors and RFID tags. The data generated from the first module are transmitted to the server module through the network module that includes the Satellite and the ZigBee coordinator. Finally, the data are available to the users through the application module, where information such as temperature deviations

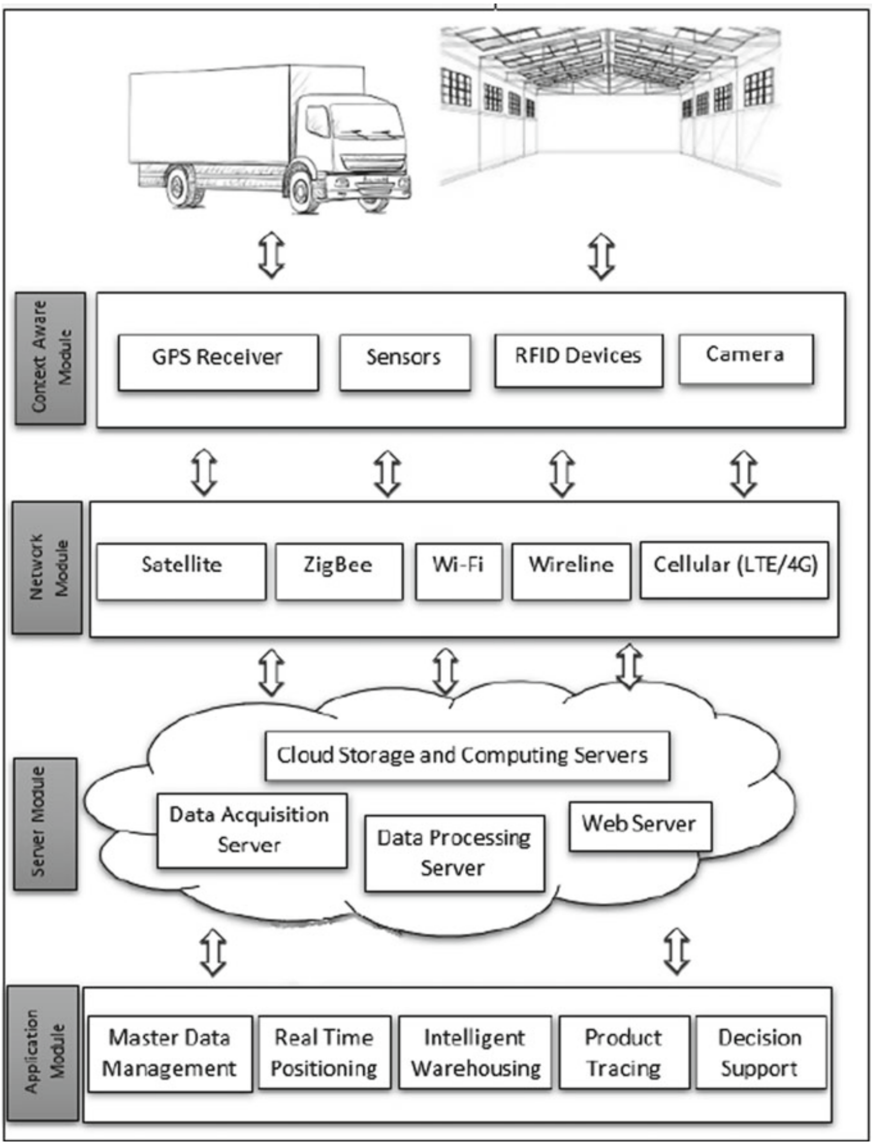


Fig. 1 The different modules of the proposed framework

and real-time positioning of the refrigerator vehicles can be generated anytime and anywhere. The cost of implementation of this platform is around 1700 GBP and the majority of the cost is incurred for the purchase of the RFID reader (Table 1).

A typical product transportation management system, based on the framework explained, provides a number of benefits such as improved food safety and quality

Table 1 Bill of materials—proposed system

Element	Cost £
RFID reader	902.00
RFID tags	8.00
Temperature and humidity sensors	21.00
Microcontroller	9.00
Wireless module kit	11.00
Real-time vehicle tracker	40.00
Integrated navigation receiver, GPS	42.00
Labor charges-electrician	700.00
Total	1733.00

for end consumers. The system also helps in the prevention of product spoilage through automatic temperature monitoring based on the use of RFID traceable tags. Furthermore, improved process efficiency resulting from an accurate estimation of the refrigerator vehicles' arrival time through GIS and prevention of long queues, unnecessary fuel consumption and waiting periods. Moreover, employees also benefit from automatic data collection, transmission, storage and analysis as it minimizes human involvement and subsequent errors. Last but not least, the users can access the cloud-based platform anytime and anywhere using smart devices such as computers, tablets and smartphones.

5 Conclusion

An IoT cloud-based platform solution was introduced based on interview findings and well-tested literature suggestions in order to enhance operational efficiency in cold chain logistics. The solution uses RFID tags and temperature/humidity sensors in order to collect data from the environment inside the refrigerator vehicles and the warehouse. The data are then sent to the cloud-based data center and are made available to the users anytime and anywhere, leading to the real-time detection of changes in the shipments' environmental context. The information obtained are beneficial to the CCL managers as they can take the appropriate and accurate decisions when it comes to unexpected situations, improving, thus, both the efficiency of the process and customer satisfaction.

References

1. Tsang, Y.P., Choy, K.L., Wu, C.H., Ho, G.T.S., Lam, H.Y., Koo, P.S.: An IoT-based cargo monitoring system for enhancing operational effectiveness under a cold chain environment. Int. J. Eng. Bus. Manag. **9**, 1847979017749063 (2017)

2. Rodrigue, J. and Notteboom, T.: The Geography of Transport Systems. Routledge (2016). Available at: https://transportgeography.org/?page_id=6585. Accessed 7 June 2019
3. Bruckner, S., Albrecht, A., Petersen, B., Kreyenschmidt, J.: Influence of cold chain interruptions on the shelf life of fresh pork and poultry. Int. J. Food Sci. Technol. **47**(8), 1639–1646 (2012)
4. Jedermann, R., Nicometo, M., Uysal, I., Lang, W.: Reducing food losses by intelligent food logistics. Philos. Trans. A Math. Phys. Eng. Sci. **372**, 20130302 (2014)
5. Raab, V., Bruckner, S., Beierle, E., Kampmann, Y., Petersen, B., Kreyenschmidt, J.: Generic model for the prediction of remaining shelf life in support of cold chain management in pork and poultry supply chains. J. Chain Netw. Sci. **8**(1), 59–73 (2008)
6. Aung, M.M., Chang, Y.S.: Temperature management for the quality assurance of a perishable food supply chain. Food Control **40**, 198–207 (2014)
7. Arduino, G., Carrillo Murillo, D., Parola, F.: Refrigerated container versus bulk: evidence from the banana cold chain. Maritime Policy Manag. **42**(3), 228–245 (2015)
8. Bharti, M.A.: Examining market challenges pertaining to cold chain in the frozen food industry in Indian retail sector. J. Manag. Sci. Technol. **2**(1), 33–40 (2014)
9. Faisal, M.N.: Prioritising agility variables for cold supply chains. Int. J. Logist. Syst. Manag. **10**(3), 253–274 (2011)
10. Montanari, R.: Cold chain tracking: a managerial perspective. Trends Food Sci. Technol. **19**(8), 425–431(2008)
11. Kuo, J.C., Chen, M.C.: Developing an advanced multi-temperature joint distribution system for the food cold chain. Food Control **21**(4), 559–566 (2010)
12. Salin, V., Nayga, R.M., Jr.: A cold chain network for food exports to developing countries. Int. J. Phys. Distrib. Logist. Manag. **33**(10), 918–933 (2003)
13. Mattoli, V., Mazzolai, B., Mondini, A., Zampolli, S., Dario, P.: Flexible tag datalogger for food logistics. Procedia Chem. **1**(1), 1215–1218 (2009)
14. Ruiz-Garcia, L., Barreiro, P., Robla, J.I.: Performance of ZigBee-based wireless sensor nodes for real-time monitoring of fruit logistics. J. Food Eng. **87**(3), 405–415 (2008)
15. Ruiz-Garcia, L., Barreiro, P., Robla, J.I., Lunadei, L.: Testing ZigBee motes for monitoring refrigerated vegetable transportation under real conditions. Sensors **10**(5), 4968–4982 (2010)
16. Trebar, M., Lotrič, M., Fonda, I., Pleteršek, A., Kovačič, K.: RFID data loggers in fish supply chain traceability. Int. J. Antennas Propag. (Article ID 875973), 9 (2013)
17. Chandra, A.A., Lee, S.R.: A method of WSN and sensor cloud system to monitor cold chain logistics as part of the IoT technology. Int. J. Multim. Ubiquit. Eng. **9**(10), 145–152 (2014)
18. Kosmatos, E.A., Tselikas, N.D., Boucouvalas, A.C.: Integrating RFIDs and smart objects into a Unified Internet of Things architecture. Adv. Internet Things **1**(01), 5–12 (2011)
19. Yin, R.: Qualitative Research from Start to Finish. The Guilford Press, New York, NY (2016)
20. Taylor, S.J., Bogdan, R., DeVault, M.L.: Introduction to Qualitative Research Methods: A Guidebook and Resource. Wiley, NJ (2016)
21. Baxter, P., Jack, S.: Qualitative case study methodology: study design and implementation for novice researchers. Qualit. Rep. **13**(4), 544–559 (2008)
22. Saunders, M., Lewis, P., Thornhill, A.: Research Methods for Business Students, 5th edn. Pearson, Harlow (2012)
23. Tracy, S.J.: Qualitative Research Methods: Collecting Evidence, Collecting Evidance, Crafting Analysis, Communicating Impact. Willey-Blackwell, UK (2013)
24. Creswell, J.W., Poth, C.N.: Qualitative inquiry and research design: Choosing among five approaches. Sage publications (2017).
25. Rubin, H.J., Rubin, I.S.: Qualitative Interviewing: The Art of Hearing Data. Sage.
26. Lu, S., Wang, X.: Toward an intelligent solution for perishable food cold chain management. In: 2016 7th IEEE International Conference on Software Engineering and Service Science (ICSESS), pp. 852–856 (2016)
27. Liu, T., Liu, J., Liu, B.: Design of intelligent warehouse measure and control system based on Zigbee WSN. In: 2010 IEEE International Conference on Mechatronics and Automation, pp. 888–893. IEEE (2010)

Improvements in Production Line Using ProModel© Simulation Software: A Case Study of Beer Beverage Company in India

Rakesh Kumar Phanden, Jatinder Chhabra, Tushar Chaudhary, and Akash Kaliramna

Abstract In the present competitive market scenarios, the beverage industries are working hard to increase the production volume without compromising the quality of products. There are many ways to improve the effectiveness and performance of the production lines, such as minimizing the transportation time between the locations, utilizing the buffer storages, removing and replacing manually operated and semi-automatic machines, use of group technology and many more methods. In the present study, a beer production company located in Sonipat (Haryana) India is a Small-to-Medium Enterprise (SME) striving to improve its production line layout. Thus, the exiting layout of the production line has been simulated using ProModel© 7.5 simulation software and two alternative production line layouts have been suggested with improved work-in-progress, higher production volume and less transportation time. In one alternative layout, the buffer storage and rearrangement of machines for shortening the travel distance have been introduced and in another alternative layout, the automatic guided vehicle has been replaced with the conveyor as well as two machines namely filling machine and capping machine have been replaced by a machine called Filling and Capping machine in order to perform both operation at the same time. Various conclusions have been drawn and the cost analysis has been presented to justify the suggested changes.

Keywords Work-in-progress · Production volume · Cost analysis · Alternative production line layouts · Simulation · ProModel© software

R. K. Phanden · T. Chaudhary · A. Kaliramna
Department of Mechanical Engineering, Amity School of Engineering and Technology, Amity University, Uttar Pradesh Noida 201313, India

J. Chhabra (✉)
Department of Mechanical Engineering, MMEC, Maharishi Markandeshwar (Deemed To Be University) Mullana, Ambala, Haryana 133207, India
e-mail: jatinderchhabra1973@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_2

1 Introduction

In the previous decades, the beer market has been matured enough in India. However, it is restricted to varieties of beers. Also, many beer beverage multinational corporations (MNCs) are entering India but owing to the mammoth import taxes; these companies have very limited access to the major cities. These MNCs are unable to achieve much more but giving tough competition to the domestic beer beverage manufacturers. The beer market witnessed a growth of 8.12% in the last decade, as reported by Goldstein Research analyst. According to a report, there are around 500,000 bars and pubs as well as around 10 million beer outlets within India. The beer industry in India is still following the traditional business structures and managed by local cooperative groups and individuals. Therefore, this industry is still using conventional and general-purpose machines and processes of beer production and bottling methods. Thus, the present work is focused on a beer beverage company in order to improve its plant performance. The production line layout of a beer beverage plant is a type of flow shop production having a product layout [1]. The present work aims to improve the facility layout of the taken case study of a beer company. It is an Indian small and medium enterprise (SME) having a production line layout and company named XYZ company, Sonipat, Haryana, India (*the name of company is not revealed due to privacy and internal policies*).

The beer beverage company possessed the product layout which is appropriate for the facilities to make a specific type of product [1, 2]. Thus, machines are arranged in an order of operations of beer production and bottling processes. In general, the facility layout problems aim to minimize material handling, lower WIP, effective utilization of space, machines and labor as well as higher production volume [3]. In general, this problem can be defined as a plan of an optimum arrangement of departments, personal, equipment's and storage spaces to design the best structure of the facilities in order to improve the performance of the production system [4]. In order to solve this problem, numerous research studies reported that the simulation-based modeling is the most convenient and proven way in order to represent the actual situations to detect bottlenecks, to enhance system performance in terms of productivity, queues, resources utilization, lead time and work-in-process [5–28]. In line with the present work, contribution by various researchers on performance improvement of plant layouts through various simulation software are presented below.

Altinkilinc [11] proposed simulation-based layout planning to improve material flow using ARENA© software. They used group technology-based computerized relative allocation of facilities method and rank order clustering technique. The author concludes with many alternative layouts that the bottleneck machines are drastically affecting the production volume. Tearwattanarattikal et al. [12] studied a case of plastic packaging industry for plant layout design and planning using ProModel© simulation software to compare the performance corresponding to the utilization rate of machines, work-in-process as well as the delivery due dates of products. Smutkupt and Wimonkasame [13] proposed a plant layout simulation model based on Microsoft VB with computerize relative allocation facilities technique and linked the model with ARENA© software. Jayachitra and Prasad [14] presented a virtual cellular plant layout using WITNESS© simulation software. They used the design of experiments (DOE) method to setup a simulation environment for three alternative layouts to find work-in-process, utilization levels of machines, and distance traveled by parts. They concluded that the performance of a virtual cellular layout is superior to that of a functional layout and inferior to a cellular layout. Edis et al. [15] successfully decreased the total transportation time consumed and cost to produce in the exiting production line of marble factory having a flow shop configuration using ARENA© simulation software.

Shariatzadeh et al. [16] determined the functionalities of layout simulation software to design and plan factories in terms of time consumption and error findings. In addition, they studied the aspects of combining the different layouts available from interoperable models, enabling the use of libraries of 3D models and handling the modifications in an individual model suggested by different vendors under dynamic conditions. John and Jenson [17] simulated a plant layout using ARENA© simulation software in order to calculate the utilization level of machines. Said and Ismail [18] presented a case study of a bicarbonate production plant through simulation using ARENA© software to improve the production volume and work-in-process. They proposed two alternative models and stated that proposed layouts perform better than exiting layouts. Kumar et al. [19] presented the effects of modifications through simulation-based analysis on productivity and cycle time on a facility layout of a manufacturing SME having job work, using ARENA© software. They stated that cycle time is decreasing drastically by improving material handling activities. In addition, they concluded that the efficiency of the system is directly affected by the increase and decrease in the number of machines, changing the machine setups and production orders. Polshettiwar et al. [20] studied the layout of an automotive manufacturing company having batch manufacturing of components in order to improve the utilization rate of resources at shop floor through simulation software. They applied many "what-if" scenarios to find out optimal layout. Patil et al. [21] used Flexsim© simulation software to optimize the layout of a machine shop. They concluded that the Flexsim© software is effective enough to conclude on the effects of modifications in the layout of a machine shop.

In this study, the facilities on a beer beverage production line are modeled and simulated in ProModel© 7.5 software. It is based on discrete-event simulation technology that is used to plan, design and improves new or existing manufacturing, logistics and other operational systems. It empowers us to accurately represent real-world processes, including their inherent variability and interdependencies, in order to conduct predictive analysis on potential changes. Optimize system around key performance indicators. ProModel© 7.5 software provides decision-makers the opportunity to test new ideas for process and system design or improvement before committing the time and resources necessary to build or alter the actual system. The subsequent sections of this paper present the methodology adopted for generating alternative production line layout models, results and discussion, cost analysis and conclusion.

2 Adopted Methodology

Table 1 shows the steps involved in a beer beverage and bottling process. The present work utilizes the same procedure to produce the final product. After a detailed study and analysis of the process, the data has been analyzed from our objective point of view. It is being noted that there are very few constraints which are responsible for the increase in work-in-process and for lower production to a great extent, which is described in detail below. The process study revealed the various constraints imposed by the manufacturing process. It is observed that the maximum time was consumed in material handling by Automatic Guided Vehicle (AGV) around 10 min per barrel to move from inspection location to the packaging area. All material handling activities were carried out by AGV and the workers were employed for loading and unloading the barrels on and from the AGV; owing to this, there is a decrease in the productivity of the production line. Hence it is concluded that the bottlenecks in the process and excessive material handling time consumed by AGV are the major causes for high work-in-process and lower production.

In this research, the type of production line in a beer beverage factory that has been studied was process layout. This is because due to the product that was produced by the company XYZ with semi-automated machines. A simulation model of the initial (original) layout was built by using ProModel© 7.5 simulation software, as shown in Fig. 1, in which it was found that the distance traveled by the material (bottle) is

Table 1 Sequential activities of a beer beverage plant [1, 2]

Activities	Description
Depalletizing and cleaning	In this process, the empty bottles are removed from pallets. Bottles are rinsed with filtered water to remove impurities and cleared of labels. Sometimes carbon dioxide is injected into a bottle to reduce oxygen level. Empty bottle inspector is used to checking the bottles for a good washing, otherwise rejects it
Filling process	Washed bottles are then sent to the filling machine, which fills the bottle with beer. A few inert gases can be injected on the top to disperse the oxygen
Capping process	Full bottle inspector is used to checking bottles for underfilling and overfilling. Capper applies bottle caps and sealed the bottles
Pasteurization process	In this process, the filled bottles are pasteurized at 1400F for 2–3 min. This helps to stop the growth of yeast that remains in beer after packaging
Labeling procedure	After pasteurization, the labeling process is applied to stamp the batch number, lot number, date and time bottling and expiry dates
Inspection procedure	The final inspection is done by the inspectors in which the defective bottles are discarded, and the remaining bottles are sent for packaging
Packaging	Bottles are then packed into boxes and send to the warehouse and ready for sale

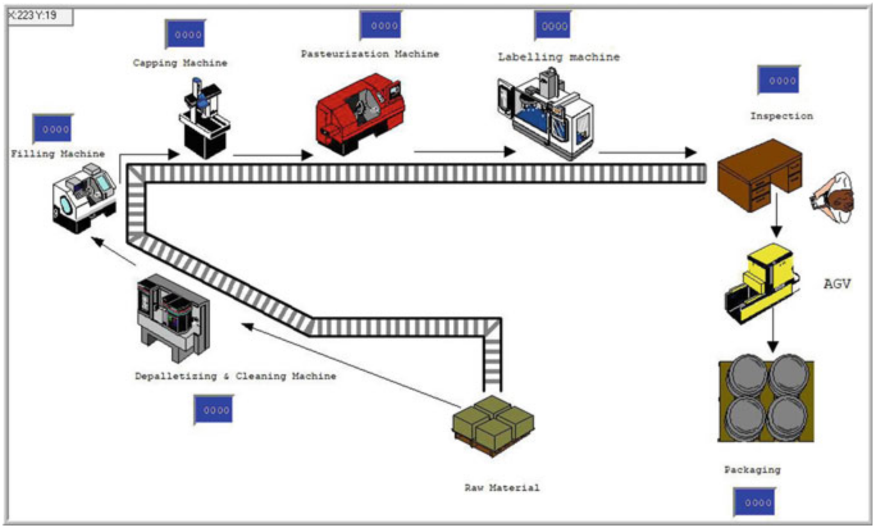


Fig. 1 Layout of actual production line

excessive and the work-in-process is more, which leads to lower productivity. For the simulation environment in this research, the factory layout was designed to produce one batch of 12 bottles. Therefore, the simulation model was designed to undergo the simulation of 38 batches for one day. Figure 1 shows the simulation model of the production line layout before improvement.

In order to improve the actual production line layout, some changes in the production line layout have been suggested. In this work, there are two alternative models proposed for improvement, which are alternative model A and alternative model B. The models are prepared different from each other in order to identify which model is better and can increase the production rate after simulation.

The process flow of the layout and rearrangement of the machines or apparatus in the factory layout were considered for the improvement. In this alternative model, the buffer storage was added, and some rearrangement of machines was done for shortening the distance. Figure 2 shows the improved simulation setup of alternative model A by using ProModel© 7.5 software.

Model B has been improved by replacing AGV with conveyor. In addition, two machines, namely filling machine and capping machine have been replaced by a machine called Filling and Capping machine in order to perform both operations at the same time. This machine is widely available in the market now a day. This machine is highly automated, which can improve the production volume and lower the average work-in-process of the system, as suggested by various previous research studies. Figure 3 shows the improved simulation model of an alternative model B by using ProModel© 7.5 software.

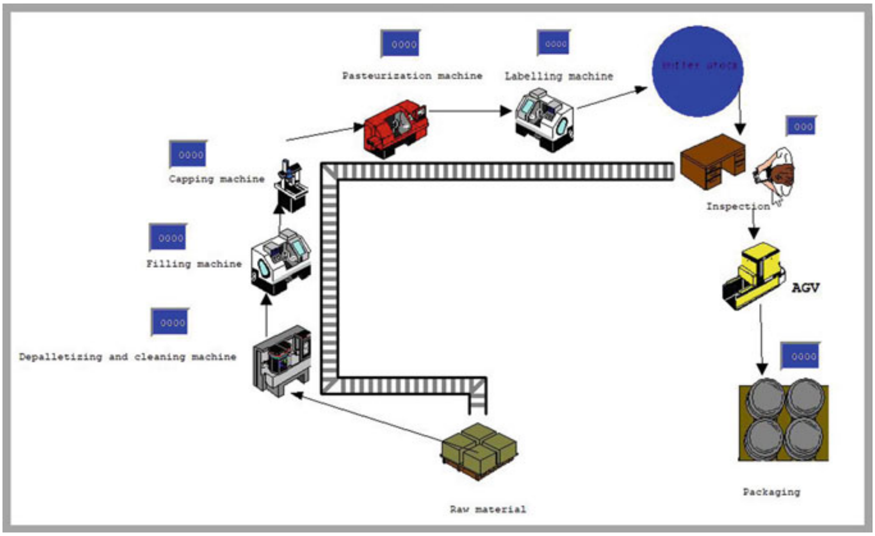


Fig. 2 Layout of alternative modal A

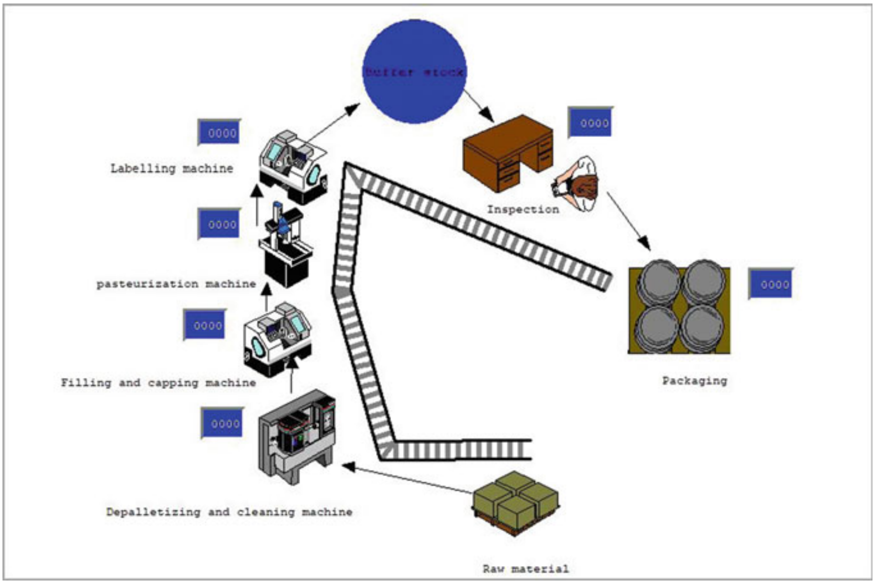


Fig. 3 Layout of alternative modal B

3 Results and Discussion

The methodology presented in the previous section has been executed to access the effects of suggested improvements. The ProModel© 7.5 simulation software was used to simulate the existing and proposed alternative models in which the eight hours of running time, 0.3 h of warmup time, and first come, first serve dispatching rule are applied. The processing time of each operation on the different machine are given in Table 2. For the simulation environment, the production line layout was designed to produce one batch of 12 bottles. The simulation model was designed to undergo the simulation for one day.

Table 3 shows the work-in-process of each machine of the actual production line of the taken beer beverage company after simulation in ProModel© 7.5 software. It also presents the number of bottles in and out for each machine and location. In addition, the maximum work-in-process is also presented. The average work-in-process of the system is 19 units. Tables 4 and 5 present the work-in-process of each machine of the alternative simulation models of the production line. The average work-in-process of the alternative model A and B is 17 and 13 units, respectively. It can be clearly revealed that the proposed alternative model A and B are significantly improved in order to reduce the work-in-process of the taken case study of the beer beverage company.

Table 2 Processing time of each operation on each machine taken from XYZ company

Machines	Processing time (min)
Depalletizing and cleaning machine	5
Filling machine	4
Capping machine	4
Pasteurization machine	2
Labeling machine	3
Inspection	6
Packaging	5

Table 3 WIP of exiting production line

Machine	Number in	Number out (actual)	WIP (Max.)
Depalletizing and cleaning machine	243	243	3
Filling machine	243	243	2
Capping machine	243	242	2
Pasteurization machine	242	241	1
Labeling machine	241	239	2
Inspection	239	238	3
Packaging	238	231	3

Legend: *WIP* work-in-process

Table 4 WIP of alternative model A of proposed production line layout

Machine	Number in	Number out (alternative model A)	WIP (Max.)
Depalletizing and cleaning machine	242	242	2
Filling machine	242	242	2
Capping machine	242	241	2
Pasteurization machine	241	240	1
Labeling machine	240	236	2
Inspection	236	234	2
Packaging	234	233	1

Legend: *WIP* work-in-process

Table 5 WIP of alternative model B of proposed production line layout

Machine	Number in	Number out (actual)	WIP (Max.)
Depalletizing and cleaning machine	242	242	2
Filling and capping machine	242	241	2
Pasteurization machine	241	241	1
Labeling machine	241	240	2
Inspection	240	238	2
Packaging	238	237	1

Legend: *WIP* work-in-process

Table 6 presents the output of production volume for one day and one week. The table clearly reveals that the proposed alternative models are effective enough to improve the production volume by 2.6%. Table 7 shows that the total transportation time of a day (two working shifts) as well as the average transportation time of each bottle for alternative model A and B. It can be stated that the proposed alternative models are consuming less total transportation time by 34.64 and 65.45% for alternative model A and B, respectively. Also, it can be safely concluded that the average

Table 6 Percentage improvement in production volume for actual and alternative models

	Number out			Improvement (%)
	Actual model	Alternative model A	Alternative model B	
One Replication (8 h)	231	233	237	2.60
One week production (14 replications)	3234	3262	3318	2.60

Table 7 Improvement in transportation time for actual and alternative models A and B

	Actual model	Alternative model A	Improvement (%)	Alternative model B	Improvement (%)
Total transportation Time (in min)	2640	1725.6	34.64	912	65.45
Avg. transportation time per product (in min)	11.43	7.41	35.17	3.85	66.31

transportation time for one unit (bottle) has been improved by 35.17% in alternative model A and the same has been improved by 66.31% in alternative model B.

Figures 4, 5 and 6 present the percentage of utilization of each machine in existing, alternative models A and B. We can see that the utilization of AGV is around 8% only. Based on this underutilization, it has been decided to replace the AGV with another alternative. The best suitable alternative of AGV could be the installation of a conveyor since the remaining connectivity in the plant is using conveyor only. Also,

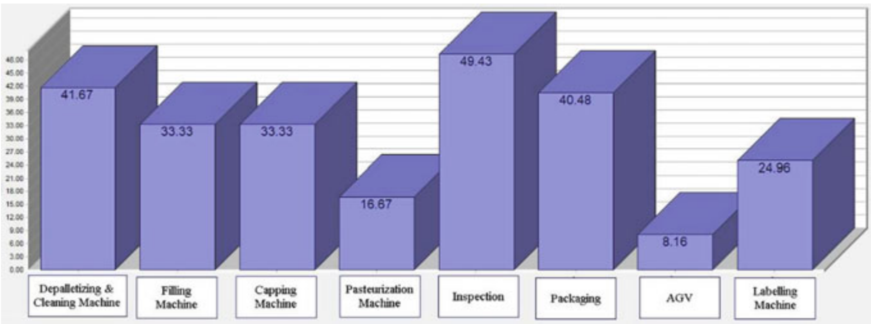


Fig. 4 Percentage of utilization of each machine in actual production line layout

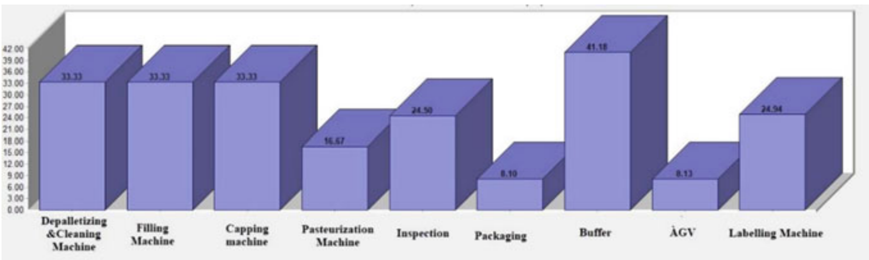


Fig. 5 Percentage of utilization of each machine in alternative modal A

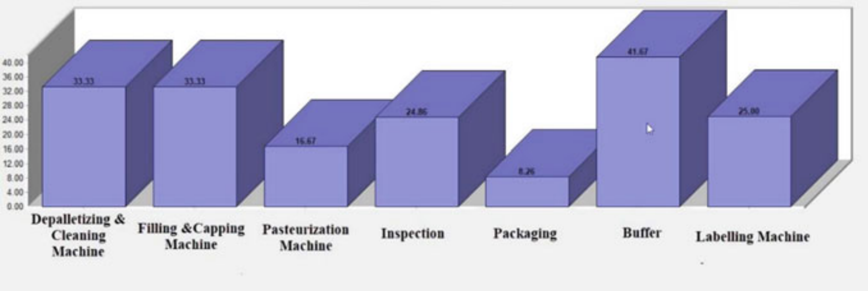


Fig. 6 Percentage of utilization of each machine in alternative modal B

it can be seen from Figs. 5 and 6 that the utilization percentage of the depalletizing and cleaning machine, filling machine and capping machine has been uniformly maintained.

4 Cost Analysis

Currently, the company makes about 10% profit from the sales of the product, that is, the cost comes out to be 162 INR and sales price up to 180 INR, that is, 18 INR profit per piece (bottle) approximately. The current profit per day for 462 items comes out to be 8316 INR. If we assume the same profit ratio is maintained by the company, the profit for 466 units per day through the alternative model A would come out to be 8388 INR, that is, an additional 72 INR per day and 2160 INR per month. So, the total profit per month would come out to be 251,640 INR, that is, total investment recovered back in two months only. Moreover, if we assume the same profit ratio for model B then, the profit for 474 units per day comes out to be 8,532 INR, that is, an additional 216 INR per day and 6480 INR per month. Thus, the total profit per month will be 255,960 INR, which means the total investment will be recovered back in one month only. Tables 8 and 9 present the costing and scrap values of each machine and equipment which is calculated from the market survey and provided by the company.

5 Conclusions

In the present work, the simulation-based improved production line layouts have been suggested to a beer beverage company located at Sonipat (Haryana) in India, using ProModel© 7.5 software. Two alternative production line layouts are suggested in which one layout is with an added buffer storage and rearrangement of machines for shortening the travel distance, in another layout, the AGV has been replaced

Table 8 Costing of each machine

Items	Cost (INR)
Depalletizing and cleaning machine	2.30 Lakh
Filling machine	1.75 Lakh
Capping machine	1.2 Lakh
Filling and capping machine	5 Lakh
Pasteurization machine	12 Lakh
Labeling machine	43,000
Inspection	40,000
Packaging	40,000
Buffer	4.36 Lakh
Automatic guided vehicle (AGV)	15 Lakh
Conveyor of original layout	26,212
Conveyor of alternative model A layout	24,625
Conveyor of alternative model B layout	20,942

Table 9 Scrap values of discarded machines and equipment

Items	Scrap value (INR)
Automatic guided vehicle (AGV)	500,000
Conveyor	417 per m
Filling machine	100,000
Capping machine	82,500

with the conveyor as well as two machines namely filling machine and capping machine have been replaced by a machine called Filling and Capping machine in order to perform both operation at the same time. The results clearly reveal that the proposed alternative models are significantly improved in order to reduce the work-in-process of the system and the proposed alternative models are effective enough to improve the production volume by 2.6%. In addition, it can be stated that the proposed alternative models are consuming less total transportation time by 34.64 and 65.45% for alternative models A and B, respectively. Also, the average transportation time for one unit (bottle) has been improved by 35.17% in alternative model A and the same has been improved by 66.31% in alternative model B. The utilization percentage of depalletizing and cleaning machine, filling machine and capping machine has been balanced at a uniform level. A cost analysis has been presented, and it is concluded that if the company adopts the changes suggested in an alternative plant layout (i.e., modal A) then the total profit per month would come out to be 251,640 INR, that is, total investment recovered back in two months only. In addition, if the company implements the changes suggested in an alternative modal B then the total profit per month will be 255,960 INR, which means the total investment will be recovered back in one month only.

Acknowledgements We are highly thankful for the company management to provide us the complete details of machines and equipment. Also, we are grateful to the managers of the company for their kind support and guidance.

References

1. Monroy, D.F.Z., Vallejo, C.C.R.: Production planning and resource scheduling of a brewery with plant simulation. In: Use Cases of Discrete Event Simulation, pp. 321–330. Springer, Berlin, Heidelberg (2012)
2. Matende, N.R.: Optimization of packaging operations for Beer production line effeciency (Doctoral dissertation, Kyambogo University) (2019)
3. Savsar, M.: Flexible facility layout by simulation. Comput. Ind. Eng. **20**(1), 155–165 (1991)
4. Drira, A., Pierreval, H., Hajri-Gabouj, S.: Facility layout problems: a survey. Annual Rev. Control **31**(2), 255–267 (2007)
5. Chierotti, M., Rozenblit, J.W.: Simulation modeling in factory layout optimization. IFAC Proc. Vol. **25**(28), 235–239 (1992)
6. Phanden, R.K., Demir, H.I., Gupta, R.D.: Application of genetic algorithm and variable neighborhood search to solve the facility layout planning problem in job shop production system. In: 2018 7th International Conference on Industrial Technology and Management (ICITM), pp. 270–274. IEEE (2018)
7. Phanden, R.K., Saharan, L.K., Erkoyuncu, J.A.: Simulation based cuckoo search optimization algorithm for flexible job shop scheduling problem. In: Proceedings of the International Conference on Intelligent Science and Technology, pp. 50–55 (2018)
8. Phanden, R.K., Palková, Z., Sindhwani, R.: A framework for flexible job shop scheduling problem using simulation-based cuckoo search optimization. In: Advances in Industrial and Production Engineering, pp. 247–262. Springer, Singapore (2019)
9. Sharma, P., Phanden, R.K., Singhal, S.: A comparative analysis of facility layout design and optimization techniques. In: Proceedings of the 2nd National Conference on Advancements in the Era of Multi Disciplinary Systems (AEMDS-2013) (2013)
10. Sharma, M., Phanden, R.K., Sharma, P.: Comparative evaluation of facility layout alternatives based on material handling cost. Int. J. Technol. Res. Eng. **7**(2), 748–751 (2015)
11. Altinkilinc, M.: Simulation-based layout planning of a production plant. In: Proceedings of the 2004 Winter Simulation Conference, 2004, vol. 2, pp. 1079–1084. IEEE (2004)
12. Tearwattanarattikal, P., Namphacharoen, S., Chamrasporn, C.: Using ProModel as a simulation tools to assist plant layout design and planning: case study plastic packaging factory. Songklanakarin J. Sci. Technol. 30(1) (2008)
13. Smutkupt, U., Wimonkasame, S.: Plant layout design with simulation. In: Proceedings of the international multi-conference of engineers and computer scientists, vol. 2, pp. 18–20 (2009)
14. Jayachitra, R., Prasad, P.S.S.: Design and selection of facility layout using simulation and design of experiments. Indian J. Sci. Technol. **3**(4), 437–446 (2010)
15. Edis, R.S., Kahraman, B., Araz, Ö.U., Özfırat, M.K.: A facility layout problem in a marble factory via simulation. Math. Comput. Appl. **16**(1), 97–104 (2011)
16. Shariatzadeh, N., Sivard, G., Chen, D.: Software evaluation criteria for rapid factory layout planning, design and simulation. Procedia CIRP **3**, 299–304 (2012)
17. John, B., Jenson, J.E.: Analysis and simulation of factory layout using ARENA. Int. J. Sci. Res. Publ. **3**(2), 1–8 (2013)
18. Said, M.A.B.M., Ismail, N.B.: Improvement of production line layout using arena simulation software. In: Applied Mechanics and Materials. vol. 446, pp. 1340–1346. Trans Tech Publications Ltd. (2014)

19. Kumar, V., Verma, P., Onkar, S.P.S., Katiyar, J.: Facility and process layout analysis of an SME using simulation: a case study of a manufacturing company. In: Conference Paper Presented at: International Conference on Industrial Engineering and Operations Management, pp. 8–10 (2016)
20. Polshettiwar, A.A., Trivedi, D.P., Sardar, M.V.B., Rajhans, N.R.: Optimization of plant layout using simulation software. In: Conference 6th International and 27th All India Manufacturing Technology, Design and Research Conference (AIMTDR-2016), 16–18 Dec 2016 at College of Engineering, Pune, Maharashtra, India (2016)
21. Patil, R.J., Kubade, P.R., Kulkarni, H.B.: Optimization of machine shop layout by using flexsim software. In: AIP Conference Proceedings, vol. 2200, no. 1, p. 020033. AIP Publishing LLC, (2019)
22. Singh, P.L., Sindhwani, R., Dua, N.K., Jamwal, A., Aggarwal, A., Iqbal, A., Gautam, N.: Evaluation of common barriers to the combined lean-green-agile manufacturing system by two-way assessment method. In: Advances in Industrial and Production Engineering, pp. 653–672. Springer, Singapore (2019)
23. Sindhwani, R., Singh, P.L., Prajapati, D.K., Iqbal, A., Phanden, R.K., Malhotra, V.: Agile system in health care: literature review. In: Advances in Industrial and Production Engineering, pp. 643–652. Springer, Singapore (2019)
24. Mittal, V.K., Sindhwani, R., Singh, P.L., Kalsariya, V., Salroo, F.: Evaluating significance of green manufacturing enablers using MOORA method for Indian manufacturing sector. In: Proceedings of the International Conference on Modern Research in Aerospace Engineering, pp. 303–314. Springer, Singapore (2018)
25. Sindhwani, R., Singh, P.L., Iqbal, A., Prajapati, D.K., Mittal, V.K.: Modeling and analysis of factors influencing agility in healthcare organizations: an ISM approach. In: Advances in Industrial and Production Engineering, pp. 683–696. Springer, Singapore, (2019)
26. Mittal, V.K., Sindhwani, R., Shekhar, H., Singh, P.L.: Fuzzy AHP model for challenges to thermal power plant establishment in India. Int. J. Oper. Res. **34**(4), 562–581 (2019)
27. Sindhwani, R., Singh, P.L., Chopra, R., Sharma, K., Basu, A., Prajapati, D.K., Malhotra, V.: Agility evaluation in the rolling industry: a case study. In: Advances in Industrial and Production Engineering, pp. 753–770. Springer, Singapore (2019)
28. Sindhwani, R., Mittal, V.K., Singh, P.L., Kalsariya, V., Salroo, F.: Modelling and analysis of energy efficiency drivers by fuzzy ISM and fuzzy MICMAC approach. Int. J. Prod. Quality Manag. **25**(2), 225–244 (2018)

Analyzing the Critical Success Factors for Industrial Symbiosis—A Chinese Perspective

Yongbo Li and Mark Christhian Barrueta Pinto

Abstract Due to globalization and industrialization, several industrial developments have been evident, which increases the global revenue significantly in recent years. Meanwhile, such increasing industrial activities prints many negative impacts on the environment through resources scavenging, an increase in waste, pollution and so on. Several strategies have been introduced to reduce these negative characteristics of industrial operations without comprising in production quantities. Industrial symbiosis is one such strategy that assists the industries in the industrial parks to engage in eco-efficient operations. Despite its key advantages, very limited studies exist in the developing context, especially with China industries. Though there are several attempts made in industrial symbiosis for its effective implementation, but no previous study details the success factors of implementation of industrial symbiosis even with the Chinese context. Addressing this gap, this study identified the common success factors for industrial symbiosis and analyzed the effective factors within the Chinese industrial context. The analytical hierarchy process has been adapted for this analysis, in which the China industrial eco park design managers are considered as case decision-makers. The results revealed that among considered 12 factors, technological factors are the key success factor for the effective implementation of industrial symbiosis in the Chinese context. With the findings, this study is having both scientific and societal contributions toward the implementation of industrial symbiosis in the Chinese context. Further, the future scope for research in addition to limitations has been presented.

Keywords Industrial symbiosis · Success factors · China

Y. Li
School of Economics and Management, China University of Petroleum (East China), Qingdao 266580, PR China

M. C. B. Pinto (✉)
School of Business, Universidad Peruana de Ciencias Aplicadas (UPC), Lima 15023, Peru
e-mail: mbarruetapinto@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_3

1 Introduction

Various pressures are continuously mounting on the industrial sector to be competitive in global markets in a sustainable way. Without compromising the production and quality, the industries are advised to utilize much less resources but reaping decent economic benefits. Concerning this momentum, several strategies have been discussed in the literature, including green manufacturing, lean manufacturing, sustainable manufacturing and so on. However, all these manufacturing strategies are limited within their internal organizations, which does not possess effective benefits as expected from the global institutions. Hence, a new strategy, industrial symbiosis, has been introduced to connect all the industries within the primary objectives of connecting three pillars of sustainability. There are several benefits of considering industrial symbiosis thinking in industrial parks, which include reducing waste, greenhouse gas emissions, landfills, tightening the loops of the circular economy, achieving economic sustainability and limited exposure to natural resources [1]. Owing to these advantages, there are several real applications started to implement; in the row, the first industrial symbiosis applications were recorded in Denmark (Kalundborg) in the period of 1990–2002 [2]. However, in these operational periods, the Danish context reaps most benefits, which includes preservation of groundwater and surface water up to 30 million and 7 million m^3, respectively. Since, the intervention, there are many success stories [3–6] that are continuously recorded all over the world. Though these continuous projects are not extended in every corner, most of the developing and underdeveloped countries are still in the infant stage while implementing the industrial symbiosis in their industrial parks. China is such a nation which is actively involved in industrial activities since long back, by contributing major Gross Domestic Product (GDP) to the nation's economy. Despite of developments in Chinese industrial parks, the best of our knowledge, there is no single case study that has been reported with the concern of industrial symbiosis.

From these discussions, the following research objectives were formulated:

- To identify the common success factors of industrial symbiosis.
- To analyze the effective success factor for the implementation of industrial symbiosis in the Chinese context.
- To provide recommendations to achieve the effective success factor (identified) for industrial symbiosis implementation.

In order to achieve these research objectives, case study methodology has been adapted in which the data were analyzed through multi-criteria decision-making methodology, Analytical hierarchy process (AHP). The common critical success factors were collected from the literature and validated with industrial experts. Further, the same has been analyzed from the replies of case decision-makers. Results will be expected to assist the China industrial park managers to identify the effective factors for implementation and to stimulate those particular factors with efficient practices. Contributions of this paper include a novel approach to identifying the CSF of industrial symbiosis within the Chinese context, which further can assist the Chinese value chain actors to effectively implement industrial symbiosis. This contribution is also a novel approach due to the gap in the existing studies within Chinese industrial symbiosis.

The remaining sections of the paper are as follows: Sect. 2 discussed the existing studies published within the concerned area, in which the literature gap has been identified. The methodology has been discussed in Sect. 3, in which the steps involved in the AHP process were listed. Section 4 deals with the application of the methodology, in which the case study has been detailed along with the analysis of critical factors through considered solution methodology. Obtained results were discussed and acknowledged with the existing studies and the same has been presented in Sect. 5. The final Sect. 6 concludes the study with important findings, future directions and limitations.

2 Literature Review

This section aims to identify the existing literature gap within the concerned research field, industrial symbiosis. For this literature review, SCOPUS has been used as a database for search engine. For initial search, the following search terms have been used, (TITLE-ABS-KEY (industrial AND symbiosis)) AND (success AND factors) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English")). These search terms result in 95 documents on industrial symbiosis, in which 81 research articles and 14 review papers are included. Several perspectives of industrial symbiosis have been studied in past years, including theories, concepts, models, barriers, promoting factors and so on.

The majority of studies proposed several business models for industrial symbiosis with various geographical context. For instance, Fraccascia et al. [7] proposed a business model for industrial symbiosis with the perspective of governance, totally four different business models were proposed. Nasiri et al. [8] discussed the business models in which the industries transition towards sustainable solutions, including industrial symbiosis. Siskos et al. [9] detail the concepts of industrial symbiosis business models with capturing synergies in organizational management. Fraccascia et al. [10] provide a guide for the industrial firms to actively participate in industrial symbiosis through suggested business models.

Few studies discussed the barriers involved in the implementation of industrial symbiosis. Corder et al. [11] discussed the barriers and enablers of Australian industrial symbiosis through empirical evidence. Bacudio et al. [12] include the MCDM tool to analyze the barriers exist with industrial symbiosis implementation through a systematic design approach.

But very few studies were considered the success factors for the implementation of industrial symbiosis, for instance, Ji et al. [13] explored the various factors which could promote the implementation of industrial symbiosis in the Chinese context. Jayakrishna et al. [14] identified the key parameters for promoting industrial symbiosis in the Indian context through numerical analysis; however, this study focused on the area, not the factors. Genc et al. [15] approached the success of industrial symbiosis through a socio-ecological approach within the Turkish context.

From the literature review, several things can be confounded, which includes:

- The current increase in publication on the topic of industrial symbiosis shows the urge towards the field.
- Most of the industrial symbiosis was adapted to the case study methodology (hence the same has been applied to this study).
- Industrial symbiosis is a global phenomenon, which can be evident from the literature with different nation applications.
- Not a single case study has been debated in terms of industrial symbiosis success factors within the Chinese perspective.
- Most of the success factors studies were included Multi-Criteria Decision Making (MCDM) tools (so as this study).

With these concerns, to address the above-mentioned literature gap, this study focused on the least studied critical success factors of industrial symbiosis in the Chinese context where not a single study explores earlier.

3 Methodology

Analyzing the critical success factors of industrial symbiosis is a tedious process; unlike other problems, there are several hidden influences that participated while assessing these factors. It is mainly due to the implementation of industrial symbiosis itself a multi-criteria progress. Concerning these points, this study included multi-criteria decision-making methodology to address one of the complex multi-criteria problems, industrial symbiosis. Though there are several MCDM methods are recommended in the existing literature, this study considers one of the most applied methodology analytical hierarchy process (AHP) for this application. AHP is well suited for the complex problem, which makes the problem to get structured. There are numerous benefits of AHP, but the most cited benefit is that this methodology makes the complex problem as simple for understanding by providing the problem with hierarchy. In addition, consistency can be check through the consistency index. On the other hand, there is some major limitation, scalability. It is become tough when the problem contains more criteria or factors; however, this limitation does not effect the present study due to the optimum number of criteria considered in this study. For applying the AHP methodology, some of the sequential steps are to be followed:

Step 1 Selecting the list of attributes (in this study—critical success factors) from the literature review and validated with the field experts.

Step 2 The case decision-makers are assigned to provide the pairwise comparison among the collected common attributes based on the Saaty scale shown in Table 1.

Step 3 With the assistance of arithmetic operations involved in AHP, the global weights of each attribute has been identified.

Step 4 In order to check the biasness in the judgments, consistency index (CI) has been identified.

Step 5 The identified CI has been checked with 0.1, in which if the CI greater than 0.1; there is some biasness in the input data; otherwise the global weights can be reliable.

Step 6 Based on the final reliable global weights, the attributes (success factors) are prioritized.

Table 1 Saaty scale of judgments [16]

Intensity of importance	Definitions	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance is demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity I has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with i	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities

4 Application of Methodology

The application of methodology has been detailed as a research framework, which is shown in Fig. 1.

This study starts with a collection of common success factors of industrial symbiosis implementation. With the combined assistance of primary and secondary data, these collected critical success factors are finalized. From secondary data, the initial CSF was collected and further, it was shortlisted through the aid of experts and practitioners act as secondary data, which is shown in Table 2.

Next to that, the collected common success factors were evaluated with the assistance of Chinese case context decision-makers. Recently, there is a project proposed

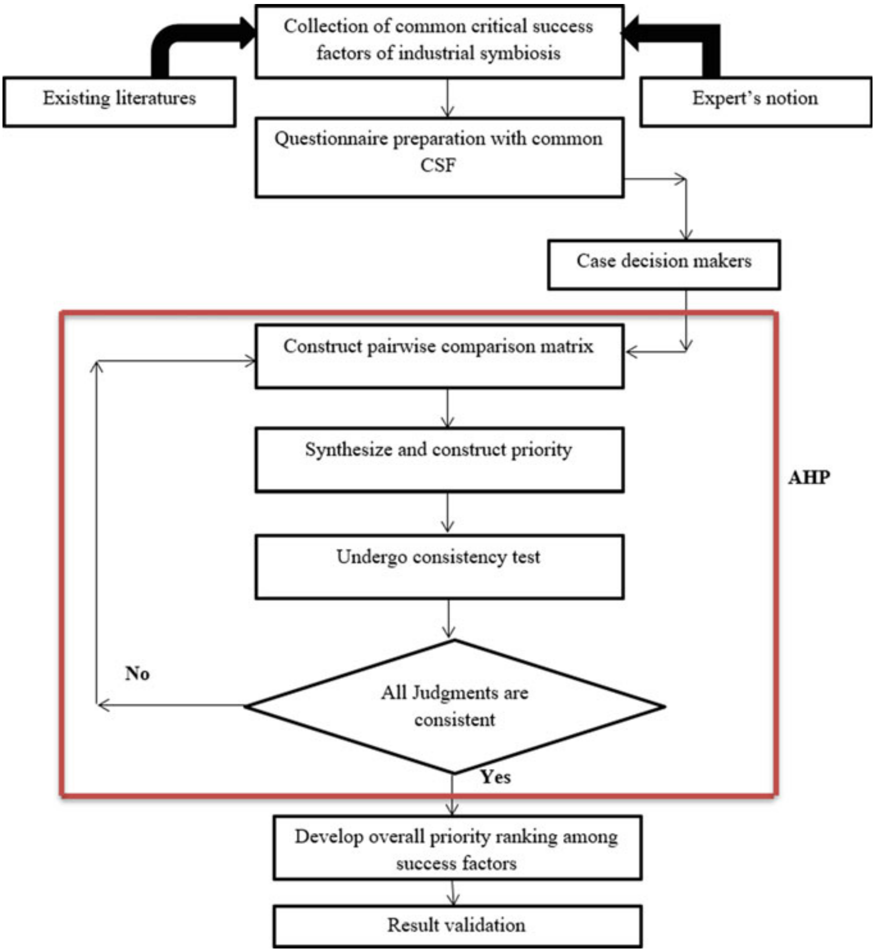


Fig. 1 Proposed framework of the study

Table 2 Collected common critical success factors of industrial symbiosis

S. No.	CSF
1	Business relationships with symbiotic perspectives
2	Technical factors
3	Technological factors
4	Economic sustainability
5	Policies and regulations
6	Education and training
7	Information sharing
8	Organization support
9	Institutional set up
10	Inter organizational relationships
11	International benchmarking
12	Stakeholder support

to design an eco-industrial park in Jiangxi, China. Hence, this study considers those eco-industrial managers as decision-makers to evaluate the collected common CSFs. Based on their replies on the Saaty scale, the factors are pairwise compared and the same has been shown in Table 3.

Next step is to process the given data through AHP arithmetic operations, including normalization, which is shown in Table 4.

Next to this, the final global weights are evaluated, and a reliability check was conducted in the upcoming sections.

Table 3 Pairwise comparison among critical success factors of industrial symbiosis

	CSF 1	CSF 2	CSF 3	CSF 4	CSF 5	CSF 6	CSF 7	CSF 8	CSF 9	CSF 10	CSF 11	CSF 12
CSF1	1	3	1	1	3	3	1	7	7	9	9	9
CSF2	0.33	1	1	1	3	3	1	5	5	7	9	9
CSF3	1	1	1	3	5	5	3	7	7	9	9	9
CSF4	1	1	0.33	1	3	3	3	5	5	7	9	9
CSF5	0.33	0.33	0.2	0.33	1	3	1	5	7	7	7	9
CSF6	0.33	0.33	0.2	0.33	0.33	1	1	3	5	7	7	9
CSF7	1	1	0.33	0.33	1	1	1	5	7	7	9	9
CSF8	0.14	0.2	0.14	0.2	0.2	0.33	0.2	1	5	7	7	7
CSF9	0.14	0.2	0.14	0.2	0.14	0.2	0.14	0.2	1	5	7	7
CSF10	0.11	0.14	0.11	0.14	0.14	0.14	0.14	0.14	0.2	1	7	7
CSF11	0.11	0.11	0.11	0.11	0.14	0.14	0.11	0.14	0.14	0.14	1	7
CSF12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.14	0.14	0.14	0.14	1

Table 4 Normalized matrix

	CSF 1	CSF 2	CSF 3	CSF 4	CSF 5	CSF 6	CSF 7	CSF 8	CSF 9	CSF 10	CSF 11	CSF 12
CSF1	0.178	0.356	0.213	0.129	0.176	0.151	0.085	0.181	0.141	0.136	0.111	0.098
CSF2	0.059	0.119	0.213	0.129	0.176	0.151	0.085	0.129	0.101	0.106	0.111	0.098
CSF3	0.178	0.119	0.213	0.386	0.293	0.251	0.256	0.181	0.141	0.136	0.111	0.098
CSF4	0.178	0.119	0.071	0.129	0.176	0.151	0.256	0.129	0.101	0.106	0.111	0.098
CSF5	0.059	0.040	0.043	0.043	0.059	0.151	0.085	0.129	0.141	0.106	0.086	0.098
CSF6	0.059	0.040	0.043	0.043	0.020	0.050	0.085	0.078	0.101	0.106	0.086	0.098
CSF7	0.178	0.119	0.071	0.043	0.059	0.050	0.085	0.129	0.141	0.106	0.111	0.098
CSF8	0.025	0.024	0.030	0.026	0.012	0.017	0.017	0.026	0.101	0.106	0.086	0.076
CSF9	0.025	0.024	0.030	0.026	0.008	0.010	0.012	0.005	0.020	0.075	0.086	0.076
CSF10	0.020	0.017	0.024	0.018	0.008	0.007	0.012	0.004	0.004	0.015	0.086	0.076
CSF11	0.020	0.013	0.024	0.014	0.008	0.007	0.009	0.004	0.003	0.002	0.012	0.076
CSF12	0.020	0.013	0.024	0.014	0.007	0.006	0.009	0.004	0.003	0.002	0.002	0.011

5 Results and Discussion

This section shows the obtained results and their corresponding discussions. Table 5 shows the final weights of the collected common critical success factors of industrial symbiosis implementation.

Table 5 shows the results of the common success factors of industrial symbiosis. From which it can be evident that “technological factors” (**CSF 1**) show more weight as “0.19695691,” on the other hand, contrary to this, “stakeholder support” (**CSF**

Table 5 Ranks and priority among critical success factors of industrial symbiosis

S. No.	Critical success factors	Eigenvalue	Rank
1	Business relationships with symbiotic perspectives (**CSF 1**)	0.16289997	2
2	Technical factors (**CSF 2**)	0.12304946	4
3	Technological factors (**CSF 3**)	0.19695691	1
4	Economic sustainability (**CSF 4**)	0.13531546	3
5	Policies and regulations (**CSF 5**)	0.08663042	6
6	Education and training (**CSF 6**)	0.06733131	7
7	Information sharing (**CSF 7**)	0.09916901	5
8	Organization support (**CSF 8**)	0.04548287	8
9	Institutional set up (**CSF 9**)	0.03326357	9
10	Inter organizational relationships (**CSF 10**)	0.02431204	10
11	International benchmarking (**CSF 11**)	0.01609585	11
12	Stakeholder support (**CSF 12**)	0.00949309	12

12) receives comparatively low weights as "0.00949309." The other priority among success factors are as follows:

CSF 1 > CSF 4 > CSF2 > CSF7 > CSF5 > CSF6 > CSF > 8 > CSF9 > CSF10 > CSF11.

These results are discussed with two stages, namely literature acknowledgement and case decision maker's feedback. As per the obtained results, technological factors hold the first position and stakeholder support holds last. However, in many studies, it has been claimed that stakeholder support is essential for any kind of strategy development in an organization. With this concern, the obtained results are contrary to the evidence found in the existing literature. Hence, this has been digging more for a better understanding of the results, which then confirms that though the stakeholder support is essential for any strategy implementation, but the stakeholder convinced once everything is fine with the proposed strategy. In this case, technological factors assist the industries to engage in industrial symbiosis, for instance, the technological development in manufacturing system including additive manufacturing, industry 4.0 and blockchain, increases the reliability among partners, efficiency on operations with less cost and more quality. In addition, these technological developments can bring new opportunities for closing the loop, which is one of the success formulae for industrial symbiosis application in any industrial park. These discussions acknowledge that the obtained results coincide with existing literature theories. Hence, for more reliable results on the impact of technological factors on other considered criteria, sensitivity analysis has been conducted, as shown in Fig. 2, in which there is enough evidence of variation of results.

Next to this, to get the feedback from the industrial managers, the results are being circulated to the case decision-makers. First, they are shocked with the final results; even the industrial managers think that they have to focus on getting support from top-level management, including various stakeholders but failed to analyze what are the factors involved to make the stakeholders proceed with industrial symbiosis. Further

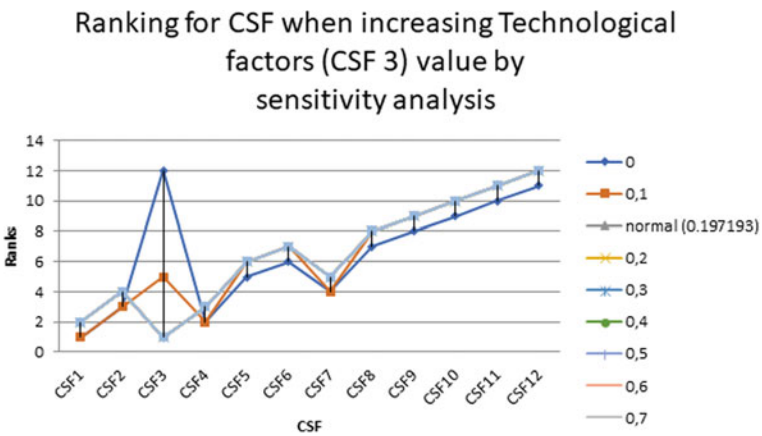


Fig. 2 Sensitivity analysis increasing technological factors (CSF3)

rounds of discussion, the effectiveness of the results have been detailed to the case decision-makers. The industrial managers agreed that they are lack in technological factors due to many intangible factors. With this, the research team suggests the industrial managers to focus and engage on recent technologies including blockchain, data-driven operations, industry 4.0 and additive manufacturing to promote and implement industrial symbiosis in their industrial parks effectively.

With these results, several managerial implications can be achieved. However, a major implication could be assisting the eco-park managers in focusing particularly one single factor for success rather than spending time on other closely related factors. In addition, these results can be used to educate the top-level management regarding the integration of industrial symbiosis in any organization.

6 Conclusion

Recent concern on the environment over the economy brought many new initiatives in industries, in the row, industrial symbiosis gaining more acknowledges among researchers and practitioners worldwide. This study considered the critical success factors for the implementation of industrial symbiosis with the Chinese context, where the previous studies are limited. Totally 12 common critical success factors have been identified from the literature and validated with field experts. The same has been analyzed with the assistance of the analytical hierarchy process as China eco-industrial park managers as case decision-makers. From the study, it has been clear that, among 12 common success factors, "technological factors" gained more global weights as "0.19695691" compared to other available factors, on the other side, "stakeholder support" gained the least global weights as "0.00949309." Apart from several scientific contributions, this study mainly assists the eco-industrial park managers of China, to focus on the key success factors and to promote effective practices to boost that factor for efficient implementation of industrial symbiosis. Though it provides various managerial implications but not exempting with limitations. The major limitation of this study is a generalization; China is vast geography; hence, there might be an influence of geographical factors involved in the study. Hence, this can be lookup as an opportunity in the future to approach the same problem through different methodologies, including cross-sectoral study, empirical analysis and so on.

References

1. Neves, A., Godina, R., Azevedo, S.G., Matias, J.C.: A comprehensive review of industrial symbiosis. J. Clean. Prod. 119113 (2019)
2. Schwarz, E.J., Steininger, K.W.: Implementing nature's lesson: the industrial recycling network enhancing regional development. J. Clean. Prod. **5**(1–2), 47–56 (1997)

3. Cao, X., Wen, Z., Xu, J., De Clercq, D., Wang, Y., Tao, Y.: Many-objective optimization of technology implementation in the industrial symbiosis system based on a modified NSGA-III. J. Clean. Prod. **245**, 118810 (2020)
4. Cecchin, A., Salomone, R., Deutz, P., Raggi, A., Cutaia, L.: Relating industrial symbiosis and circular economy to the sustainable development debate. In: Industrial Symbiosis for the Circular Economy, pp. 1–25. Springer, Cham (2020)
5. Simboli, A., Taddeo, R., Raggi, A., Morgante, A.: Structure and relationships of existing networks in view of the potential industrial symbiosis development. In: Industrial symbiosis for the circular economy, pp. 57–71. Springer, Cham (2020)
6. Schlüter, L., Mortensen, L., Kørnøv, L.: Industrial symbiosis emergence and network development through reproduction. J. Clean. Prod. **252**, 119631 (2020)
7. Fraccascia, L., Giannoccaro, I., Albino, V.: Business models for industrial symbiosis: a taxonomy focused on the form of governance. Resour. Conserv. Recycl. **146**, 114–126 (2019)
8. Nasiri, M., Rantala, T., Saunila, M., Ukko, J., Rantanen, H.: Transition towards sustainable solutions: product, service, technology, and business model. Sustainability **10**(2), 358 (2018)
9. Siskos, I., Van Wassenhove, L.N.: Synergy management services companies: a new business model for industrial park operators. J. Ind. Ecol. **21**(4), 802–814 (2017)
10. Fraccascia, L., Magno, M., Albino, V.: Business models for industrial symbiosis: A guide for firms. Procedia Environ. Sci. Eng. Manag **3**(2), 83–93 (2016)
11. Corder, G.D., Golev, A., Fyfe, J., King, S.: The status of industrial ecology in Australia: barriers and enablers. Resources **3**(2), 340–361 (2014)
12. Bacudio, L.R., Benjamin, M.F.D., Eusebio, R.C.P., Holaysan, S.A.K., Promentilla, M.A.B., Yu, K.D.S., Aviso, K.B.: Analyzing barriers to implementing industrial symbiosis networks using DEMATEL. Sustain. Prod. Consum. **7**, 57–65 (2016)
13. Ji, Y., Liu, Z., Wu, J., He, Y., Xu, H.: Which factors promote or inhibit enterprises' participation in industrial symbiosis? An analytical approach and a case study in China. J. Clean. Prod. **244**, 118600 (2020)
14. Jayakumar, J., Jayakrishna, K., Vimal, K.E.K., Hasibuan, S.: Modelling of sharing networks in the circular economy. J. Model. Manag. (2020)
15. Genc, O., van Capelleveen, G., Erdis, E., Yildiz, O., Yazan, D.M.: A socio-ecological approach to improve industrial zones towards eco-industrial parks. J. Environ. Manage. **250**, 109507 (2019)
16. Saaty, T.: The Analytic Hierarchy Process (AHP) for Decision Making. In Kobe, Japan (1980)

Implementation of Industry 4.0 Practices in Indian Organization: A Case Study

Ravinder Kumar, Piyush Gupta, Sahil Singh, and Dishank Jain

Abstract Digitization of manufacturing processes is the need for hours for industries. Indian manufacturing industries are currently changing from mass to customized production. The rapid advancements in applications of technologies help in increasing the productivity of processes. The term Industry 4.0 stands for the fourth industrial revolution, which includes the blend of technologies such as big data analytics, simulation, augmented reality, cloud computing, internet of things, cyber-physical systems, system integration, autonomous robots, additive manufacturing. The objective of this paper is to discuss the implementation of Industry 4.0 practices in Indian organizations and their outcomes after successful implementation. The authors have used the situation actor process and learning action performance technique (SAP-LAP) for the case study.

Keywords Industry 4.0 · Manufacturing · Indian · SAP-LAP

1 Introduction

The adoption of Industrial 4.0 is at the initial stage in developing economies. The amount of investment required and different other challenges push it to a slow implementation [1–7]. Industry 4.0 is highly recommended in the global competitive world, as it can provide efficient, faster, and economical manufacturing facilities. After going through three revolutions over a period of more than two centuries, these revolutions have made significant technical development. Industry 4.0 is a combination of various technologies working together. It is a fine blend of cyber and physical systems such as big data and analytics, autonomous robotics, industrial internet of things, simulation, system integration (horizontal and vertical integrated system), cybersecurity, cyber-physical system, the cloud, additive manufacturing and augmented reality. The journey from Industry 1.0 to Industry 4.0 has enriched the industries with many

R. Kumar (✉) · P. Gupta · S. Singh · D. Jain
Department of Mechanical Engineering, Amity School of Engineering and Technology, Amity University, Noida, Uttar Pradesh 201313, India
e-mail: rkumar19@amity.edu

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_4

technologies [8–22]. This industrial development has made industries and manufacturing organizations more competitive and facilitated them in decreasing human efforts. Section 2 of the research paper has discussed the related literature. Section 3 has discussed the methodology of the study. Section 4 has discussed the case study. Section 5 discusses observations of the case study. Section 6 discusses the conclusion.

2 Literature Review

Industry 4.0 is the spheres of economy in which the fully automatic production process is based on the artificial intellect and the internet creates new machines without human participation [14]. In the Industry 4.0 atmosphere, the industrial components communicate with each other [15]. Rossit et al. [16] observed that the essence of Industry 4.0 conceptions is the introduction of network-linked intelligent systems, which realize self-regulating production: people, machines, equipment and products will communicate to one another. Masood and Egger [10] observed that Industry 4.0 is an umbrella used to describe a group of connected technological advances that provide a foundation for increased digitization of business. Sahal et al. [17] stated that Industry 4.0 significantly influences the production environment with radical changes in the execution of operations. In contrast to conventional forecast-based production planning, Industry 4.0 enables real-time planning of production plans, along with dynamic self-optimization.

Vaidya et al. [21] proposed that Industry 4.0 represents nothing less than the fourth industrial revolution, comprising 3D printing, Big Data, Internet of Things, and Internet of Services, that is, all the ingredients needed to facilitate smart manufacturing and logistics processes. The term Industry 4.0 was first coined in Germany in 2011, and since then, it has gained much importance in almost every sector, whether it be engineering, management, medical or any other governmental body. It has encouraged Indian organizations to move towards automation, and with time it is significantly achieved, reducing human effort and production time and increasing production rates and quality. Some of the companies that already implement industry 4.0 at broader level include General Electric, Siemens and Mitsubishi. Table 1 shows the different technologies of industry 4.0.

3 Methodology

In this paper, the authors have identified key technologies from literature. Research papers were downloaded from science direct, emerald insight, Taylor and Frances e-sources. Selected papers were highly related to Industry 4.0 and its implementation in the Indian scenario. Then, a case study was conducted in a company manufacturing agricultural machinery for national as well as international markets. Company plant was visited, and processes were observed, personal interview of one industry

Table 1 Different technologies of industry 4.0

I4.0 technologies	Description	References
Internet of things	Internet of things consists of internet of manufacturing and related service	[10, 14–16]
Big data	Big data consist of four dimensions: value of data, variety of data, volume of data, velocity of generation of new data and analysis	[1, 16, 17, 21]
Cloud computing	Clouds are storage spaces. Clouds are public and private	[6–8, 16]
Simulation	Simulation is the way to watch activity of physical world into virtual mode. It save energy and excessive material use	[5–7, 12, 19]
Autonomous robots	As robot is more accurate, flexible, and cooperative so they can be used to enhance work efficiency	[5, 20, 21]
System integration	System integration has been divided in horizontal and vertical integration	[18]
Augmented reality	It supports a variety of services, such as maintenance procedure, and other specified procedures with advanced technologies	[2, 10, 13, 22]
Additive manufacturing	In additive manufacturing, we add material to fabricate a component. It decreases the wastage of material and production cost	[2, 4, 6, 7]
Cyber security	Due to drastic digitalization Cyber threats has increased. Because of this, there is the maximum risk of attack in industry's data	[3, 9, 11, 14]

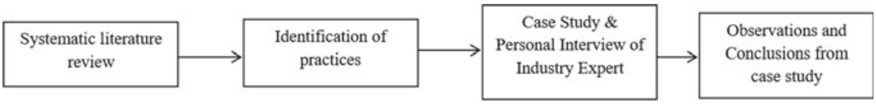


Fig. 1 Research methodology

expert was also conducted and the details were documented. The case study has been conducted using Situation Actors Process and Learning Action Performance (SAP-LAP) methodology. Figure 1 shows the research methodology,

4 Case Study

The xyz company began its operations in India in 1998 with the launch of its initial seventy HP tractor in the Indian market. Since then, it is tasted unequaled success with near about 300, tractors oversubscribed in various applications across India and abroad. The company selected for case study is a worldwide leader in the capital goods sector and specializes in making and selling equipment used for agricultural and construction purposes, and vehicles such as trucks, buses and other commercial vehicles, apart from a large range of power train applications. They provide power-train solutions for marine vehicles that are on-road and off-road as well. In this case, study only the Noida plant is taken into consideration. In the Noida facility, the case organization is making agricultural machinery for national as well as international market. Case organization has got many prestigious awards in the past years for its various CSR initiatives and for manufacturing tractors in particular categories. The market share held by the company in India is around 16% and worldwide is 18%. As this company has a big market share in the international market, hence the Noida facility focuses primarily on manufacturing for export. It has also collaborated with an Italian company for producing a new range of machineries with state or art facility and world-class designs.

SAP-LAP analysis of xyz organization is conducted with context to implementation of Industry 4.0 practices in the background. Figure 2 shows the SAP-LAP interface for Industry 4.0 technology implementation.

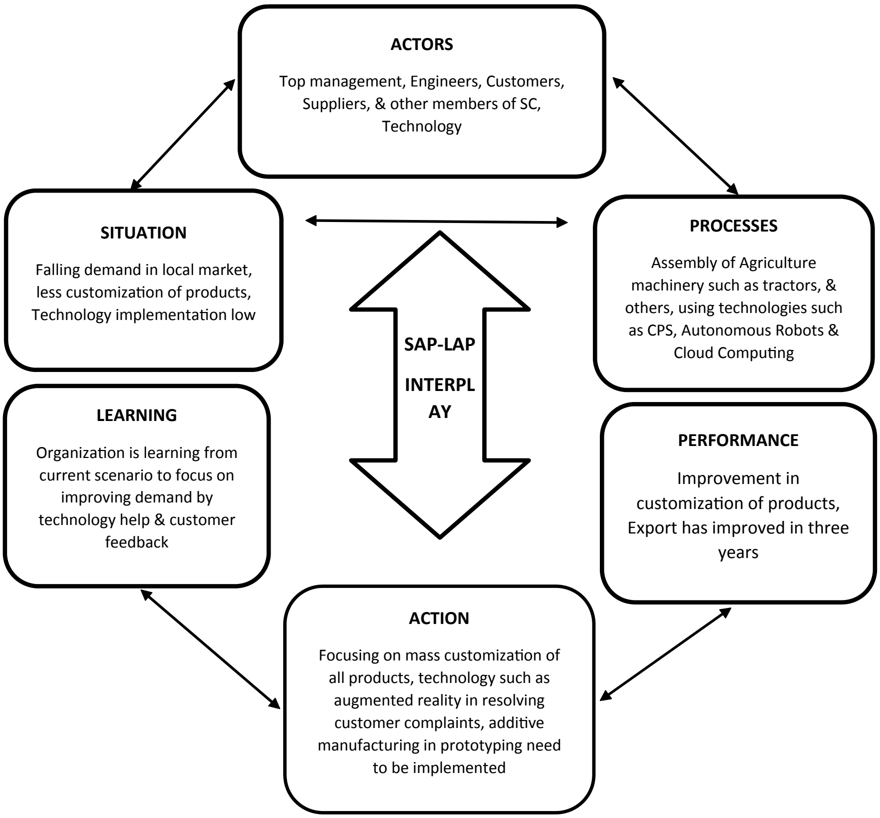


Fig. 2 SAP-LAP interface for industry 4.0 technology implementation

4.1 Situation

This section describes the present status of xyz in terms of different issues in technology and implementation of Industry 4.0 practices in the assembly line, inventory maintenance, parts specifications, export, coordination with higher management, performance and many such factors that could affect the production. The case organization began its operation in India in the year 1998, and since then, it is giving a lot of challenges and cutthroat competition to the automobile industry in terms of Agricultural machinery. Case organization manufactures a wide range of heavy-duty vehicles such as agricultural tractors, hay and forage, combine harvesters and sugarcane harvesters. It is currently using modern technology in various steps involved in the assembly line of the tractor, such as a barcode scanner, to reduce the time of selecting the assembling parts for a particular assembly that was earlier done manually and eventually lead to wastage of time. The second place where modern technology is implemented is, use of trolley equipped with sensors for the transportation of materials from storeroom to workstations. Statistical and graphical methods were used to determine the production rate per shift, and it also helped to indicate the production milestone that is to be achieved.

4.2 Actors

The opinions laid down in this paper are based on the case study of xyz by making an industrial visit to the organization. It involved interaction with production engineers working on the shop floor, top-level management, inventory control department and employees. Employees can place an order online or by visiting the organization. Orders once received are then sent to the production department with the deadline for delivering. The production department then communicates with the shop floor management and inventory control management to determine whether the ordered quantity can be prepared within the time period allotted; if yes, then the order is confirmed by the organization and is intimated to the production department. Once the order is prepared, it is then dispatched to the customer.

4.3 Process

The main processes of the assembly line of tractor followed in case organization are as follow: Loading/Unloading Chassis (This process deals with loading and unloading of the tractor chassis); Radiator Assembly on Chassis (In this process, the radiator is placed on the assembly chassis); Battery Assembly on Chassis (In this step the battery is placed on tractor chassis assembly); Parking Sensor; Fuel Tank Assembly on Chassis. Latest technology such as autonomous robots is partially used for transportation of side parts between different workstations. Cloud computing is also used by XYZ to keep the data attachable to the assembly, which reduces production time by keeping the track of which part is to be attached to which assembly. Data analysis of replacement done by the vendors also provided XYZ with the challenges for the future development of their product. Cybersecurity is also being used by the organization to keep confidential data safe for future reference and use. Orders by XYZ are accepted by various means, which include email, phone, fax and personal meetings. Simulation is also used by XYZ to determine the physical characteristics of the product. XYZ exports more than 50% of their production outside India, which makes it more diverse and classified. After the assembling of the final product, the product is taken for final inspection and is then dispatched by XYZ. If any defect is found in the final inspection, then the product is reversed to the manufacturing department for the rectification of the defect, which reduces the chances of replacement and helps XYZ to make customers more reliable on their brand name.

4.4 Learning

As there is tough competition in the manufacturing sector, XYZ has implemented simulation, autonomous robots, cloud computing, which is the pillars of I4.0 to ensure its survival against big MNCs. From our point of view, big data analysis can be done to improve the rate of production and gain customer reliability. Augmented reality can also be implemented to determine the blueprint of any new development and highlight areas of improvement.

Coordination of various departments can be brought together by implementation of horizontal and vertical system integration. Autonomous robots can be completely implemented to perform the repairing at places where humans cannot reach easily and for the transportation of parts. The industrial internet of things can also be implemented by the organization to get real-time response and decision-making. As there is a fall in demand for agricultural machinery in India, XYZ has changed its strategy and more focused on exporting its product to agriculture dominant countries.

4.5 Action

As XYZ is mainly responsible for assembling parts and converting them into finished goods, the task performed at each workstation is fixed. To give tough competition to its competitors, XYZ has changed its working environment condition by using some upgraded technologies. As competition is increasing, the inclination of companies is also increasing towards industry 4.0 pillars. XYZ can increase the uses of cloud computing in the system to improve the effectiveness of the inventory management system. All the data is saved digitally, which helps in the rough estimation of the requirement of parts in the future to better utilization of the warehouse. XYZ also decided to use a robot moving along the assembly line on a predefined path carrying essential parts such as small screws, nuts etc. These robots are equipped with IOT sensors so that they stop when they face any obstruction. XYZ can implement big data analytics to determine efficient production by keeping a record of replacements done in the year. The company can use robots instead of humans working on the assembly line as they perform specific operations in limited time with high accuracy. Augmented reality can also be implemented in industries, as the utility department requires professionals to carry out repairing in machines if any fault occurs, so to overcome this problem and to keep in mind the production time lag, this practice will help increase the production of organization. Sometime in critical situation company, utility department need outsource maintainers. So they approach them, which causes an unusual delay in production. Augmented reality is the ideal technology in maintenance activities.

4.6 Performance

At present, the organization is using some pillars like cloud computing and Big data. So the performance has increased by adding this. Now the organization is able to send the correct part at the right location in a different section of assembly line. It increases productivity and reduces time. And with the use of cloud computing, the XYZ organization is able to keep their data as much as XYZ wants to keep. And the organization is not worried about keeping the data server and maintain it. By implementing the few new technologies in the tractor production process, the case organization has improved its production by 15–25% per shift.

5 Observations of Study

During the case study, authors observed that instead of lying off workers, they had devised a way to keep them in the system while also utilizing their skills. They have done this is by developing Standard of Processes (SOPs), which are basically written instructions with pictures/diagrams that can be understood by any worker with basic skills such as reading and writing. Now, earlier, these SOP's were printed on a sheet of paper that was used by the workers manually to check and inspect the parts on the assembly line themselves. However, keeping implementation in mind and promoting it, they implemented a degree of autonomy to the system by making the SOPs digital. Now, instead of checking and verifying the correct parts manually, that is, by hand and eyes, the parts are now scanned by a barcode or RFID scanner. By implementing digital SOPs, they have increased their working capacity in the same working space as the on-paper SOP earlier required two men on the job, whereas digital SOP requires one, so they installed a second assembly line and shifted the additional workers on the job to the new line.

They have focused on other essential techniques such as Poka Yoke, End on Correction (EoC) and ergonomics to increase their quality of products and efficiency of production. In the case study, authors observed that to make the current organizations flexible in terms of manufacturing lines, companies have to invest a lot; however, the case organization has kept this in mind since the beginning, which has resulted in their manufacturing lines being 100% flexible, hence need of high initial investment is eliminated. Their manufacturing lines are capable of creating a fully customized product for their customers. The company also calls some selected customers once a year to their facility and make their products right in front of them, and the customer is free to customize the machine according to their own needs and interests.

6 Conclusion

In the current research, paper authors have demonstrated the implementation of industry 4.0 technologies in Indian manufacturing organization by a case study. The case organization is one of the leading manufacturers of agricultural machinery in India. The case study has given important insights into the importance of modern technologies. Implementation of key technologies has shown a positive impact on the performance of the case organization by showing improvement in export in the last two years. SAP-LAP analysis of an organization has been conducted based on industrial visits and interviews of the technical experts of the case organization. Some of the key observations from the case study are:

- Bar code and RFID tags are used to identify assembly components and autonomous robots are used to transfer the assembly components to assembly line.
- All the suppliers and vendors of case organization are connected by common software for sharing information.
- By using different IOT devices, information is gathered and data is stored on a private cloud accessible from any part of the globe by user ID.
- Big data analytics should be used to analyze the data gathered from IOT devices to improve the performance of machines/manpower and the overall efficiency of the organization. Different assemble errors can be reduced by developing AI tools, algorithms and augmented reality tools.
- Mass customization of products can be increased by inviting suggestions from different customers with the help of modern technologies.
- Data on customer demand and market scenario can be analyzed by using AI and Data analytical techniques.

Observation and finding of the study, find implication in the manufacturing sector of developing economies. Industry and academia researchers may further study on similar backgrounds for other economies.

References

1. Belhadi, A., Zkik, K., Cherrafi, A.,Yusof, M.: Understanding the capabilities of big data analytics for manufacturing process: insights from literature review and multiple case study. Comput. Indust. Eng. 106099 (2019)
2. Ceruti, A., Marzocca, P., Liverani, A., Bil, C.: Maintenance in aeronautics in an Industry 4.0 context: the role of augmented reality and additive manufacturing. J. Comput. Des. Eng. **6**(4), 516–526 (2019)
3. Cobo, M.J., Jürgens, B., Herrero-Solana, V., Martínez, M.A., Herrera-Viedma, E.: Industry 4.0: a perspective based on bibliometric analysis. Procedia Comput. Sci. **139**, 364–371 (2018)
4. Dilberoglu, U.M., Gharehpapagh, B., Yaman, U., Dolen, M.: The role of additive manufacturing in the era of industry 4.0. Procedia Manuf. **11**, 545–554 (2017)
5. Dutta, G., Kumar, R., Sindhwani, R., Singh, R.: Digital transformation priorities of India's discrete manufacturing SMEs—a conceptual study in perspective of Industry 4.0. Compet. Rev. Int. Bus. J. (Forthcoming) (2020). https://doi.org/10.1108/CR-03-2019-0031
6. Kumar, R.: Sustainable supply chain management in the era of digitalization: issues and challenges. In: Idemudia, E.C. (ed.) Handbook of Research on Social and Organizational Dynamics in the Digital Era. IGI Global, pp. 446–460. Web. 1 Aug. 2019. Arkansas Tech University, USA (2020). https://doi.org/10.4018/978-1-5225-8933-4.ch021. Publisher & ISSN/ISBN No. 290319-062455
7. Kumar, R.: Espousal of Industry 4.0 in Indian manufacturing organizations: analysis of enablers. In: Gaur, L., et al. (eds.) Handbook of Research on Engineering Innovations and Technology Management in Organizations. IGI Global (2020). ISBN13: 9781799827726|ISBN10: 1799827720|EISBN13: 9781799827733. https://doi.org/10.4018/978-1-7998-2772-6
8. Liao, Y., Deschamps, F., Loures, E.D.F.R., Ramos, L.F.P.: Past, present and future of Industry 4.0-a systematic literature review and research agenda proposal. Int. J. Prod. Res. **55**(12), 3609–3629 (2017)
9. Lins, T., Oliveira, R.A.R.: Cyber-physical production systems retrofitting in context of industry 4.0. Comput. Indust. Eng. **139**, 106193 (2020)
10. Masood, T., Egger, J.: Augmented reality in support of Industry 4.0—implementation challenges and success factors. Rob. Comput. Integr. Manuf. **58**, 181–195 (2019)
11. Meissner, H., Aurich, J.C.: Implications of cyber-physical production systems on integrated process planning and scheduling. Procedia Manuf. **28**, 167–173 (2019)
12. Mourtzis, D., Vasilakopoulos, A., Zervas, E., Boli, N.: Manufacturing system design using simulation in metal industry towards education 4.0. Procedia Manuf. **31**, 155–161 (2019)
13. Mourtzis, D., Vlachou, E., Dimitrakopoulos, G., Zogopoulos, V.: Cyber-physical systems and education 4.0–the teaching factory 4.0 concept. Procedia Manuf. **23**, 129–134 (2018)
14. Paravizo, E., Chaim, O.C., Braatz, D., Muschard, B., Rozenfeld, H.: Exploring gamification to support manufacturing education on industry 4.0 as an enabler for innovation and sustainability. Procedia Manuf. **21**, 438–445 (2018)
15. Promyoo, R., Alai, S., El-Mounayri, H.: Innovative digital manufacturing curriculum for industry 4.0. Procedia Manuf. **34**, 1043–1050 (2019)
16. Rossit, D.A., Tohmé, F., Frutos, M.: Industry 4.0: smart scheduling. Int. J. Prod. Res. **57**(12), 3802–3813 (2019)
17. Sahal, R., Breslin, J.G., Ali, M.I.: Big data and stream processing platforms for Industry 4.0 requirements mapping for a predictive maintenance use case. J. Manuf. Syst. **54**, 138–151 (2020)

18. Schumacher, A., Nemeth, T., Sihn, W.: Roadmapping towards industrial digitalization based on an Industry 4.0 maturity model for manufacturing enterprises. Procedia Cirp **79**, 409–414 (2019)
19. Tiacci, L.: Object-oriented event-graph modeling formalism to simulate manufacturing systems in the Industry 4.0 era. Simulation Model. Pract. Theory **99**, 102027 (2020)
20. Tosello, E., Castaman, N., Menegatti, E.: Using robotics to train students for Industry 4.0. IFAC-Papers On Line **52**(9), 153–158 (2019)
21. Vaidya, S., Ambad, P., Bhosle, S.: Industry 4.0–a glimpse. Procedia Manuf. **20**, 233–238 (2018)
22. Yang, S., Hamann, K., Haefner, B., Wu, C., Lanza, G.: A method for improving production management training by integrating an industry 4.0 innovation center in China. Procedia Manuf. **23**, 213–218 (2018)

Analytical and Decision Modeling Approaches in Circular Economy: A Review

Priyanshu Sharma, Bhupendra Prakash Sharma, Umesh Kumar Vates, Sanjay Kumar Jha, and Shyam Sunder Sharma

Abstract With the increasing concerns of the world towards environmental, social and economic factors, a multi-lateral attitude towards sustainable development and management policies is much needed now, hence a shift of the linear economy to the circular economy, famously known as closed-loop supply chain, is being exercised. The increase in exploration by academicians and industrialists to address various implementation issues and challenges is now vital and transition in many industries has been initiated. Numerous decision-making approaches are evaluated for the major domains of industry, *namely*, optimization of activity, processes, coordination, network design and marketing issues. With the categorization of the closed-loop supply chain as circular economy and emission reduction, the three factors (environmental, social and economic factors) are evaluated single-handedly. The present paper attempts to discuss various decision approaches and analytical models realized, evaluated and implemented by industries after careful assessment, based on the respective and customized network design models.

Keywords Circular economy · Closed-loop · Analytical models · Decision approach

1 Introduction

Circular Economy endorses the idea of R's associated with it, namely, recycle, repair, and remanufacture [1], turning the open end into a closed-loop [2, 3]. The economy part associated with being 'circular' with any supply chain extensively focuses on the cost involved in collecting, repairing, re-extracting and launching the associated

P. Sharma (✉) · B. P. Sharma · U. K. Vates
Amity University, Noida, Uttar Pradesh, India
e-mail: sharmapriyanshu20@gmail.com

S. K. Jha
Birsa Institute of Technology, Sindri, Jharkhand, India

S. S. Sharma
Manipal University, Jaipur, Rajasthan, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_5

product in the market in a given span of the secondary product life cycle [4]. The emergence of the concept of the circular economy goes back to 1990, which was introduced by David Pearce, and after since then is used by several researchers extensively in their research [2]. The implementation of CE in the supply chain involves the understanding of the process and involved factors as well as building a unique business model [5, 6] to carry out changes such as:

- Reuse of existing resources.
- Recreating the value within the supply chain.
- Realizing the value and meeting market demand.
- Receive a competitive edge.

The business model represents the elements of a complex organizational system and their association within the internal as well as with outside factors. While designing the distinctive business model for any unique supply chain, the concept is built while evaluating the idea of product or service, its creation and delivery, as well as value capturing aiming the analysis of the idea, planning the implementation and communicating it back to the system.

This business model is implemented, aiming reduction of waste, emission and addition of value in the supply chain. CE focuses on rebuilding and remodeling of manufacturing, financial, human, social and natural reserves [7]. The three-principle focused on the foundation on ReSOLVE, that is, regenerate, share, optimize, loop, virtualize, exchange, which further attributes its core on the elimination of waste, powering of renewable resources and respect for human as well as natural systems [8, 9]. Circular economy refers to the model of consumption and production with economic, ecological and social objectives in its main framework [10, 11].

With the alarming need to save the resources such as environment, human, time and money, researchers, industrialists and scholars are working in collaboration to solve issues related to linear to circular model conversions, implementation of CE model in business front, operational challenges occurring in CE, involved dynamics of circular economy and more. The amount of work happening on CE and the criticality of conceptualizing the circular economy by bridging the gap between theoretical and pragmatic CE is considered a vital agenda [3]. Researchers are intensely publishing their work and are on the increase every year, in the year 2014 around 30 articles were published, whereas two years later, the number was increased to 100. With the development in the sector of the circular economy several definitions are being practiced based on R's, that is, Reduce, Reuse and Recycle [12]. Various consulting firms such as Accenture, Deloitte, EY, McKinsey and company are expanding the horizons of CE in multiple businesses. In 2012 at World Economic Forum in Davos, a report was published by Ellen MacArthur Foundation and McKinsey Company, which highlighted the benefits of CE enactment and evaluated an opportunity of US$630 billion a year for EU manufacturing sector [12]. While defining a circular economy is considered as an alternative of "end of life" concept by reducing, reusing, recycling and recovering material at different stages of production, distribution and consumption processes. This helps in attaining a sustainable system at micro, meso and macro level, by creating environment quality, economic prosperity and social equity [3]. The business delivering product or services focuses on value addition in the supply chain by focusing on the concept of triple bottom line, that is, economic, environmental and social value. The sustainable supply chain emphasizes on environmental and social impact along with yield expansion and customer fulfillment, commonly called as PPP system, profit, people and planet [13]. Circular economy is also explored into two perspectives, namely, circular economy and emission reduction focusing on the reuse of used products and environmental pollution, respectively. Circular economy or closed-loop supply chain works in five phases, converging primarily on remanufacturing, reverse logistics process, coordinating the reverse supply chain, closing the loop, process and markets [14]. To develop a suitable business model with the intention of implementation, it must embrace various factors such as stakeholders, employees, clients, suppliers, customer, consumer, environment, society, government, and must actively be involved and prioritized or ranked depending upon the product/ service system. To utilize the business model to its fullest potential integrating with organizational level, the foremost elements, that is, value creation and addition, managerial participation and a long-term outlook, are essentially incorporated [15].

Numerous authors have published their work by performing innumerable case studies on different product/service-based organizations, aiming to study the challenges and issues in CE implementation and conversion of an open-ended supply chain to a closed one. The main framework followed by all was

- Decide on the type of industry to be focused.
- Decide on the product or service, based on the prior decided area of exploration.
- Decide on the prime factors and associated parameters that need to be considered.
- Prepare a method to gather information, mostly meeting individuals, surveys or questionnaires was prepared.
- Gathering of answer and assigning of nominal ranks or weightage to the parameters was done simultaneously.
- The best-fitted model was adopted.
- There are various models that are studied for multi-criteria decision making and are applied for the betterment of the circular economy and industrial relationship [16, 17]. Many countries around the globe, including the Organization for Economic Co-operation and Development (OCED) countries, are working on the implementation process of the circular economy to the industries [18, 19].
- India holds a huge job opportunity in CE transformation, to which major areas highlighted are metal and mining sector, electronics and high-tech sector, agriculture, food and beverage sector [20–23].

2 Modeling Approaches

2.1 Decision Tree Model

The benefits of the decision tree model approach used for understanding the business strategies employed in circular economy implementation in European SMEs (generally mezzo/meso level) holding the objective to attain entrepreneurial sustainability [24]. The work focuses on the applied practices at the company level and their effect on the economic performance of the companies. The model tree contains like-grouped characterized companies and their classes as parent and child nodes of the tree. More than ten thousand SMEs, focusing the area of manufacturing, industry, retail and service, were interviewed during the course and microdata was obtained from Flash Eurobarometer 441. The studied group was targeted to adopt various R's of the circular economy ranging from waste reduction by recycling and reusing, reduction in energy consumption by re-planning, redesigning of product and services, adopting renewable practices and resources. Several dependent and independent variables were studied such as geographical belongings, size of the organization, dominant area or sector, type of employees, overall business margins, etc., resulting in 100 parents and 30 child nodes.

Numerous vital and crucial findings were highlighted in the current research.

- SMEs implementing CE in their organization is highly getting influenced by country and region, turnover and market, type of sectors, level of inclination towards CE.
- Countries (European) in industry, manufacturing and retail have shown the highest implementation rate of around 88%.
- Companies having a higher end of turnover, that is, more than 10 million euros have successfully implemented CE in respective sectors making the rate to be 98%.
- The economic performance of the companies was influenced by drivers such as an investment of firm in CE R&D, sector and location of the establishment, skill-based people, degree of investment in CE, shift to renewables.
- The most common activity incorporated by the SMEs includes a reduction in waste by recycling or selling, redesigning of products focusing on renewable resources and re-planning water usage.
- Implementation of CE and entrepreneurial sustainability highly depends on managerial support and investment, institutional framework, and incentives.

Hence Decision tree model serves the purpose of a clear interpretation, identification of patterns, provides ease in a compilation of data, effective segregation of data, identification of indicators and variables along with their coding (nature-dependent or independent; weightage in the form of a percentage).

2.2 Shannon Entropy. Evaluation Algorithm Based

Entropy is the measure of uncertainty or randomness or fuzziness. By measuring the level of uncertainty, a precise statement or conclusion can be answered of the formed question [25]. Shannon's entropy is a solution to abundant and uncertain information following probability distribution. Based on Shannon's Entropy, if the differences in the indicators is high then entropy will have a smaller value and vice versa. Also, if the indicator gives more information, than the assigned weightage will be also more.

Shannon entropy approach is used for the analysis of the data collected from the Statistical Office of the European Union (EUROSAT) for 28-member states from 2007 to 2016. However, for modeling the data of year 2007 was extracted, weights and indicators were formed by the algorithms [26]. To measure circular economy output, data of countries and their respective recycling rate and economic growth were noted. After the collection of the data, its standardization is done, followed by the assignment of weights (Table 1).

Hence, the Shannon Entropy approach is suitable for processes that contain information in the most random manner and need categorization with a greater number of parameters. The entropy approach is used for understanding the level of uncertainties or fuzziness. Shannon entropy quantifies the expected value of a discrete random variable [27].

2.3 Multiple Criteria Decision Making (MCDM) Approach

The involvement of multiple factors in any supply chain cannot be denied; like this, their effects, as well as information handled at each step, cannot be ignored. This information helps the decision-makers to model, establish and execute the needed sustainable model. During the designing of the model, consideration of dynamic environment of market, stakeholders, interconnected suppliers, product user and the subsets, namely, engineering and technology, economics, environment and social aspects, becomes vital.

Sustainability needs a model that considers the dynamism of state and providing with the most optimum solution. A hybrid MCDM approach for evaluation of the issues and essential strategies for its sustainable execution is extensively used in energy, environment and sustainability domains due to its malleable behavior in both discrete and continuous information handling [28]. Identified and selected criteria's can be provided with direct weight, equal weight, subjective and objective weight based on opted selection techniques such as direct ranking, outranking, multi-attribute utility theories, multi-objective programming, elementary aggregation method [29]. Multiple criteria decision-making approach is clubbed with other techniques such as genetic algorithm (GAs), Analytic network process (ANP), constraint logic programming (CLP), the technique of order performance similarity to idea solution (TOPSIS), decision making trial and evaluation laboratory

Table 1 Shannon entropy formulation

Steps		Formulae
1	Standardization of original (X) data: Y Z and U	$X = \left(x_{ij}\right)$; $Y = y_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}}, \quad j = 1, 2$ $Z = z_{ij} = \frac{y_{ij} - \min \bar{y}_j}{S_j}, \quad j = 1, 2$ $U = u_{ij=d} + z_{ij}$ where S_j is standard deviation and $\overline{y}_j$ is mean value of jth index
2	Calculation of weights	Probabilities of jth index of the ith sample are calculate $= d$ by; $p_{ij} = \frac{u_{ij}}{\sum_{i=1}^{m} u_{ij}}, \quad$ where $j = 1$ to n and $i = 1$ to m
3	Calculation of entropy	Entropy $e_j = \frac{-1}{\ln(m)} \sum_{i=1}^{m} p_{ij} \ln\left(p_{ij}\right)$; where $j = 1$ to n Standardize the weight by $w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}$, where $j = 1$ to n
4	Evaluate the samples and obtain final ranking	$f_i = \sum_{j=1}^{n} f_{ij} = w_j \cdot y_{ij}$, where $I = 1$ to m

Investment indicator = government 10-year average investment in R&D for Circular Economy
Efficiency Index = ratio between the Outcomes
Conclusion: Higher expenditure on R&D, higher is the efficiency score, High level of CE percentage, higher efficiency index

(DEMATEL), resulting it into a hybrid approach. Using a hybrid approach over classical MCDM is preferred due to the following reasons

- Finding an appropriate model for a dynamic situation that proves apt and suitable every time is an ongoing challenge.
- Providing weights and orders to any criteria highly depends upon the fact which factor is analyzed in the problem. The hybrid approach enables us to work on determining weights (values) and integrating to function value at the same time.
- The closeness of the formulated model to the practical scenario is helped by including fuzzy logics in the MCDM approach.

Hybrid Multi-Criteria Decision making approach has extended its arms in various domains such as engineering and operational sectors [28]; the progress and key points for HMCDM are as follows,

- The first paper with HMCDM was sited in the year 1975, progressing at a very slow pace, the year 2008–2015 observed tremendous growth.
- Out of 2450 papers analyzed, 251 different research were dedicated to hybrid MCDM.
- A total of 85 countries, China and Taiwan must be observed maximum papers on classical MCDM and hybrid MCDM approach till 2015, that is, 455 in Taiwan and 323 in China.
- Taiwan has been credited a maximum of 103 papers dedicated to HMCDM emerging as a dominant contributor.
- Amongst the various used analytical techniques ANP, DEMATEL TOPSIS, AHP and VIKOR most frequently used.
- Techniques such as MOORA, WASPAS and MULTIMOORA are gaining interest among the authors and researchers.
- Domains such as Computer science, Engineering, Operational Research and Management Science, have primarily been found to be extensively working towards sustainability hence exploring the analytical techniques with fuzzy logic.

Hence the hybrid MCDM approach is used to design sustainable business models having many uncertain information and involving several variable coefficients. HMCDM can be applied to the development and selection of best-suited model accounting technical, economic, environmental, and social aspects. Weights assigned to the criteria can be equal, direct, subjective, and objective, and hence the ranking order will vary for each situational model. Many researchers are actively working on creating an optimum hybrid model by endeavoring various blends of analytical techniques.

2.4 MULTIMOORA Integrated with Shannon's Entropy

The employee is a critical factor in designing of closed-loop supply chain model and for successful circular economy implementation. For a loyal and dedicated employee, appraisal and recognition act as a catalyst in the development of a team and organization [26]. Therefore, an optimum performance analysis method is needed which is an optimum integration between business policies and human resource activities [30]. MULTIMOORA integrated with Shannon's entropy has two approaches that are adopted for identification of criteria, that is, MULTIMOORA and Entropy MULTIMOORA, whereas, for deciding rankings TOPSIS and TOPSIS integrated with Shannon's entropy is explored. The Multimoora approach has three parts, namely ratio system, reference point and full multiplicative form, Shannon's entropy is given by the following [27]

$$E_j = -k \sum_{i=1}^{m} p_{ij} \ln p_{ij}, \text{ where } k = \frac{1}{\ln(m)}$$

Certain observation noted are as follows

- Input data is obtained in the form of decision criteria from the experts. From input, various other possible alternatives were evaluated.
- Interviews and questionnaires were prepared. The question formed was in the form of linguistic terms, that is, very poor to very good, and later convert into a nominal scale.
- Shannon's entropy coefficient, if formulated and weights of the criteria are assigned.
- For MULTIMOORA, the three designed steps, that is, ratio system, reference point approach and full multiplicative form are calculated.
- A total of eight criteria are formulated, including the possibility and compatibility of method, cost employed in designing and training, validation with a pragmatic outlook and employee satisfaction.
- Different PA methods are compared such as ranking method, graphic rating scales, narrative essay management, objective management, BARS (Behaviorally Anchored Rating Scale Human), 360° stakeholder approach, 720° customer and investor approach.
- Once ranked are being assigned, they were compared by MULTIMOORA, Entropy MULTIMOORA,
- TOPSIS and TOPSIS with integrated Shannon's entropy and a decision matrix are generated.
- In the work, the best approach for performance appraisal post evaluation was "360°" approach with a final ranking of one, which considers stakeholder, that is, managers, peers, assistants, and customers were involved in input data collection. The collected questionnaire had 75 questions and were compared on a scale of 0–20. The appraisals were evaluated after every 6 months and out of 475 total involved participants only 275 candidates have provided complete and accurate answers.
- In a larger size of the organization, the conventional PA method becomes a failure; therefore, MCDM, along with the entropy approach, helps in considering major uncertainties and possibilities.

3 Conclusion

The current study is a review study exploring different modeling approaches and their applications in various fields is being understood. Following concluding observations are made:

- The choice of modeling approach depends on involved factors and their variants such as industry involved, geographical location, size of organization, stakeholders, dynamics of customer demand, technological involvement, managerial voice and many more.
- Multi-Criteria Decision Models benefits by considering multiple factors involved and understanding their complex behavior.
- The methodology of different tools also considers the application of the industry as is production or consumption-based, top-down or down-up based. While designing a quantitative model for the circular economy, focusing on inventory redesign, lot size modeling, can also act as an enabler to achieve a circular economy.
- The world is moving toward the accomplishment of a sustainable or closed-loop supply chain in two paradigms, that is, circular economy, in which specific models are formulated and emission reduction, where policy development is practiced. Many European SMEs have started the redesigning of their supply chains and analysis of optimum business model targeting to achieve entrepreneurial sustainability.
- Amongst many MCDM tools, EU-SME's have evaluated Shannon's entropy approach with MCDM, by defining a complex index, efficiency index, considering all the uncertainties in criteria development and ranking methods.
- MCDM methods also have their utility in the selection of material, investigating the durability of the product, performance study of the material based on property, which may use mathematical techniques such as CORPS, MOORA, ANP, AHP and others.
- Evaluation of weights and ranks by these methods also encounters fuzzy issues in the domains of environment, energy, technology, answering the most optimum approach by hybrid modeling of MCDM. CE has influenced by indicators such as economic, social and environmental factors, research and development investment, education on recycling and reuse.
- General Assembly of UN has also issued a preamble for CE transition and achievements on sustainable production and usage, reflecting the essential urge to adopt this transition.
- The future work focusses on exploring performance assessment methods such as LCA (Life cycle Assessment)/LCI (Life Cycle Inventory)/LCSA (Life Cycle Sustainability Assessment), PF (productivity Factor), through MCDM methodology.

References

1. Daniel, V., Guide, R., Jr.: Production planning and control for remanufacturing: industry practice and research needs. J. Oper. Manag. **18**, 467–483 (2000)

2. Pishchulov, G.V., Richter, K.K., Pakhomova, N.V., Tsenzharik, M.K.: A circular economy perspective on sustainable supply chain management: an updated survey. J. Econ. Stud. **34–2**, 267–297 (2018)
3. Kirchherr, J., Reike, D., Hekkert, M.: Conceptualizing the circular economy: an analysis of 114 definitions. Resour. Conserv. Recycling **127**, 221–232 (2017)
4. Brandao, M., Lazarevic, D., Finnveden, G.: Prospects for the circular economy and conclusions. In: Handbook of Circular Economy (2020)
5. Geissdoerfer, M., Morioka, S.N., de Carvalho, M.M., Evans, S.: Business models and supply chains for the circular economy. J. Clean. Prod. (2018). https://doi.org/10.1016/2018.04.159
6. Xavier, G.D., Ana Sanchez, L., et al.: Methodological framework for the implementation of circular economy in urban systems. J. Clean. Prod. 119227 (2019)
7. Potting, J., Hekkert, M., Worrell, E., Hanemaaijer, A.: Circular Economy: Measuring Innovation in The Product Chain, Pbl Netherlands Environmental Assessment Agency The Hague, PBL Publication Number: 2544 (2017)
8. Ellen MacArthur Foundation.: Circular Economy in India: Rethinking growth for long-term prosperity (2016)
9. Gupta, S., Chen, H., et al.: Circular economy and big data analytics: a stakeholder perspective. Technol. Forecast. Soc. Change (Elsevier) **144**, 466–474 (2019)
10. Sassanelli, C., Rosa, P., et al.: Circular economy performance assessment methods: a systematic literature review. J. Clean. Prod. **299**, 440–453 (2019)
11. Sauve, S., Bernard, S., Sloan, P.: Environmental sciences, sustainable development and circular economy: alternative concepts for trans-disciplinary research. Environ. Dev. **17**, 48–56 (2016)
12. Wautelet, T.: The Concept of Circular Economy: its Origins and its Evolution Research Gate 2.19 Oxford University Press (2018)
13. Witjesa, S., Lozano, R.: Towards a more circular economy: proposing a framework linking sustainable public procurement and sustainable business models. Conserv. Recycling **112**, 37–44 (2016)
14. Guide, V.D.R. Jr., Van Wassenhove, L.N.: The evolution of closed loop supply chain research, INSEAD Fountainbleau France JSTOR **57**(1), 10–18 (2009)
15. Molinier, R.: Quantitative Models for the Circular Economy (2010) Sustainable Production Planning, International workshop in lot sizing IWLS in Gardanne GT P2LS (2010)
16. Mardani, A., Jusoh, A., Nor, K.M.D., Khalifah, Z., Zakwan, N., Valipour, A.: Multiple criteria decision-making techniques and their applications—a review of the literature from 2000 to 2014. Econ. Res. Ekonomska Istraživanja **28**(1), 516–571 (2015)
17. Kalmykova, Y., Sadagopan, M, Rosado, L.: Circular economy—from review of theories and practices to development of implementation tools. Conserv. Recycling **135**, 190–200 (2018)
18. Căutișanu, C., Asandului, L., Borza, M., Turturean, C.: Quantitative approach to circular economy in the OECD countries. Amfiteatru Econ. **20**(48), 262–277 (2018)
19. Rosa, P., Sassanelli, C., Urbinati, A., Chiaroni, D., Terzi, S.: Assessing relations between circular economy and industry 4.0: a systematic literature review. Int. J. Prod. Res. 0020–7543 (2019)
20. Ellen MacArthur Foundation.: Towards a circular economy vol. 3: accelerating the scale-up across global supply chains (2014)
21. Preston, F.: A Global Redesign: Shaping the Circular Economy, Energy, Environment and Resource Governance, EERG BP vol. 2 (2012)
22. Rajput, S., Singh, S.P.: Connecting circular economy and industry 4.0. Int. J. Inf. Manag. https://doi.org/10.1016/2019.03.002 (2019)
23. Balany, R., Halog, A.: Tools for circular economy: review and potential application for the Philippine textile industry. Circ. Econ. Textile Apparel (2019). https://doi.org/10.1016/B978-0-08-102630-4.00003-0
24. Zamfir, A.M., Mocanu, C., Grigorescu, A.: Circular economy and decision models among European SMEs. MPDI-Sustain. **9**, 1507 (2017)
25. Iltaf Hussain, S.A., Mandal,U.K.: Entropy based MCDM approach for Selection of material. In: National Level Conference on Engineering Problems and Application of mathematics National Level Conference on Engineering Problems and Application of mathematics (2017)

26. Busu, C., Busu, M.: Modeling the Circular Economy Processes at the EU Level Using an Evaluation Algorithm Based on Shannon Entropy MPDI-Processes 6 225 (2018)
27. Maghsoodi, A.I., Abouhamzeh, G., Khalilzadeh, M., Zavadskas, E.K.: Ranking and selecting the best performance appraisal method using the MULTIMOORA approach integrated Shannon's entropy. Front. Bus. Res. China **12**, 2 (2018)
28. Zavadskas, E.K., Govindan, K., Antucheviciene, J., Turskis, Z.: Hybrid multiple criteria decision-making methods: a review of applications for sustainability issues. Econ. Res. Ekonomska Istraživanja **29**(1), 857–887 (2016)
29. Ibáñez-Forés, V., Bovea, M.D., Pérez-Belis, V.: A holistic review of applied methodologies for assessing and selecting the optimal technological alternative from a sustainability perspective. J. Clean. Prod. **70**, 259–281 (2014)
30. Narayanan, A.K., Jinesh, N.: Application of SWARA and TOPSIS methods for supplier selection in a casting unit. Int. J. Eng. Res. Technol. **7**(5) (2018)

Analyzing the Production of the Plastic Manufacturing Through Fuzzy Analytic Hierarchy Process

P. Abirami and O. S. Deepa

Abstract This paper presents a successful implementation of six sigma methodology in manufacturing unit of small- and large-scale plastic industries by identifying the root causes and by improving the economic benefits of the firm through project selection. The present study aims to develop and improve the project selection by weight evaluation criteria and by ranking using fuzzy analytic hierarchy process (FAHP). This FAHP is based on triangular fuzzy numbers to increase the overall productivity, profitability, and quality of the organization. The study follows the application of the DMAIC technique for investigating the defects and provides a solution to reduce these defects by evaluating the best process environment which could simultaneously satisfy requirements of operational excellence. The optimum settings of the parameters during machining process for various plastic products were found using design of experiments. An empirical case study is carried out to show the effectiveness of the project. The results are checked by fuzzy linear regression control charts which would help the organization to create eco-friendly environment.

Keywords Fuzzy analytic hierarchy process · DMAIC technique · Signal to noise ratio · Fuzzy regression · Control charts

1 Introduction

To meet the demands of the consumers, companies must improve their performance to maintain organizational excellence [1]. Industries are using six sigma methodology for sustaining company's overall performance. Six sigma increases the efficiency to improve customer satisfaction. A large number of enterprises, including Motorola, General Electrical, Du Pont, Honeywell and Sony, have implemented six sigma in order to maintain the success of the organization. Six sigma is an innovative methodology used to improve the process by using a series of statistical techniques to determine and analyze the manufacturing process. It involves in-depth analysis

P. Abirami · O. S. Deepa (✉)
Department of Mathematics, Amrita School of Engineering, Amrita Vishwa Vidyapeetham, Coimbatore, India
e-mail: os_deepa@cb.amrita.edu

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_6

and strategic decision-making with the goal of finding an optimal solution rather than a rational one. With a view to improving quality, the fundamental concept in Six Sigma is to analyze the variations in both product and process. Motorola Corporation created the six sigma to boost the production efficiency [2, 3]. A systematic factory-in-factory (FiF) framework of the production system is studied by minimising wastes according to the unresolved issues of the current continuous improvement program [4]. Recently a case study was studied and implemented on lean six sigma framework in a large-scale industry [13]. An improved modified FMEA model for prioritization of lean waste risk was modelled by the inclusion of the waste-worsening factors and Taguchi loss functions which has enabled the FMEA team to articulate the severity level of waste Fuzzy Interpretive Structural Modeling (FISM) approach has been used to analyze the interrelationships among the health care factors [5].

2 Selection of Six Sigma Project

The six sigma is a project-oriented approach that helps the organization through a successful project to achieve its strategic objective. Especially when performing six sigma initiations, project generation and priority performs the most critical parts. Six sigma is a tool for the pursuit of operational excellence that has significant value. MADM approaches can easily solve a project selection problem having common factors and conflicting requirements as these methods are used to correct competing plans with different parameters for selection.

The decision-maker may need to take into account the best and most useful range of the Six Sigma project. In the selected plastic manufacturing industry, these three requirements have been established. After the various decision makers had expressed their views, the criteria were finalized. Alternatives for six Sigma project selection should be evaluated to these established criteria. Quantitatively, it is not easy to express all the parameters. in dealing with ambiguity, it is appropriate to use the fuzzy set theory for selecting six sigma projects FAHP. Among these FAHP algorithms, Fuzzy Extent Analysis (FEA) method is the most frequently used FAHP algorithm [6]. It utilizes the concept of extent analysis combined with degree of possibility to calculate weights from fuzzy comparison matrices.

3 Fuzzy Set and Fuzzy Logic

Fuzzy set and fuzzy logics are important computational tools for modeling and management of an uncertain process in industries and society. In the absence of complete and accurate data they promote intuitive reasoning in decision making. The fuzzy philosophy also provides a systematic structure to deal with the fuzzy values e.g. most, many, few and not much etc. this furbishing philosophy involves both established theory of logic and probability and it deals with fuzzy vague approach.it

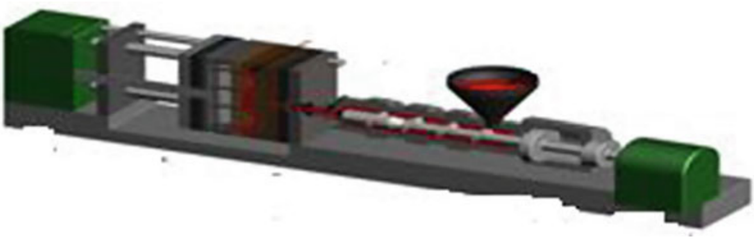


Fig. 1 Injection molding machine

includes the interval of the element [0, 1] which expresses the significance of the element to be part of a set [7–9].

Let a, b and c be real numbers with $a < b < c$. Then the Triangular Fuzzy Number (TFN) $A = (a, b, c)$ is special case of fuzzy number with membership function:

$$\mu_A(x)\begin{cases} \frac{(x-a)}{(b-a)}, & a \leq x \leq b \\ \frac{(c-x)}{(c-b)}, & b \leq x \leq c \\ 0, & \text{otherwise} \end{cases}$$

3.1 Define Phase

It's an injection molding unit that produces plastic products which we use in our daily life [10–16]. The raw material used here is the chips (the final product of the plastic recycling) and polypropylene is the plastic material type used in this study. Figure 1 shows the injection molding machine of the plastic manufacturing process.

3.2 Measure Phase

Three objectives for choosing the best six sigma project alternative set by the organization are, PA1 (energy saving), PA2 (temperature control), PA3 (defect minimization). Further, care was taken to enlist possible sub criteria for each major criterion, which are considered by them as vital for achieving the objective. Figure 2 displays the criteria and sub criteria. The comparison of the importance of one criterion against the other criteria's, one sub-criterion against the other sub-criterion and an alternative against the others alternative were estimated by means of a pre-test questionnaire. The 7-point scaling approach was introduced in determining the value of one criterion, sub criterion or alternative compared with another (extremely low, very low, moderately low, moderate or extremely high). Table 1 displays the triangular fuzzy

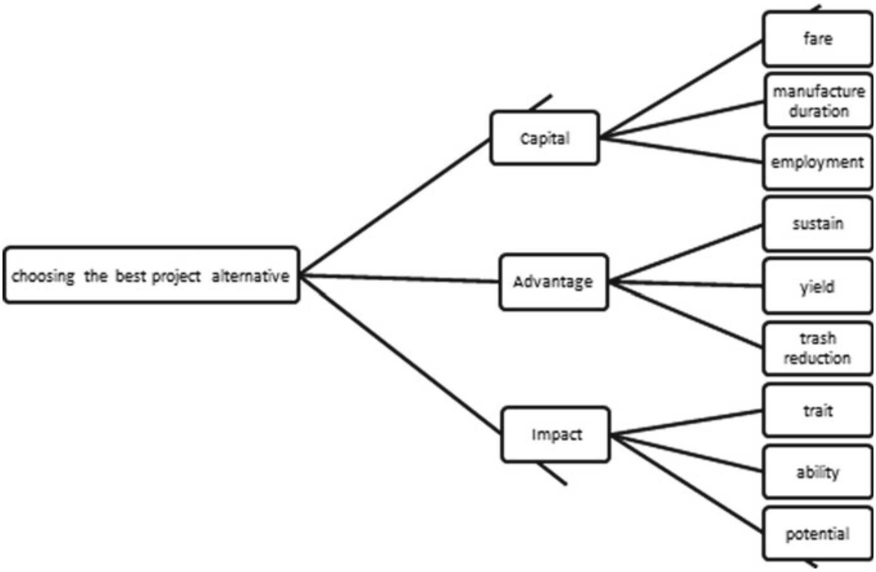


Fig. 2 Criteria's and sub criterions for selection of best project alternative

Table 1 TFN scale

Statement	TFS
Extremely low	(0, 0.05, 0.15)
Very low	(0.1, 0.2, 0.3)
Low	(0.2, 0.35, 0.5)
Medium	(0.3, 0.5, 0.7)
High	(0.5, 0.65, 0.8)
Very high	(0.7, 0.8, 0.9)
Extremely high	(0.85, 0.95, 1)

numbers scale. Figure 2 Criteria's and sub criterions for selection of best project alternative. The fuzzy matrix table is built by comparing the criteria subjected to the model in pairs as shown in Table 2. Table 3. The fuzzy pair wise comparison matrix of sub criterions.

For Table 2, wt = $(0.3903, 0.2753, 0.3414)^T$ and from Table 3, wt = (0.3793, 0.286). Table 4 shows the fuzzy pair wise comparison matrix of sub-criteria under

Table 2 The fuzzy pair wise comparison matrix of decision criteria's

	Capital	Advantage	Impact
Capital	(1, 1, 1)	(0.7, 0.8, 0.9)	(0.3, 0.5, 0.7)
Advantage	(0.7, 0.8, 0.9)	(1, 1, 1)	(0.7, 0.8, 0.9)
Impact	(0.5, 0.65, 0.8)	(0.7, 0.8, 0.9)	(1, 1, 1)

Table 3 The fuzzy pair wise comparison matrix of sub criteria's

	Fare	Manufacture duration	Employment
Fare	(1, 1, 1)	(0.5, 0.65, 0.8)	(0.3, 0.5, 0.7)
Manufacture duration	(0.5, 0.65, 0.8)	(1, 1, 1)	(0.7, 0.8, 0.9)
Employment	(0.3, 0.5, 0.7)	(0.7, 0.8, 0.9)	(1, 1, 1)

Table 4 The fuzzy pair wise comparison matrix of sub-criteria under advantage

	Trait	Ability	Potential
Trait	(1, 1, 1)	(0.85, 0.95, 1)	(0.3, 0.5, 0.7)
Ability	(0.85, 0.95, 1)	(1, 1, 1)	(0.5, 0.65, 0.8)
Potential	(0.3, 0.5, 0.7)	(0.5, 0.65, 0.8)	(1, 1, 1)

Table 5 The fuzzy pair wise comparison matrix of sub-criteria under impact

Sustain	(1, 1, 1)	(0.7, 0.8, 0.9)	(0.5, 0.65, 0.8)
Yield	(0.7, 0.8, 0.9)	(1, 1, 1)	(0.3, 0.5, 0.7)
Trash reduction	(0.5, 0.65, 0.8)	(0.3, 0.5, 0.7)	(1, 1, 1)

advantage and Table 5 shows the fuzzy pair wise comparison matrix of sub-criteria under impact.

The weight vector from Table 4 is calculated as wt = $(0.3479, 0.4018, 0.2501)^T$ and wt = $(0.3801, 0.3324, 0.2873)^T$. In accordance with the respective parameters, the comparison matrix of decision alternatives and corresponding weighted vector of each alternative are calculated. The project assessment in relation to the sub-criteria is shown in the Table 6.

The sub-attributes of capital advantage and impact were also calculated. The combination of priority weights for criteria, sub criteria and alternatives are used to determine the priority weight for the selection of the best Six Sigma and is shown in Table 7. Based on this result PA1 (Energy saving) which has the highest alternative priority weight 0.4355 is found to be the best six sigma project. Table 8 shows inner radius of the plastic caps and Table 9 shows Triangular fuzzy number.

3.3 Analyze Phase

Materials that are used in the plastic manufacturing industry have been heated and brought to the molten state. The team has decided to evaluate the energy used and to achieve the optimal condition from which we can make good products. This helps us to reduce the electricity consumption of defective products.

Table 6 The fuzzy pair wise comparison matrix for sub-criteria's

Fare				Yield			
	PA1	PA2	PA3		PA1	PA2	PA3
PA1	(1, 1, 1)	(0.3, 0.5, 0.7)	(0.5, 0.65, 0.8)	PA1	(1, 1, 1)	(0.3, 0.5, 0.7)	(0.7, 0.8, 0.9)
PA2	(0.5, 0.65, 0.8)	(1, 1, 1)	(0.85, 0.95, 1)	PA2	(0.5, 0.65, 0.8)	(1, 1, 1)	(0.3, 0.5, 0.7)
PA3	(0.7, 0.8, 0.9)	(0.3, 0.5, 0.7)	(1, 1, 1)	PA3	(0.2, 0.35, 0.5)	(0, 0.05, 0.15)	(1, 1, 1)
Manufacture duration				Trash reduction			
	PA1	PA2	PA3		PA1	PA2	PA3
PA1	(1, 1, 1)	(0.85, 0.95, 1)	(0.3, 0.5, 0.7)	A1	(1, 1, 1)	(0.5, 0.65, 0.8)	(0.3, 0.5, 0.7)
PA2	(0.5, 0.65, 0.8)	(1, 1, 1)	(0.3, 0.5, 0.7)	PA2	(0.3, 0.5, 0.7)	(1, 1, 1) P	(0.5, 0.65, 0.8)
PA3	(0.2, 0.35, 0.5)	(0.7, 0.8, 0.9)	(1, 1, 1)	PA3	(0.3, 0.5, 0.7)	(0.2, 0.35, 0.5)	(1, 1, 1)
Employment				Trait			
	PA1	PA2	PA3		PA1	PA2	PA3
PA1	(1, 1, 1)	(0.2, 0.35, 0.5)	(0.5, 0.65, 0.8)	PA1	(1, 1, 1)	(0.5, 0.65, 0.8)	(0.5, 0.65, 0.8)
PA2	(0, 0.5, 0.15)	(1, 1, 1)	(0.3, 0.5, 0.7)	PA2	(0.3, 0.5, 0.7)	(1, 1, 1)	(0.7, 0.8, 0.9)
PA3	(0.3, 0.5, 0.7)	(0.5, 0.65, 0.8)	(1, 1, 1)	PA3	(0.1, 0.2, 0.3)	(0.1, 0.2, 0.3)	(1, 1, 1)
Sustain				Ability			
	PA1	PA2	PA3		PA1	PA2	PA3
PA1	(1, 1, 1)	(0.7, 0.8, 0.9)	(0.2, 0.35, 0.5)	PA1	(1, 1, 1)	(0.7, 0.8, 0.9)	(0.7, 0.8, 0.9)
PA2	(0.7, 0.8, 0.9)	(1, 1, 1)	(0.3, 0.5, 0.7)	PA2	(0.85, 0.95, 1)	(1, 1, 1)	(0.5, 0.65, 0.8)

(continued)

Table 6 (continued)

Fare				Yield			
	PA1	PA2	PA3		PA1	PA2	PA3
PA3	(0.3, 0.5, 0.7)	(0.5, 0.65, 0.8)	(1, 1, 1)	PA3	(0.5, 0.65, 0.8)	(0.1, 0.2, 0.3)	(1, 1, 1)
				Potential			
					PA1	PA2	PA3
				PA1	(1, 1, 1)	(0.85, 0.95, 1)	(0.7, 0.8, 0.9)
				PA2	(0.5, 0.65, 0.8)	(1, 1, 1)	(0.3, 0.5, 0.7)
				PA3	(0.3, 0.5, 0.7)	(0.5, 0.65, 0.8)	(1, 1, 1)

Table 7 *S/N* ratio and Mean for different parameters

Position	Speed	Power	Pressure	t_1	t_2	t_3	t_4	Mean	*S/N* ratio
42	40	85	50	132	130	132	132	131.5	26.11465
42	50	90	60	140	140	140	142	140.5	30.85777
42	40	85	50	138	138	138	136	137.5	28.97427
200	40	90	50	155	156	156	157	156	42.86011
200	50	85	50	160	163	159	168	162.5	33.06295
200	40	85	60	150	150	152	150	150.5	45.1545
480	40	85	60	162	162	164	160	162	33.52699
480	50	85	50	169	170	168	171	169.5	28.31044
480	40	90	50	166	166	164	168	166	30.36563

The parameters are identified and there were 24 combinations (3 parameters with two stage and one with 3 stage). Three separate positions were taken. energy, pressure, and power were taken over two stages. With these variations, readings were taken in 30 min from manufacturing to raise the melting temperature (ti) of plastic material. s/n ratio with largest value is chosen as the optimal solution and hence the optimal setting are as follows: position: 200, speed: 40, power: 90, pressure: 50.

3.4 Improve Phase

The optimal setting as per *S/N* ratio was discussed with team members. Necessary steps were taken by the production department to reduce the manufacturing defect.

Table 8 Inner radius of the plastic caps

Sample number	Inner radius (mm)
1	0.358
	0.362
	0.361
	0.36
	0.36
2	0.364
	0.366
	0.362
	0.36
	0.361
…	…
12	0.372
	0.37
	0.366
	0.376
	0.373

Table 9 Triangular fuzzy number

Sample number	x_1	x_2	x_3
1	0.353	0.358	0.359
	0.361	0.362	0.366
	0.358	0.361	0.364
	0.359	0.36	0.361
	0.355	0.36	0.365
2	0.363	0.364	0.365
	0.36	0.366	0.369
	0.357	0.362	0.365
	0.354	0.36	0.362
	0.359	0.361	0.364
…	…	…	…
12	0.37	0.372	0.375
	0.369	0.37	0.373
	0.36	0.366	0.372
	0.372	0.376	0.378
	0.369	0.373	0.375

3.5 Control Phase

The regression control charts are used for monitoring and control.it allows for monitoring a change in a process where two or more variables are correlated. The change in a dependent variable can be detected and compensatory change in the independent variable can be recommended. The linear regression equation was taken from [7–9].

The radius of the plastic caps produced were taken to find the product condition α-level fuzzy midrange for α-level fuzzy $\tilde{\tilde{X}}$ regression control chart and α-level fuzzy midrange for α cut fuzzy $\overline{R}$ control chart are implemented. The plastic cap radius has been collected. The data obtained is further transformed into a triangular fuzzy figure. 12 samples of each sample size 5 were collected over a period of time. $\left(\overline{X}_{x_1,ki}, \overline{X}_{x_2,ki}, \overline{X}_{x_3,ki},\right)$ are the triangular fuzzy number. The radius obtained and the corresponding triangular fuzzy number are shown in Tables 10 and 11. The fuzzy linear regression model for the average of each fuzzy number can be found using the following formula

$$\overline{X}_{\text{Regression}-x_1,i} = \widehat{\beta}_{0x_1} + \widehat{\beta}_{1x_1} T_i + \varepsilon \quad (1)$$

$$\overline{X}_{\text{Regression}-x_2,i} = \widehat{\beta}_{0x_2} + \widehat{\beta}_{1x_2} T_i + \varepsilon \quad (2)$$

Table 10 Control limits using the α-level fuzzy midrange for the α-cut fuzzy $\tilde{\tilde{X}}$-regression control chart based on ranges

Sample number	$s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i}$	$0.00099 - 0.00184T_i \leq s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} \leq 0.007914 - 0.00184T_i$	Result
1	0.004664	$-0.00085 \leq s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} \leq 0.00607$	Controlled
2	0.004706	$-0.00122 \leq s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} \leq 0.00570$	Controlled
3	0.004749	$-0.00159 \leq s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} \leq 0.005333$	Controlled
4	0.004833	$-0.00233 \leq s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} \leq 0.004595$	**Out of control**
5	0.004791	$-0.00196 \leq s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} \leq 0.004964$	Controlled
6	0.004727	$-0.00141 \leq s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} \leq 0.005517$	Controlled
7	0.004812	$-0.00214 \leq s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} \leq 0.00478$	**Out of control**
8	0.00477	$-0.00178 \leq s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} \leq 0.005149$	Controlled
9	0.004717	$-0.00131 \leq s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} \leq 0.005609$	Controlled
10	0.004727	$-0.00141 \leq s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} \leq 0.005517$	Controlled
11	0.004738	$-0.0015 \leq s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} \leq 0.005425$	Controlled
12	0.004685	$-0.00104 \leq s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} \leq 0.005886$	Controlled

Table 11 Control limits using the α-level fuzzy midrange for an α-cut fuzzy $\overline{R}$ control chart

Sample number	$\leq s^{\alpha}_{\text{midrange}-\text{Range},i} \leq$	$0 \leq s^{\alpha}_{\text{midrange}-\text{Range},i} \leq 0.012684$	Result
1	0.004875	$0 \leq s^{\alpha}_{\text{midrange}-\overline{X},i} \leq 0.012684$	Controlled
2	0.0065	$0 \leq s^{\alpha}_{\text{midrange}-\overline{X},i} \leq 0.012684$	Controlled
3	0.00725	$0 \leq s^{\alpha}_{\text{midrange}-\overline{X},i} \leq 0.012684$	Controlled
4	0.005125	$0 \leq s^{\alpha}_{\text{midrange}-\overline{X},i} \leq 0.012684$	Controlled
5	0.008	$0 \leq s^{\alpha}_{\text{midrange}-\overline{X},i} \leq 0.012684$	Controlled
6	0.006	$0 \leq s^{\alpha}_{\text{midrange}-\overline{X},i} \leq 0.012684$	Controlled
7	0.005	$0 \leq s^{\alpha}_{\text{midrange}-\overline{X},i} \leq 0.012684$	Controlled
8	0.00525	$0 \leq s^{\alpha}_{\text{midrange}-\overline{X},i} \leq 0.012684$	Controlled
9	0.006	$0 \leq s^{\alpha}_{\text{midrange}-\overline{X},i} \leq 0.012684$	Controlled
10	0.00425	$0 \leq s^{\alpha}_{\text{midrange}-\overline{X},i} \leq 0.012684$	Controlled
11	0.004	$0 \leq s^{\alpha}_{\text{midrange}-\overline{X},i} \leq 0.012684$	Controlled
12	0.00975	$0 \leq s^{\alpha}_{\text{midrange}-\overline{X},i} \leq 0.012684$	Controlled

$$\overline{X}_{\text{Regression}-x_3,i} = \widehat{\beta}_{0x_3} + \widehat{\beta}_{1x_3} T_i + \varepsilon \tag{3}$$

where $\widehat{\beta}_{0x_1}, \widehat{\beta}_{0x_2}, \widehat{\beta}_{0x_3}$ are constants and $\widehat{\beta}_{1x_1}, \widehat{\beta}_{1x_2}, \widehat{\beta}_{1x_3}$ are coefficients of T_i.

The coefficients $(\widehat{\beta}_{0x_1}, \widehat{\beta}_{1x_1})$, $(\widehat{\beta}_{0x_2}, \widehat{\beta}_{1x_2})$ and $(\widehat{\beta}_{0x_3}, \widehat{\beta}_{1x_3})$ are calculated using the following least square method formulas.

$$\widehat{\beta}_{0x_1} = \frac{\sum_{i=1}^{q} \overline{x}_{x_1,i} - \widehat{\beta}_{1x_1} \sum_{i=1}^{q} T_i}{q} \tag{4}$$

$$\widehat{\beta}_{1x_1} = \frac{\sum_{i=1}^{q} \overline{x}_{x_1,i}(T_i - \overline{T})}{\sum_{i=1}^{q} (T_i - \overline{T})^2} \tag{5}$$

where $\overline{x}_{x_1,i} = \overline{X}_{x_1,i} - \overline{\overline{X}}$.

$\overline{X}_{x_1,i}$ is the average of ith sample containing 5 readings.
$\overline{\overline{X}}$ is the average of $\overline{X}_{x_1,i}$.
T_i is the time measured during the particular sample ($i = 1, 2, \ldots, 12$).
$\overline{T}$ is the average of T_i.
$\overline{X}_{x_1,i}$ is the p average of observations in ith sample ($k = 1, 2, 3, \ldots, p$) and ($i = 1, 2, 3, \ldots, q$).

$$\overline{X}_{x_1,i} = \sum_{k=1}^{p} \overline{X}_{x_1,ki} \quad (6)$$

and similar formulas for $\overline{X}_{x_2,i}$ and $\overline{X}_{x_3,i}$.

$$\overline{\overline{X}}_{x_1} = \frac{\sum_{k=1}^{q} \overline{X}_{x_1,i}}{q} \quad (7)$$

Similarly, for $\overline{\overline{X}}_{x_2}$ and $\overline{\overline{X}}_{x_3}$.

The coefficients $(\widehat{\beta}_{0x_2}, \widehat{\beta}_{1x_{2,}})$ and $(\widehat{\beta}_{0x_3}, \widehat{\beta}_{1x_{3,}})$ are estimated in a similar way.

The regression equation for the data are obtained as follows:

$$\overline{X}_{\text{Regression}-x_1,i} = 0.00309 - 0.00225T_i + \varepsilon \quad (8)$$

$$\overline{X}_{\text{Regression}-x_2,i} = 0.004656 - 0.00339T_i + \varepsilon \quad (9)$$

$$\overline{X}_{\text{Regression}-x_3,i} = 0.004591 - 0.00334T_i + \varepsilon \quad (10)$$

The mean of range obtained are as follows:

$\overline{R}x_1 = 0.00117$, $\overline{R}x_2 = 0.00583$, $\overline{\mathrm{R}}x_3 = 0.01183$. $\overline{R}x_1$ is the average of Rx_1,$\overline{R}x_2$ is the average of Rx_2 and $\overline{R}x_3$ is the average of Rx_3.

The UCL, CL and LCL for various control charts are computed to test whether the sample points lie within the control limits. The formulas for fuzzy $\tilde{\overline{X}}$ and $\overline{R}$ control chart is shown from Eqs. (11)–(16) and for any T_i the samples can be tested for in or out control process. Only for the α-level fuzzy midrange based on the α-cut fuzzy $\tilde{\overline{X}}$ regression and $\overline{R}$ control charts the formulation has been done elaborately and shown in Tables 10 and 11.

Fuzzy $\tilde{\overline{X}}$ control chart for the radius of the inner cap are obtained by the following equations

$$\begin{aligned}\widetilde{\text{ucl}}_{\text{Regression}-\bar{X},i} &= \Big(\widehat{\beta}_{0x_1} + \widehat{\beta}_{1x_1}T_i + A_2\bar{R}_{x_1}, \widehat{\beta}_{0x_2} + \widehat{\beta}_{1x_2}T_i \\ &\quad + A_2\bar{R}_{x_2}, \widehat{\beta}_{0x_3} + \widehat{\beta}_{1x_3}T_i + A_2\bar{R}_{x_3}\Big) \\ &= (0.003765 - 0.00225T_i, 0.008019_i \\ &\quad -0.00339T_i, 0.011416 - 0.00334T)\end{aligned} \quad (11)$$

$$\widetilde{\text{cl}}_{\text{Regression}-\overline{X},i} = \Big(\widehat{\beta}_{0x_1} + \widehat{\beta}_{1x_1}T_i, \widehat{\beta}_{0x_2} + \widehat{\beta}_{1x_2}T_i, \widehat{\beta}_{0x_3} + \widehat{\beta}_{1x_3}T_i\Big)$$

$$= (0.00309 - 0.00225T_i, 0.004656_i$$
$$-0.00339T_i, 0.004591 - 0.00334T) \quad (12)$$

$$\widetilde{\text{lcl}}_{\text{Regression}-\bar{X},i} = \Big(\widehat{\beta}_{0x_1} + \widehat{\beta}_{1x_1}T_i - A_2\bar{R}_{x_1}, \widehat{\beta}_{0x_2} + \widehat{\beta}_{1x_2}T_i$$
$$-A_2\bar{R}_{x_2}, \widehat{\beta}_{0x_3} + \widehat{\beta}_{1x_3}T_i - A_2\bar{R}_{x_3}\Big)$$
$$= (0.002414 - 0.00225T_i, 0.012920$$
$$- 0.00339T_i, -0.002234 - 0.00334T_i) \quad (13)$$

where A_2 is constant and when subsample size is 5, $A_2 = 0.577$.

Where T_i is time required for a plastic cap of required radius to be manufactured.

Fuzzy $\overline{R}$ control charts for triangular fuzzy

$$\widetilde{\text{ucl}}_{\text{Range}} = D_4\big(\overline{R}_{x_1}, \overline{R}_{x_2 2}\overline{R}_{x_3}\big) = (0.00247, 0.01232, 0.02501) \quad (14)$$

$$\widetilde{\text{cl}}_{\text{Range}} = \big(\overline{R}_{x_1}\overline{R}_{x_2}\overline{R}_{x_3}\big) = (0.00117, 0.00583, 0.01183) \quad (15)$$

$$\widetilde{\text{lcl}}_{\text{Range}} = D_3\big(\overline{R}_{x_1}, \overline{R}_{x_2}, \overline{R}_{x_3}\big) = (0)(0.00117, 0.00583, 0.01183)$$
$$= (0, 0, 0) \quad (16)$$

where D_3 and D_4 are constants and when subsample size is 5 $D_3 = 0$, $D_4 = 2.114$.

The α-cut regression equation of fuzzy mean and fuzzy mean of range are calculated as follows

$$\overline{\tilde{\tilde{X}}}_{x_1}^{0.75} = (1-\alpha)\Big(\widehat{\beta}_{0x_1} - \widehat{\beta}_{1x_1}T_i\Big) + \alpha\Big(\widehat{\beta}_{0x_2} + \widehat{\beta}_{1x_2}T_i\Big)$$
$$= 0.004265 - 0.00198T_i \quad (17)$$

$$\overline{\tilde{\tilde{X}}}_{x_3}^{0.75} = (1-\alpha)\Big(\widehat{\beta}_{0x_3} - \widehat{\beta}_{1x_3}T_i\Big) + \alpha\Big(\widehat{\beta}_{0x_2} + \widehat{\beta}_{1x_2}T_i\Big)$$
$$= 0.00464 - 0.00171T_i \quad (18)$$

$$\overline{R}_{x_1}^{0.75} = \overline{R}_{x_1} + \alpha\big(\overline{R}_{x_2} - \overline{R}_{x_1}\big) = 0.004667 \quad (19)$$

$$\overline{R}_{x_3}^{0.75} = \overline{R}_{x_3} - \alpha\big(\overline{R}_{x_3} - \overline{R}_{x_2}\big) = 0.007333 \quad (20)$$

The $\propto$-cut fuzzy $\overline{\tilde{\tilde{X}}}$ - regression control chart for triangular fuzzy numbers are as follows:

$$\widetilde{\text{ucl}}^{0.75}_{\text{Regression}-\overline{X},i} = \left(\overline{X}^{0.75}_{x_1,i} + A_2\overline{R}^{\propto}_{x_1}, \overline{X}_{x_2,i} + A_2\overline{R}_{x_2}, \overline{X}^{0.75}_{x_3,i} + A_2\overline{R}^{\propto}_{x_3}\right)$$
$$= (0.006957 - 0.00198T_i, 0.008019 - 0.00339T_i, 0.008871 - 0.00171T_i) \quad (21)$$

$$\widetilde{\text{cl}}^{0.75}_{\text{Regression}-\overline{X},i} = \left(\overline{X}^{0.75}_{x_1,i}, \overline{X}_{x_2,i}, \overline{X}^{0.75}_{x_3,i}\right)$$
$$= (0.004265 - 0.00198T_i, 0.004656 - 0.00339T_i, 0.00464 - 0.00171T_i) \quad (22)$$

$$\widetilde{\text{lcl}}^{0.75}_{\text{Regression}-\overline{X},i} = \left(\overline{X}^{0.75}_{x_1,i} + A_2\overline{R}^{\propto}_{x_1}, \overline{X}_{x_2,i} - A_2\overline{R}_{x_2}, \overline{X}^{0.75}_{x_3,i} - A_2\overline{R}^{\propto}_{x_3}\right)$$
$$= (0.0015721 - 0.00198T_i, 0.012920 - 0.00339T_i, 0.004088 - 0.00171T_i) \quad (23)$$

The $\propto$-cut fuzzy $\tilde{R}$ control chart for triangular fuzzy numbers are as follows:

$$\widetilde{\text{ucl}}^{0.75}_{\text{Range}} = (0.00986, 0.01232, 0.01549)$$
$$\widetilde{\text{cl}}^{0.75}_{\text{Range}} = (0.00117, 0.00583, 0.01183)$$
$$\widetilde{\text{lcl}}^{0.75}_{\text{Range}} = (0.004667, 0.00583, 0.007333) = (0, 0, 0)$$

The α-level fuzzy midrange for the α-cut fuzzy $\tilde{\overline{X}}$ regression and $\overline{R}$ control charts for the inner radius are as follows:

$$\text{ucl}^{\propto}_{\text{midrange-reg}-\overline{X},i} = \left[\frac{\left(\overline{\tilde{X}}^{\alpha}_{x_1} + \overline{\tilde{X}}^{\alpha}_{x_3}\right)}{2}\right] + A_2\left[\frac{\left(\overline{R}^{\propto}_{x_1} + \overline{R}^{\propto}_{x_3}\right)}{2}\right]$$
$$= \left[\frac{\left(\overline{\tilde{X}}^{0.75}_{x_1} + \overline{\tilde{X}}^{0.75}_{x_3}\right)}{2}\right] + A_2\left[\frac{\left(\overline{R}^{0.75}_{x_1} + \overline{R}^{0.75}_{x_3}\right)}{2}\right]$$
$$= 0.007914 - 0.00184T_i \quad (24)$$

$$\text{cl}^{\propto}_{\text{midrange-reg}-\overline{X},i} = \left[\frac{\left(\overline{\tilde{X}}^{\alpha}_{x_1} + \overline{\tilde{X}}^{\alpha}_{x_3}\right)}{2}\right] = \left[\frac{\left(\overline{\tilde{X}}^{0.75}_{x_1} + \overline{\tilde{X}}^{0.75}_{x_3}\right)}{2}\right]$$
$$= 0.004452 - 0.00184T_i \quad (25)$$

$$\begin{aligned}
\mathrm{lcl}^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} &= \left[\frac{\left(\overline{\tilde{X}}^{\alpha}_{x_1} + \overline{\tilde{X}}^{\alpha}_{x_3}\right)}{2}\right] - A_2\left[\frac{\left(\overline{R}^{\propto}_{x_1} + \overline{R}^{\propto}_{x_3}\right)}{2}\right] \\
&= \left[\frac{\left(\overline{\tilde{X}}^{0.75}_{x_1} + \overline{\tilde{X}}^{0.75}_{x_3}\right)}{2}\right] - A_2\left[\frac{\left(\overline{R}^{0.75}_{x_1} + \overline{R}^{0.75}_{x_3}\right)}{2}\right] \\
&= 0.00099 - 0.00184T_i \qquad (26)
\end{aligned}$$

where A_2 is constant. For sample size $n = 5$ $A_2 = 0.577$.

$\overline{\tilde{X}}^{\alpha}_{x_1}$, $\overline{\tilde{X}}^{\alpha}_{x_3}$, $\overline{R}^{\alpha}_{x_1}$, $\overline{R}^{\alpha}_{x_3}$ are obtained using Eqs. (17)–(20)

$$\begin{aligned}
\mathrm{ucl}^{0.75}_{\text{midrange}-\text{Range}} &= D_4 f^{\propto}_{\text{midrange}-\text{range}}\left(C\tilde{L}\right) \\
&= (2.114) \times \left[\frac{(0.004667 + 0.007333)}{2}\right] \\
&= 0.012684 \qquad (27)
\end{aligned}$$

$$\begin{aligned}
\mathrm{cl}^{0.75}_{\text{midrange}-\text{Range}} &= \left[\frac{\overline{R}^{\propto}_{x_1} + \overline{R}^{\propto}_{x_3}}{2}\right]\left[\frac{(0.004667 + 0.007333)}{2}\right] \\
&= 0.006 \qquad (28)
\end{aligned}$$

$$\begin{aligned}
\mathrm{lcl}^{0.75}_{\text{midrange}-\text{Range}} &= D_3 f^{\propto}_{\text{midrange}-\text{range}}\left(C\tilde{L}\right) \\
&= (0) \times \left[\frac{(0.004667 + 0.007333)}{2}\right] = 0 \qquad (29)
\end{aligned}$$

where D_4 and D_3 are constants, for $n = 5$, $D_4 = 2.114$ and $D_3 = 0$.

The $s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i}$ is calculated using the following formula,

$$\begin{aligned}
s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} &= \frac{\left(\overline{X}_{\text{Regression}-x_1,i} + \overline{X}_{\text{Regression}-x_3,i}\right)}{2} \\
&+ \frac{\propto\left(\left(\overline{X}_{\text{Regression}-x_2,i} - \overline{X}_{\text{Regression}-x_1,i}\right) - \left(\overline{X}_{\text{Regression}-x_3,i} - \overline{X}_{\text{Regression}-x_2,i}\right)\right)}{2} \qquad (30)
\end{aligned}$$

where $\overline{X}_{\text{Regression}-x_1,i}$ $\overline{X}_{\text{Regression}-x_2,i}$, $\overline{X}_{\text{Regression}-x_3,i}$ are obtained using Eqs. (8)–(10).

$$\text{Result} = \begin{cases} \text{controlled}, & \text{lcl}^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} \leq s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} \leq \text{ucl}^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} \\ \text{out of control}, & \text{otherwise} \end{cases} \tag{31}$$

where $s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i} = 0.00445 + 0.00021175\ T_i$.

$\text{lcl}^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i}$ and $\text{ucl}^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i}$ are obtained using Eqs. (24) and (26)

The $s^{\propto}_{\text{midrange}-\text{Range},i}$ is calculated using the following formula,

$$s^{\propto}_{\text{midrange}-\text{Range},i} = \frac{(R_{x_1,i} + R_{x_3,i})}{2} + \frac{\propto((R_{x_2,i} + R_{x_1,i}) - (R_{x_3,i} + R_{x_2,i}))}{2} \tag{32}$$

$$\text{Result} = \begin{cases} \text{controlled}, & \text{lcl}^{\propto}_{\text{midrange}-\text{Range},i} \leq s^{\propto}_{\text{midrange}-\text{Range},i} \leq \text{ucl}^{\propto}_{\text{midrange}-\text{Range},i} \\ \text{out of control}, & \text{otherwise} \end{cases} \tag{33}$$

where $\text{lcl}^{\propto}_{\text{midrange}-\text{Range},i}$ and $\text{ucl}^{\propto}_{\text{midrange}-\text{Range},i}$ are obtained using Eqs. (27) and (29).

In $s^{\propto}_{\text{midrange}-\text{reg}-\overline{X},i}$ table the 4th and 7th values are out of control. This may be due the time consumption during the sample production. This can be overcome by monitoring the process twice. All the products considered are under control except 4th and 7th.

4 Conclusion

Here, the six sigma methodology is used in the plastic injection molding during production. The study follows the applications of the DMAIC technique to investigate the defects and provide a solution which could simultaneously satisfy requirements of operational excellence. The problem was well studied in define phase. In measure phase, the best six sigma alternative projects were selected and found to be PA1 (Energy saving). This FAHP is based on triangular fuzzy numbers so as to increase the overall productivity, profitability and quality of the organization. In analyze phase signal to noise ratio was calculated and the optimum value is obtained. The study was improved in discussion with the members of the company and is checked using fuzzy linear regression control charts. Hence the proposed approach will be useful for plastic industries to maintain a sustainability in the production process with an eco-friendly environment.

References

1. Almannai, B., Greenough, R., Kay, J.: A decision support tool based on QFN and FMEA for the selection of manufacturing automation technique. Rob. Comput. Integr. Manuf. **24**(4), 501–507 (2008)

2. Behara, R., Fontent, G.F., Gresham, A.: Customer satisfaction measurement and analysis using six sigma. Int. J. Qual. Reliab. Manag. **12**, 9–18 (1995)
3. Linderman, K., Schrocder, R.G., Zaheer, S., Choo, A.S.: Six sigma: a goal theoretic perspective. J. Oper. Manag. **21**, 193–203 (2003)
4. Che Ani, M.N., Kamaruddin, S., Azid, I.A.: Factory-in-factory concept as a new business model for automotive production system. Int. J. Six Sigma Compet. Adv. **11**(2/3) (2019)
5. Ajmera, P., Jain, V.: A fuzzy interpretive structural modeling approach for evaluating the factors affecting lean implementation in Indian healthcare industry. Int. J. Lean Six Sigma **11**(2) (2020)
6. Bilgen, B., Sen, M.: Project selection through fuzzy analytic hierarchy process and case study on six sigma implementation in an automotive industry. Prod. Plan. Control **23**(1) (2012)
7. Mandel, J.: The regression control chart. J. Qual. Technol. 1 (1969)
8. Deepa, O.S.: Optimal production policy for the design of green supply chain model. Int. J. Appl. Eng. Res. **10**(2), 1600–1601 (2015)
9. Deepa, O.S.: Application of acceptance sampling plan in green design and manufacturing. Int. J. Appl. Eng. Res. **10**(2), 1498–1499 (2015)
10. Phanden, R.K., Ferreira, J.C.E.: Biogeographical and variable neighborhood search algorithm for optimization of flexible job shop scheduling. In: Advances in Industrial and Production Engineering, pp. 489–503. Springer, Singapore (2019)
11. Phanden, R.K., Saharan, L.K., Erkoyuncu, J.A.: Simulation based cuckoo search optimization algorithm for flexible job shop scheduling problem. In: Proceedings of the International Conference on Intelligent Science and Technology, pp. 50–55 (2018)
12. Phanden, R.K., Demir, H.I., Gupta, R.D.: Application of genetic algorithm and variable neighborhood search to solve the facility layout planning problem in job shop production system. In: 2018 7th International Conference on Industrial Technology and Management (ICITM), pp. 270–274. IEEE (2018)
13. Trehan, R., Gupta, A., Handa, M.: Implementation of lean six sigma framework in a large scale industry: a case study. Int. J. Six Sigma Compet. Adv. **11**(1) (2019)
14. Ray, S., Das, P., Bhattacharyay, B.K., Antony, J.:. Measuring six sigma project effectiveness using fuzzy approach. Qual. Reliab. Eng. Int. (2012)
15. Shruthi. G., Deepa, O.S.: Average run length for exponentiated distribution under truncated life test. Int. J. Mech. Eng. Technol. (IJMET) **9**(6), 1180–1188 (2018)
16. Krishnan, S.M., Deepa, O.S.: Control charts for multiple dependent state repetitive sampling plan using fuzzy poisson distribution. Int. J. Civ. Eng. Technol. (IJCIET) **10**(1), 509–519 (2019)

Probabilistic and Fuzzy Models for Risk Analysis of Processing and Manufacturing System

Priyank Srivastava, Navnidh, Sarthak Bali, Rishabh Gupta, Rajendra Kumar Shukla, Ruchika Gupta, Dinesh Khanduja, Melfi Alrasheedi, and Rakesh Kumar Phanden

Abstract Risk is defined as the chance of failures or a state occurrence of the possible loss. The risk of one can be a benefit to others. To survive in today's competitive market situation, proper risk management is essential. In the present study, various models, that is, probabilistic and fuzzy models used for risk analysis in processing and manufacturing systems, have been discussed. This article critically reviews the use of probabilistic and fuzzy models in context with the type of publications, area of application, region-specific details, citations results to answer the research questions framed. This main contribution of this article is the examination of the current state of the art for risk analysis. The findings from this article will be helpful for risk managers and analysts, respectively, for proper understanding, identification, analysis, and management of risk.

Keywords Risk analysis · Probabilistic models · Fuzzy models

P. Srivastava (✉) · Navnidh · S. Bali · R. Gupta · R. K. Phanden
Department of Mechanical Engineering, Amity School of Engineering and Technology, Amity University, Noida, Uttar Pradesh 201313, India
e-mail: psrivastava5@amity.edu

R. K. Shukla
Department of Mechanical Engineering, ABES Engineering College, Ghaziabad, Uttar Pradesh, India

R. Gupta
Amity University, Greater Noida, India

D. Khanduja
Department of Mechanical Engineering, National Institute of Technology Kurukshetra, Kurukshetra, India

M. Alrasheedi
King Faisal University, Hofuf, Saudi Arabia

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_7

1 Introduction

Risk Analysis is a proactive approach to assess the robustness of the system under study for possible failure causes that may or may not happen in the future. Risk analysis is essential for improving safety levels of operating systems, identifying elements having a high probability of risk, formulating risk mitigation policies, and formulating emergency planning. Many tools have been used by the practitioners for risk analysis of process systems [1–4]. Risk analysis is a systematic approach where risk is first identified and prioritization is done. There are various risk identification techniques like fishbone diagram [5], fault tree analysis [6], what-if analysis, bow-tie method, consequence diagram, checklist method, etc. The integration of risk identification, risk analysis and risk mitigation come under the umbrella of risk management. The ISO 31000 is the standard formulating standard operating procedure and guideline for risk management. Often system analysts and practitioners of conventional methods of risk analysis are faced with the issue of imprecision in the form of states of nature, available information and possible outcome [7]. The uncertainty in judgment is the main reason for imprecision. There are different types of uncertainty [8]. To overcome this issue, intelligent computing-based risk analysis is required. With advances in intelligent computing, new tools have been developed for risk analysis. Intelligent computing systems can be classified into two groups:

(a) Approximate Reasoning.
(b) Functional Approximation.

This work deals with the application of approximate reasoning methods of intelligent computing. The approximate reasoning methods can be classified into probabilistic and fuzzy logic models, respectively. These models are used in integration with multi-attribute decision making method (MADM) or multi-criteria decision making method (MCDM). There has been a lot of development in integrated models in the last decade. The research questions of "What are different probabilistic and fuzzy model used for risk analysis?" (RQ1), "What are is present state of art for risk analysis?" (RQ2), "What are the trends in journals publication in the field of approximate reasoning-based risk analysis?" (RQ3), "What is the country/region wise details of contribution to field of risk analysis?" (RQ5), becomes important for the understanding application of approximate reasoning-based risk analysis.

The present study presents a comprehensive literature review for finding out answers to the pertinent questioned asked in the preceding paragraph. It is also the main contribution of the paper. The rest of the paper is structured as Sect. 2: explores the structured literature review, Sect. 3 presents results and discussion of the review, Sect. 4 presents discussion as perceived from the results, Sect. 4 presents the concluding remarks.

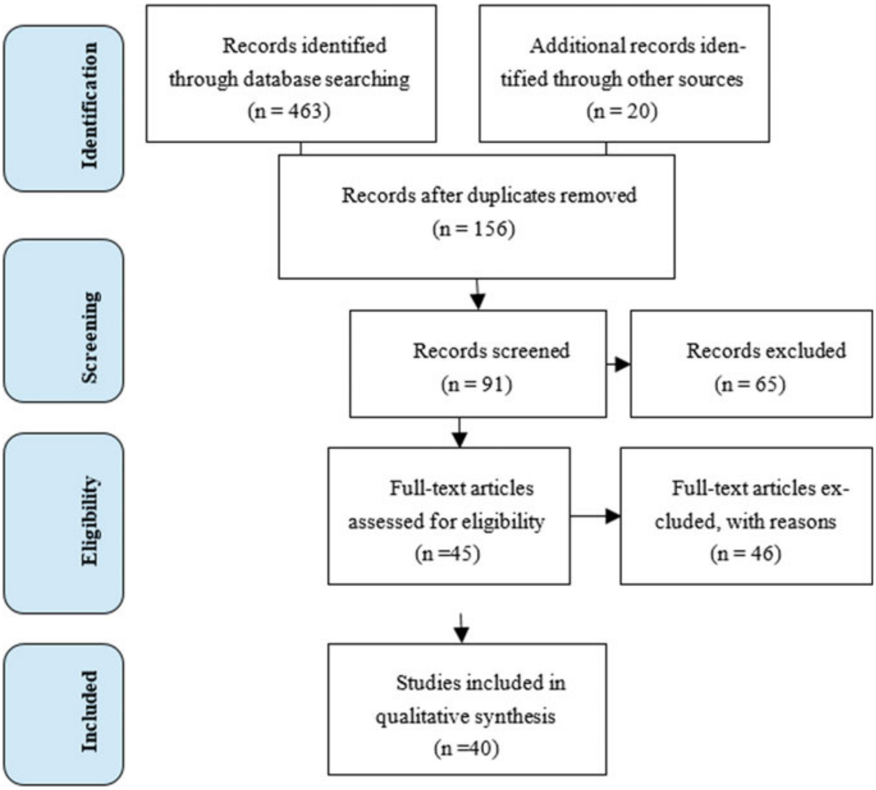


Fig. 1 Flowchart of literature review

2 Literature Review

This section discusses the scientific and standard operating procedures for conducting a structured literature review.

2.1 Literature Review Process

For doing an exhaustive literature review, a structured approach was followed. The literature review starts with the framing of research questions. The keywords were identified and extracted from the research questions. These keywords were arranged in combination using operator "AND" and "OR". The combinations were used for the identification of studies for further processing. The search engine of "Web of Sciences" and "Scopus" were used. The PRISMA flowchart [9] was used as basis (see Fig. 1) for a protocol to be followed for a systematic literature review. The different stages, according to the flowchart are as follow:

2.1.1 Identification (1st Stage)

The keyword strings of:

"TITLE: (Probabilistic model for risk analysis) *OR* **TITLE:** (Fuzzy Model for Risk Analysis) *OR* **TITLE:** (MADM OR MCDM AND Risk Analysis) *OR* **TOPIC:** (Fault tree AND Risk Analysis) *AND* **TOPIC:** (Risk Identification)"

was used for the identification of the study. From this process, a total of "463" articles were identified from keywords. An additional of 15 articles were identified through another sources. A screening was done for duplication of articles. A total of five articles were removed because of the duplication. Therefore, the total number of articles identified were 478. Figures 1, 2, 3, 4 and 5 show the flowchart of literature review, categories versus % and year wise analysis, publication year-wise, %age contribution of the journal and %age contribution of countries, respectively.

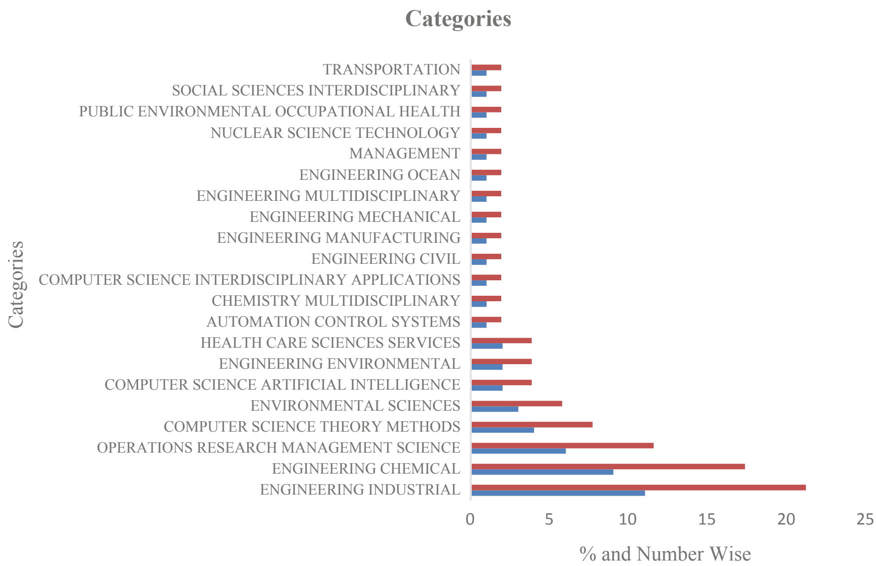


Fig. 2 Categories versus % and year wise analysis

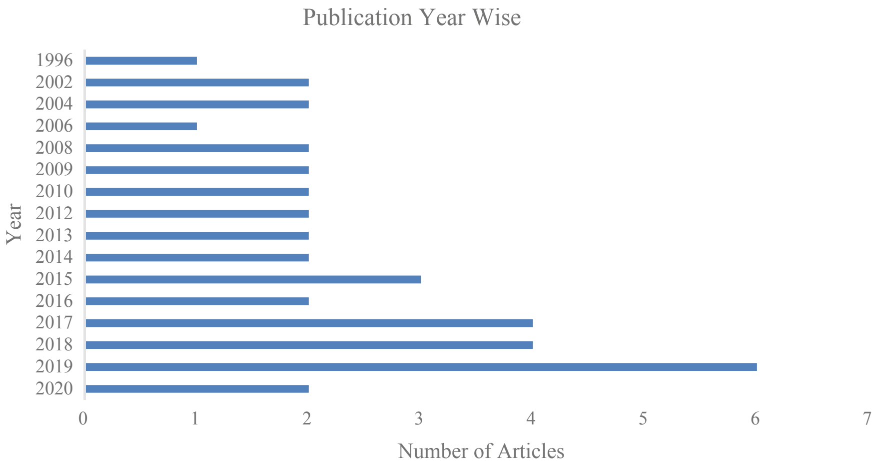


Fig. 3 Publication year wise

2.1.2 Screening and Eligibility Check (2nd and 3rd Stage)

The initial screening of the remaining articles from the identification stage was done by defining and using the inclusion and exclusion criteria. Table 1 shows the inclusion and exclusion criteria, respectively.

After this process, 156 articles were included, and the rest were articles that were excluded. In the next stage, the included articles were assessed for final screening. The included articles were screened for the abstract. Here second inclusion and exclusion criteria were applied to refine the process. Only articles addressing risk analysis of process and manufacturing industry were selected. MADM and MCDM technique used other than failure cause was the exclusion criteria. After this process, 91 articles were included and rest were excluded. The included articles were further processed for checking the eligibility of full article screening. The 45 articles were found eligible for full article screening.

2.1.3 Final Articles Inclusion and Extraction (4th Stage)

In this stage exhaustive full article screening was done for the eligible articles. Further from full screening, 40 articles were included in the study. The extracted field consists of author's name, year of publication, ISSN/ISBN, keywords, author identifier, publisher information, times cited.

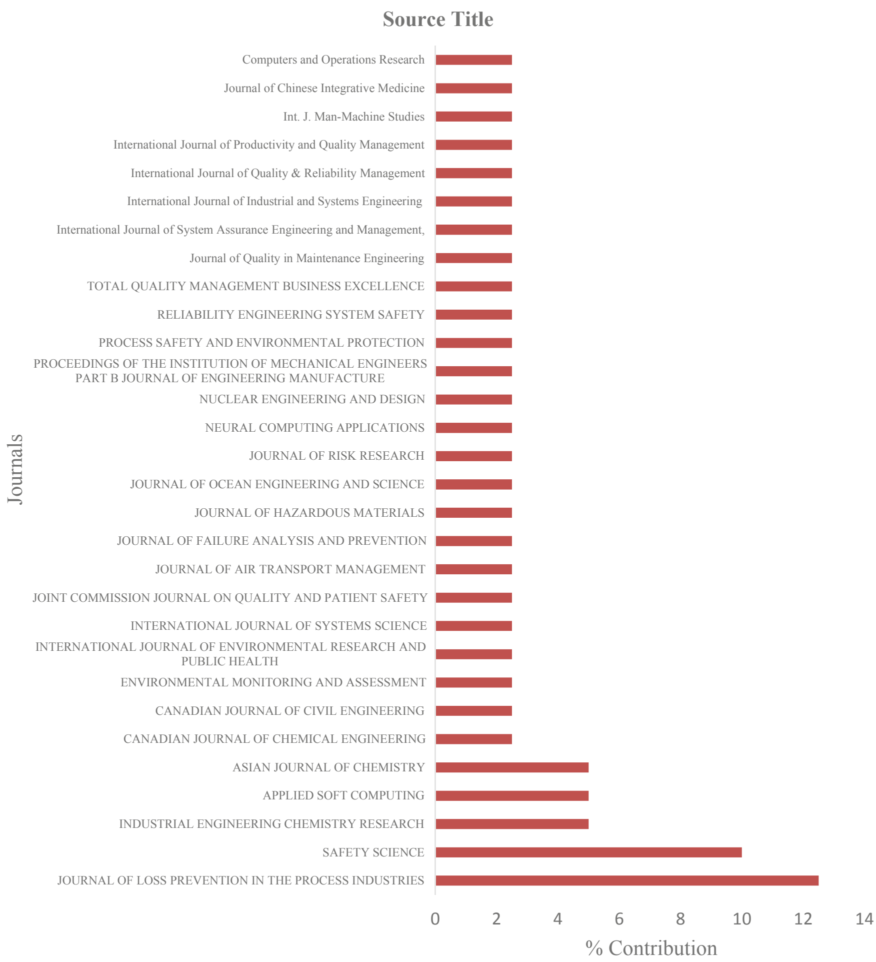


Fig. 4 % contribution of the journal

3 Result and Discussion

This section presents the interesting results of the literature review. It had provided vital insights to the research question asked. The subject categorization (see Fig. 2) shows that the maximum percentage, that is, 23% of the articles for risk analysis, MADM, probabilistic and fuzzy model are addressing issues of industrial engineering field [1–5, 10–15]. Figure 2 also shows that risk analysis founds its application in a diverse field [16–19]. Both probabilistic and fuzzy models are used for risk analysis in offshore and deep-water drilling for oil and gas exploration [20–22]; chemical plant [23]; mining industry [24]; nuclear plant [25]; airline industry [26]. Figure 3, shows an increasing trend of application risk analysis integrated with the probabilistic and

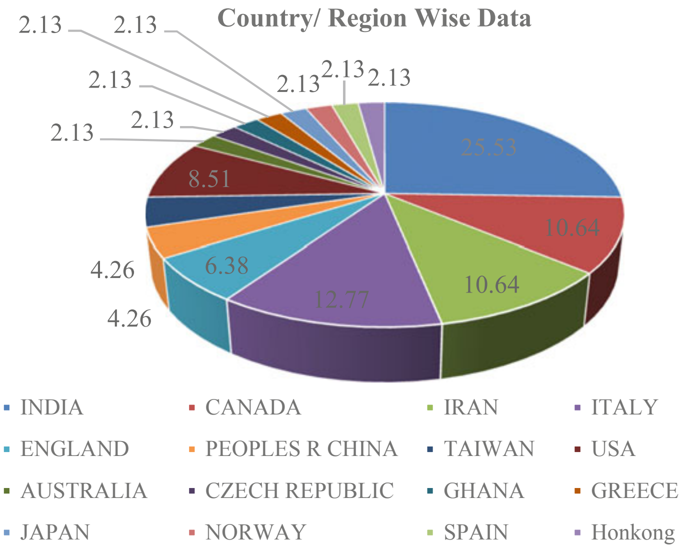


Fig. 5 % contribution of countries

Table 1 Inclusion and exclusion criteria (2nd Stage)

Inclusion criteria	Exclusion criteria
Fuzzy and Probabilistic Model for risk analysis; FTA, Bow Tie, String Diagram, FMEA, What-if analysis	Not in English; Statistical study

fuzzy model by researchers. The *Journal of Loss Prevention in Process Industries*, is the top journal publishing articles on risk analysis of process industries (refer Fig. 4). India is the leading country in contributing articles of probabilistic and fuzzy risk analysis (refer Fig. 5).

4 Conclusion

The result and discussion section throw light to some important observations. The research questions asked in "Introduction" section.

(a) RQ1: From literature review it is quite evident that integrated approach of "probabilistic or fuzzy model" with MADM has been used for risk analysis. Various tools such as FTA [18, 21, 23], petrinets [22, 27].
(b) RQ2: The fuzzy and probabilistic models have been increasingly used for risk modeling of the complex system, for example, offshore drilling and allied operations of oil and gas exploration [16–19]; chemical plant [23]; mining industry [24]; nuclear plant [25]; airline industry [26].

(c) RQ3: From Fig. 5, it is evident that for the present pretext of study, risk analysis techniques are being used all across the world, with India as the largest contributor.
(d) RQ4: The "Journal of Loss Prevention in Process Industries", is the top journal publishing articles of risk analysis of process industries (refer Fig. 4).

The literature review has been able to answer research questions explicitly. Though, more research questions could have been framed for a better understanding of the context. The answers to research question will be helpful to researchers and system analyst for proper understanding of risk and associated processes. In the future, the authors of the paper will add more research questions and critically examine the literature for finding out answers.

References

1. Panchal, D., Kumar, D.: Risk analysis of compressor house unit in thermal power plant using integrated fuzzy FMEA and GRA approach. Int. J. Ind. Syst. Eng. **25**(2), 228–250 (2017)
2. Panchal, D., Mangla, S.K., Tyagi, M., Ram, M.: Risk analysis for clean and sustainable production in a urea fertilizer industry. Int. J. Qual. Reliab. Manag. **35**(7), 1459–1476 (2018)
3. Panchal, D., Srivastava, P.: Qualitative analysis of CNG dispensing system using fuzzy FMEA–GRA integrated approach. Int. J. Syst. Assurance Eng. Manag. **10**(1), 44–56 (2019)
4. Srivastava, P., et al.: Risk analysis of CNG dispensing unit by fuzzy digraph matrix and dempster-shafer approach. Int. J. Product. Qual. Manag. **28**(2), 228–255 (2019)
5. Srivastava, P., Khanduja, D., Ganesan, S.: Fuzzy methodology application for risk analysis of mechanical system in process industry. Int. J. Syst. Assurance Eng. Manag. (2019)
6. Sharma, P., Sharma, R.K.: System failure behaviour and maintenance decision making using, RCA, FMEA and FM. J. Qual. Maintenance Eng. **16**(1), 64–88 (2010)
7. Chin, K.-S., Wang, Y.-M., Ka Kwai Poon, G., Yang, J.-B.: Failure mode and effects analysis using a group-based evidential reasoning approach. Comput. Oper. Res. **36**(6), 1768–1779 (2009)
8. Pat-Cornell, M.E.: Uncertainties in risk analysis: six levels of treatment. Reliab. Eng. Syst. Saf. **54**, 95–111 (1996)
9. David, D.A.M., Liberati, A., Tetzlaff, J., Altman, D.G., Altman, D., Antes, G.: Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. J. Chin. Integr. Med. **7**(9), 889–896 (2009)
10. Ilangkumaran, M., Karthikeyan, M., Ramachandran, T., Boopathiraja, M., Kirubakaran, B.: Risk analysis and warning rate of hot environment for foundry industry using hybrid MCDM technique. Saf. Sci. **72**, 133–143 (2015)
11. Aneziris, O.N., Papazoglou, I.A., Konstantinidou, M., Nivolianitou, Z.: Integrated risk assessment for LNG terminals. J. Loss Prevent. Process Industr. **28**(SI), 23–35 (2014)
12. Sano, K., Koshiba, Y., Ohtani, H.: Risk assessment and risk reduction of an acrylonitrile production plant. J. Loss Prevent. Process Industr. **63** (2020)
13. Khaloo, S.S., Saeedi, R., Sanjari, A.: Environmental risk assessment and corrective measures for the metal rolling industry. Environm. Monitor. Assess. **191**(9) (2019)
14. Animah, I., Shafiee, M.: Application of risk analysis in the liquefied natural gas (LNG) sector: an overview. J. Loss Prevent. Process Industr. 63 (2020)
15. Dadkhah, S.M., Golbabaei, F., Malakootikhah, J., Mohamadfam, I.: Appropriateness criteria for choosing proper risk assessment model of nanomaterial manufacturing processes. Asian J. Chem. **24**(8), 3719–3723 (2012)

16. Song, Y.H., Yu, H.Q., Lv, W.: Risk analysis of dairy safety incidents in China. Food Control **92**, 63–71 (2018)
17. Luis Fuentes-Bargues, J., Carmen Gonzalez-Cruz, M., Gonzalez-Gaya, C., Piedad Baixauli-Perez, M.: Risk analysis of a fuel storage terminal using HAZOP and FTA. Int. J. Environ. Res. Public Health **14**(7) (2017)
18. Komal: Fuzzy fault tree analysis for patient safety risk modeling in healthcare under uncertainty. Appl. Soft Comput. **37**, 942–951 (2015)
19. Kou, G., Peng, Y., Wang, G.: Evaluation of clustering algorithms for financial risk analysis using MCDM methods. Inf. Sci. **275**, 1–12 (2014)
20. Khakzad, N., Khan, F., Amyotte, P.: Quantitative risk analysis of offshore drilling operations: a Bayesian approach. Saf. Sci. **57**, 108–117 (2013)
21. Cheliyan, A.S., Bhattacharyya, S.K.: Fuzzy fault tree analysis of oil and gas leakage in subsea production systems. J. Ocean Eng. Sci. **3**(1), 38–48 (2018)
22. Chang, Y., et al.: Comprehensive risk assessment of deepwater drilling riser using fuzzy Petri net model. Process Saf. Environ. Protect. **117**, 483–497 (2018)
23. Khan, F.I., Husain, T.: Risk assessment and safety evaluation using probabilistic fault tree analysis. Human Ecol. Risk Assess. **7**(7), 1909–1927 (2001)
24. Yasli, F., Bolat, B.: A risk analysis model for mining accidents using a fuzzy approach based on fault tree analysis. J. Enterprise Inf. Manag. **31**(4), 577–594 (2018)
25. Burgazzi, L.: Probabilistic safety analysis of an accelerator—lithium target based experimental facility. Nuclear Eng. Des. **236**(12), 1264–1274 (2006)
26. Barak, S., Dahooei, J.H.: A novel hybrid fuzzy DEA-Fuzzy MADM method for airlines safety evaluation. J. air Transp. Manag. **73**, 134–149 (2018)
27. Wang, Y.F., Chang, C.T.: Petri-net-based deductive reasoning strategy for fault identification in batch processes. Ind. Eng. Chem. Res. **43**(11), 2704–2720 (2004)

Analyzing the Influence of Leagile Manufacturing Tools in Peru Context

Mark Christhian Barrueta Pinto and Yongbo Li

Abstract Recent manufacturing sectors facing several challenges worldwide due to various disruptions and economic instabilities. Hence, it becomes necessary for the industries to think about new strategies that could sustain in these tough environments. Such a strategy has been discussed in this paper, Leagile manufacturing within Peru context. Despite having several benefits with the implementation of Leagile manufacturing system, since there are many tangible and intangible barriers hinders its effective implementation in Peru industries. These barriers mainly rise due to less clarity among the tools and lack of ease to implementation within the concern of an industrial perspective. This study considers addressing this gap by evaluating the most influential tools for the effective implementation of Leagile manufacturing. From the combined support of both primary and secondary data, this study considered 12 Leagile manufacturing tools, which further evaluated based on their influence in implementation on Peru context with Decision Making and Trial Evaluation Laboratory (DEMATEL).

Keywords Leagile manufacturing · Peru · DEMATEL

1 Introduction

Due to raising customized demand among customers and rapidly changing technologies force the manufacturers to increase the responsiveness in a sustained way by less harming the environments. These combined values can be achieved through Leagile strategies, in which the lean and agile concepts are combined in such a way to integrate two key variables, including reducing waste and agility. However, it is not a new concept to discuss, which has been in debate since long time as "de-coupling point."

M. C. B. Pinto (✉)
School of Business, Universidad Peruana de Ciencias Aplicadas (UPC), Lima 15023, Peru
e-mail: mbarruetapinto@gmail.com

Y. Li
School of Economics and Management, China University of Petroleum, Qingdao 266580, PR China

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_8

Several studies [1–4] exist with the consideration of combining leagile strategies in various applications majorly including supply chain and manufacturing. These studies validate the importance of exploring the leagile in manufacturing sectors predominantly. Despite the urge, there are no detailed discussions on leagile manufacturing in Peru context. This context lies on the South American continent, which serves as 12th largest nation in the world. The third big sector in Peru is Manufacturing (next to fishing and mining) and contributes about 15% of Gross Domestic Product (GDP) to the nation's economy [5]. Recent years, most of the Peru manufacturers become a supplier to big multinational American brands, which increases their pressure to outperform the conventional manufacturing processes. Concerning the fact, this study took itself the responsibility to explore the leagile manufacturing concepts within Peru context, where existing studies are limited. The pilot study among Peru manufacturers revealed that they have a lack of clarity among the implementation of leagile in their system, especially with the tools. For example, Virmani and Saha [4] reviewed and listed nearly 51 lean tools, 34 agile tools and combinedly 31 leagile tools. It is tough for the practitioners to explore the best tools in real context due to the time limitation and process setup. Hence, this study decided to evaluate the efficient tools for implementing leagile in Peru manufacturing context through their influence on one another.

With the assistance of the above discussions, the following research questions are developed:

- What are the common leagile manufacturing tools for Peru?
- Which is the most influential tool for the implementation of legagile in Peru manufacturing?
- What are the comparative influences of other considered common tools?

In order to address these considered research questions, this study includes both primary and secondary data sources. The primary data source includes a pilot study on Peru manufacturers and data collection in the case industry. The secondary data sources mainly consider academic literature available in the reputed database, such as SCOPUS. From the secondary data sources, the common leagile tools were collected. All these collected data were processed using multi-criteria decision making tool, decision making trail and evaluation laboratory (DEMATEL).

The remaining section are as follows: Sect. 2 discussed state of the art within the current scope of the study, Sect. 3 explained the methodology considered in this study. Considered Peru case has been detailed in Sect. 4, obtained results and its valuable discussions are detailed in Sect. 5. Finally, the paper concludes with various insights in Sect. 6.

2 Literature Review

Leagile concept has been established initially as "decoupling point," which was first defined by Hoekstra and Romme in 1992 [6] as the connecting point of customer needs and material flow. Further, this concept has been developed and formed as leagile. Naylor et al. [7] given the definition as, "It is the combination of the lean and agile paradigms within a total supply chain strategy by positioning the decoupling point so as to best suit the need for responding to a volatile demand downstream yet providing level scheduling upstream from the marketplace." Since this inception, there are very few studies that includes leagile in theory and practice, especially with the supply chain. However, there is enough room for exploration of leagile concepts in the manufacturing context, but contrary to this urge, only 19 documents have found with the search term TITLE-ABS-KEY ("leagile manufacturing") in SCOPUS database. Among which, 14 documents exactly matched with the considered research. With all these studies not, a single study has been considered Peru context with leagile manufacturing, as shown in Fig. 1.

These studies considered various concepts, models, theories and application perspectives of leagile manufacturing. For instance, Faur and Bungau [8] studied the readiness of the industry to adapt the leagile manufacturing. Balakrishnan et al. [3] designed a leagile manufacturing model with the application of the pump industry through a hypothetical case study.

Only one study [9] connects the leagile with a sustainable perspective, in which shift towards the legaile has been studied through a theoretical review within the context of Morgan motor company.

Some studies analyzed the enablers, barriers, drivers and so on. For instance, Matawale et al. [10] identified the enablers of lean, agile and leagile manufacturing system. Likewise, Virmani and Sharma [11] studied the enablers of leagile manufacturing using a Multi-criteria Decision Making (MCDM) tool, interpretive structural modeling. Virmani et al. [12] assessed the success factors for the implementation of leagile manufacturing, in which strategic management has been identified as a key success factor. However, this strategic management includes effective utilization of tools. Virmani et al. [13] focused on the barriers that exists in the implementation of leagile manufacturing system.

Few studies involved in the performance measurement and comparison of leagile manufacturing with other alternative manufacturing strategies. Virmani et al. [14]

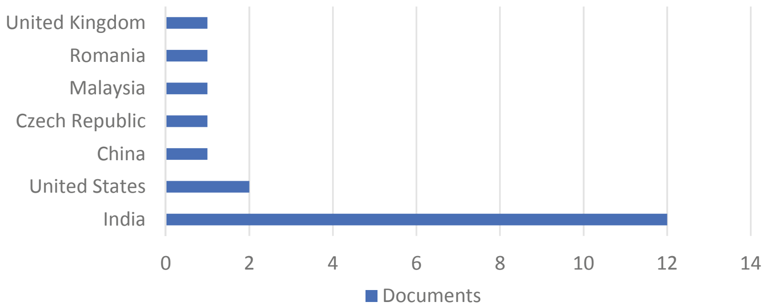


Fig. 1 Documents published on leagile manufacturing by country/territory

proposed performance indicators for leagile manufacturing for its evaluation of effective implementation. Prakash et al. [15] evaluated the effective manufacturing system among considered alternative systems, which includes lean, agile, flexible, leagile and cellular manufacturing system. This study validates that leagile is the most suitable manufacturing system among all other considered alternatives.

From this literature review, several elements have been concluded and listed as follows:

- Among different alternative manufacturing, leagile manufacturing system performed better.
- Most of the existing studies focus on Indian context and not a single study with Peru context.
- Strategic management (i.e., handling tools) is the key success factor for leagile manufacturing implementation.

With these concerns, this study sought to address the gap in evaluating the leagile manufacturing tools in Peru context.

3 Methodology

This study adapted two-step methodology, namely data collection and DEMATEL application.

(i) ***Data collection***:
This step includes data collection from combined primary and secondary sources. The tools for leagile manufacturing have been identified and listed in Table 1,

Table 1 List of collected common tools for leagile manufacturing implementation

S. No.	Leagile manufacturing tools	Source
1	Centralized and collaborative planning	[1; 7; 8; 9]
2	Information driven virtual supply chain	[9; 6; 1–3; 14]
3	Total preventive maintenance	[1–4; 7–9; 11; 15]
4	Market sensitiveness and responsiveness	[1–4; 6–10]
5	Electronic data exchange	[1–4; 7–9; 11; 15]
6	Flexible set ups	[1–4; 7–9; 11; 15]
7	Assurance of quality	[1–4; 6–10]
8	Integration of performance measurement for processes	[9; 6; 1–3; 14]
9	Lead time reduction	[1–4; 6–10]
10	Enterprise resource planning	[9; 6; 1–3; 14]
11	Technological (advanced) manufacturing	[1–4; 7–9; 11; 15]
12	Supplier selection	[12–14; 3; 7; 9; 11]

which is a result of the literature review and expert opinion. The collected tools will be evaluated based on their influential values with the assistance of MCDM methodology through the case study.

(ii) ***DEMATEL application***
The DEMATEL tool was first introduced by Fontela and Gabus [15] in 1976 for handling complex problems which are having many tangible and intangible factors. However, these specifications are significantly fit for the considered problem, leagile manufacturing. Hence, this study adapted DEMATEL to analyze the influence of collected common leagile manufacturing tools.

In order to apply the DEMATEL, sequential steps to be followed:

Step 1: Initial Relationship Matrix

This is the first step of DEMATEL, in which the initial relationship matrix has been set up with the assistance of the case decision makers as shown in Eq. 1. The criteria are evaluated based on their influence, which ranges from "no influence" to "high influence" through linguistic scale 0 to 4, respectively.

$$\tilde{A} = \begin{bmatrix} 1 & a\_12 & a\_13 & \ldots.\ a\_1(n-1) & & a\_1n \\ a\_21 & 1 & a\_23 & \ldots.\ a\_2(n-1) & & a\_2n \\ \ldots. & \ldots. & \ldots. & \ldots. & \ldots. & \ldots. \\ \ldots. & \ldots. & \ldots. & \ldots. & \ldots. & \ldots. \\ a\_(n-1)1 & a\_(n-1)2 & a\_(n-2)3 & \ldots. & 1 & a\_(n-1)n \\ a\_n1 & a\_n2 & a\_n3 & \ldots.\ a\_n(n-1) & & 1 \end{bmatrix} \tag{1}$$

Step 2: Normalized Matrix

Next step to normalize the initial influence matrix through Eqs. 2 and 3 and denoted as "X".

$$K = \frac{1}{\max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}} \tag{2}$$

$$X = K \times A \tag{3}$$

Step 3: Total Influence Matrix

Through the number of equations, the total influence matrix has been derived and denoted as "T", in which the "I" stands for the identity matrix.

$$\boldsymbol{T} = \boldsymbol{X} + \boldsymbol{X}^2 + \cdots + \boldsymbol{X}^h = \boldsymbol{X}(\boldsymbol{I} - \boldsymbol{X})^{-1}, \text{ when } \lim_{h \to \infty} \boldsymbol{X}^h = [0]_{n \times n} \tag{4}$$

Explanations,

$$\begin{aligned} \boldsymbol{T} &= \boldsymbol{X} + \boldsymbol{X}^2 + \cdots + \boldsymbol{X}^h \\ &= \boldsymbol{X}\left(\boldsymbol{I} + \boldsymbol{X} + \boldsymbol{X}^2 + \cdots + \boldsymbol{X}^{h-1}\right)(\boldsymbol{I} - \boldsymbol{X})(\boldsymbol{I} - \boldsymbol{X})^{-1} \\ &= \boldsymbol{X}(\boldsymbol{I} - \boldsymbol{X}^h)(\boldsymbol{I} - \boldsymbol{X})^{-1} \end{aligned}$$

then,

$$\boldsymbol{T} = \boldsymbol{X}(\boldsymbol{I} - \boldsymbol{X})^{-1}, \text{ when } h \to \infty$$

Step 4: Influential Diagraph

This is the final step of DEMATEL, in which the influential diagraph will be framed with the assistance of the sum of the number of rows and columns, which highlights as "r" and "s" as given in Eq. 5.

$$\boldsymbol{r} = [r_i]_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1}, \ \boldsymbol{s} = \left[s_j\right]_{n\times 1} = \left[\sum_{i=1}^{n} t_{ij}\right]'_{1\times n} \tag{5}$$

$$\boldsymbol{T} = \left[t_{ij}\right], \quad i, j = 1, 2, ..., n,$$

4 Case Description

To understand the Peru context, especially with manufacturing, this study considers one of the leading bus manufacturers in Peru as a case company. This company a long history of bus manufacturer with different variant transportation including urban, personal, interprovincial and personal. Based on the customer needs, they are manufacturing the buses and distributed all over American states. They are having several branches across the country while the labor force accounts up to 1000. Recent years, due to the demand for customized products, their existing manufacturing system fails in several places, including delay in lead time. Hence, this company is in the position to propose a new manufacturing system, which could balance the point that meets the customer customized demand with less lead time in a sustainable way. With this concern, it is highly helpful for the case company to shift towards one of the best existing alternative leagile manufacturing. However, due to the lack of knowledge and experience in leagile, especially with Peru context, the company is in a theoretical state of approaching the leagile manufacturing system. In the row, this study assists in their process of identifying the most influential tool for the effective implementation of leagile manufacturing system.

With the application of the defined methodology in the earlier section, this study identifies the influential tool. Based on the replies of case decision makers, the

Table 2 Initial relationship matrix

	$T1$	$T2$	$T3$	$T4$	$T5$	$T6$	$T7$	$T8$	$T9$	$T10$	$T11$	$T12$
$T1$	0	2	4	4	1	4	4	3	3	3	2	3
$T2$	1	0	4	4	1	4	4	3	3	3	2	3
$T3$	1	1	0	4	1	1	1	2	1	1	2	1
$T4$	1	1	2	0	1	1	1	2	1	1	2	1
$T5$	2	2	4	4	0	4	4	2	3	3	2	3
$T6$	1	1	4	4	1	0	1	3	1	1	2	1
$T7$	1	1	4	4	1	4	0	3	1	1	2	1
$T8$	1	1	4	4	1	4	4	0	1	1	2	1
$T9$	1	1	4	4	1	4	4	3	0	3	2	3
$T10$	1	1	4	4	1	4	4	3	1	0	2	3
$T11$	2	2	4	4	3	4	4	3	3	3	0	3
$T12$	1	1	4	4	1	4	4	3	1	1	2	0

Table 3 Normalized matrix

	$T1$	$T2$	$T3$	$T4$	$T5$	$T6$	$T7$	$T8$	$T9$	$T10$	$T11$	$T12$
$T1$	0	0.045	0.091	0.091	0.023	0.091	0.091	0.068	0.068	0.068	0.045	0.068
$T2$	0.0227	0	0.091	0.091	0.023	0.091	0.091	0.068	0.068	0.068	0.045	0.068
$T3$	0.0227	0.023	0	0.091	0.023	0.023	0.023	0.045	0.023	0.023	0.045	0.023
$T4$	0.0227	0.023	0.045	0	0.023	0.023	0.023	0.045	0.023	0.023	0.045	0.023
$T5$	0.0455	0.045	0.091	0.091	0	0.091	0.091	0.045	0.068	0.068	0.045	0.068
$T6$	0.0227	0.023	0.091	0.091	0.023	0	0.023	0.068	0.023	0.023	0.045	0.023
$T7$	0.0227	0.023	0.091	0.091	0.023	0.091	0	0.068	0.023	0.023	0.045	0.023
$T8$	0.0227	0.023	0.091	0.091	0.023	0.091	0.091	0	0.023	0.023	0.045	0.023
$T9$	0.0227	0.023	0.091	0.091	0.023	0.091	0.091	0.068	0	0.068	0.045	0.068
$T10$	0.0227	0.023	0.091	0.091	0.023	0.091	0.091	0.068	0.023	0	0.045	0.068
$T11$	0.0455	0.045	0.091	0.091	0.068	0.091	0.091	0.068	0.068	0.068	0	0.068
$T12$	0.0227	0.023	0.091	0.091	0.023	0.091	0.091	0.068	0.023	0.023	0.045	0

tools were evaluated using DEMATEL and the process involved are tabulated below (Tables 2, 3 and 4).

5 Results and Discussion

From Fig. 2, it can be clearly confounded that, among 12 leagile tools considered, seven tools lie in the cause group of the diagraph and the remaining five tools lie in the effect group. The cause group generally consists of the criteria (in this case,

Table 4 Total influence matrix

	$T1$	$T2$	$T3$	$T4$	$T5$	$T6$	$T7$	$T8$	$T9$	$T10$	$T11$	$T12$
$T1$	0.04	0.085	0.21	0.219	0.063	0.192	0.18	0.157	0.116	0.121	0.114	0.127
$T2$	0.0609	0.04	0.205	0.214	0.062	0.188	0.176	0.154	0.114	0.119	0.112	0.124
$T3$	0.043	0.044	0.061	0.151	0.044	0.075	0.071	0.089	0.05	0.052	0.079	0.054
$T4$	0.0412	0.042	0.1	0.061	0.042	0.072	0.068	0.085	0.048	0.05	0.075	0.052
$T5$	0.0842	0.086	0.21	0.22	0.041	0.193	0.181	0.137	0.118	0.123	0.115	0.128
$T6$	0.047	0.048	0.158	0.165	0.048	0.062	0.079	0.119	0.054	0.057	0.086	0.059
$T7$	0.0501	0.051	0.169	0.176	0.051	0.155	0.062	0.126	0.058	0.06	0.092	0.063
$T8$	0.0512	0.052	0.172	0.18	0.052	0.158	0.148	0.065	0.059	0.062	0.094	0.064
$T9$	0.0583	0.06	0.196	0.205	0.059	0.18	0.169	0.147	0.045	0.114	0.107	0.119
$T10$	0.0558	0.057	0.188	0.196	0.057	0.172	0.161	0.141	0.064	0.045	0.102	0.114
$T11$	0.0872	0.089	0.219	0.228	0.109	0.2	0.188	0.163	0.121	0.127	0.076	0.132
$T12$	0.0535	0.055	0.18	0.188	0.054	0.165	0.155	0.135	0.062	0.064	0.098	0.045

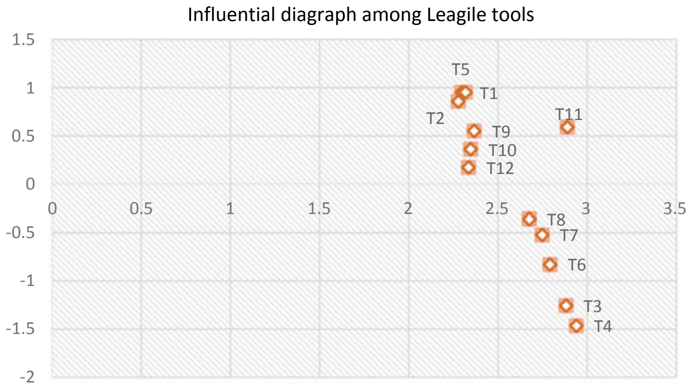


Fig. 2 Influential graph

leagile tools), which are having an influence on other considered criteria, whereas the effect group consists of the tools which are influenced by the tools presented in the cause group. With this discussion, seven tools ($T5$, $T1$, $T2$, $T11$, $T9$, $T10$ and $T12$) are the most influential tools in the implementation of legaile manufacturing systems in Peru context. However, among these seven tools, electronic data exchange ($T5$) holds the top position in the graph, which concludes that "$T5$" is the most influential tool among other common considered tools of leagile manufacturing system (Table 5).

However, this result is totally contrary to the existing studies; most of the literature evident that enterprise resource planning (ERP) and lead time reduction is the major success factors of leagile manufacturing systems. By which the research team extended to research, the reason for this contradiction in the obtained results. The

Table 5 Sum of rows and columns

Tools	r_i	s_i	$r_i + s_i$	$r_i - s_i$
Centralized and collaborative planning (***T*1**)	1.624704	0.67253814	2.297242	0.952166
Information driven virtual supply chain (***T*2**)	1.567646	0.70970565	2.277352	0.85794
Total preventive maintenance (***T*3**)	0.811966	2.06922973	2.881196	−1.25726
Market sensitiveness and responsiveness (***T*4**)	0.736468	2.2026745	2.939143	−1.46621
Electronic data exchange (***T*5**)	1.635082	0.68290082	2.317983	0.952181
Flexible set ups (***T*6**)	0.980713	1.81068048	2.791393	−0.82997
Assurance of quality (***T*7**)	1.112761	1.63501295	2.747774	−0.52225
Integration of performance measurement for processes (***T*8**)	1.157713	1.51790376	2.675617	−0.36019
Lead time reduction (***T*9**)	1.458384	0.90801836	2.366402	0.550366
Enterprise resource planning (***T*10**)	1.353772	0.99281917	2.346591	0.360953
Technological (advanced) manufacturing (***T*11**)	1.739273	1.14922148	2.888494	0.590052
Supplier selection (***T*12**)	1.253611	1.08138892	2.335	0.172222

recent development in manufacturing sectors, including the technological shift like industry 4.0, blockchain and IoT are changing the existing pattern of thinking and operations. This technological shift includes a lot of data involved and the manufacturers are in the position to analyze all the data included in the manufacturing system for efficient and smooth operations. Now, the obtained result can coincide with the recent shift of manufacturing systems. This study suggests the electronic data exchange as a key success factor, which will highly help to maintain and transfer the data involved in recent manufacturing systems, which further promotes the key elements of leagile manufacturing system.

On the other side, market sensitiveness and responsiveness hold the least position as less influential factors for the successful implementation of leagile manufacturing in Peru context. Both these results are further communicated with the case industrial decision makers for their feedback within the obtained results. Initially, it is tough for industrial managers to know that conventional success factors are not influential factors anymore. Soon, with the proper discussions on the results, the decision makers admit the results are well suited for their recent shift towards leagile manufacturing in the technological context.

Though this study serves many tangible and intangible managerial implications, one of the key implications is that this study assists the industrial managers to focus on the most influential factor of leagile manufacturing rather than proposing systems and practices for other common leagile tools. This will lead to effective implementation of leagile manufacturing system with less time and effective cost.

6 Conclusion

The combined pressures from customers customized demands and global technological developments, force the manufacturers to actively participate in new kinds of manufacturing strategies. This study considers one such strategy, leagile manufacturing system in Peru context. Due to the literature gap and ample room for opportunities, this study focused on the effective implementation of legagile manufacturing system through the identification of influential tools. From the assistance of primary and secondary sources, a totally 12 leagile manufacturing tools were identified and evaluated with the replies from case decision managers. Through numerical modeling, DEMATEL, the tools were analyzed, in which it has been concluded that, electronic data exchange (***T*5**), is the effective tool for implementing leagile manufacturing system. By implementing this influential tool have a positive correlation with other essential tools to activate on its own. The proper focus on the most influential tool reduces the setting time and cost of experiments to the case company. This assists the case company in addressing the customer demands within a short period of time with less negative impacts to the environment by reducing waste. Though this study has several scientific contributions, not exempted from limitations. The major limitation of this study is the case study methodology, since case studies can help the industrial managers to get a deep understanding of the core problem, still it limits with generalization. In order to address the generalization limitations, this study can be extended with an empirical focus among Peru manufacturing companies.

References

1. Li, Y., Diabat, A., Lu, C.C.: Leagile supplier selection in Chinese textile industries: a DEMATEL approach. Annals Oper. Res. 1–20 (2019)
2. Fadaki, M., Rahman, S., Chan, C.: Leagile supply chain: design drivers and business performance implications. Int. J. Prod. Res. 1–23 (2019)
3. Balakrishnan, K., Devadasan, S.R., Murugesh, R.: Design of a model for implementing leagile manufacturing paradigm in the pump industry. Int. J. Manag. Pract. **12**(3), 321–342 (2019)
4. Virmani, N., Saha, R., Sahai, R.: Leagile manufacturing: a review paper. Int. J. Product. Qual. Manag. **23**(3), 385–421 (2018a)
5. Nordeatrade: (2020). https://www.nordeatrade.com/dk/explore-new-market/peru/economical-context. Accessed on 15–06–2020
6. Hoekstra, S., Romme, J., Argelo, S.M.: Integral Logistic Structures: Developing Customer-Oriented Goods Flow. McGraw-Hill Book Co Ltd. (1992)
7. Naylor, J.B., Naim, M.M., Berry, D.: Leagility: integrating the lean and agile manufacturing paradigms in the total supply chain. Int. J. Prod. Econ. **62**(1–2), 107–118 (1999)
8. Faur, M., Bungau, C.: Exploring the insights of a consignment stock program implementation in a leagile supply chain. In: IOP Conference Series: Materials Science and Engineering, vol. 568, no. 1, pp. 012055. IOP Publishing (2019)
9. Nieuwenhuis, P., Katsifou, E.: More sustainable automotive production through understanding decoupling points in leagile manufacturing. J. Clean. Prod. **95**, 232–241 (2015)
10. Matawale, C.R., Datta, S., Mahapatra, S.S.: Interrelationship of capabilities/enablers for lean, agile and leagile manufacturing: an ISM approach. Int. J. Process Manag. Benchmarking **3**(3), 290–313 (2013)

11. Virmani, N., Sharma, V.: Prioritisation and assessment of leagile manufacturing enablers using interpretive structural modelling approach. Eur. J. Industr. Eng. **13**(6), 701–722 (2019)
12. Virmani, N., Saha, R., Sahai, R.: Identifying and ranking critical success factors for implementing leagile manufacturing industries using modified TOPSIS. Management **10**(20), 28 (2017a)
13. Virmani, N., Saha, R., Sahai, R.: Understanding the barriers in implementing leagile manufacturing system. Int. J. Product. Qual. Manag. **22**(4), 499–520 (2017b)
14. Virmani, N., Saha, R., Sahai, R.: Evaluating key performance indicators of leagile manufacturing using fuzzy TISM approach. Int. J. Syst. Assurance Eng. Manag. **9**(2), 427–439 (2018b)
15. Prakash, R., Singhal, S., Agarwal, A.: An integrated fuzzy-based multi-criteria decision-making approach for the selection of an effective manufacturing system. Benchmarking Int. J. (2018)

Analyzing the Cause-Effect Relationship Among Deming's Quality Principles to Improve TQM Using DEMATEL

Sucheta Agarwal, Vivek Agrawal, Jitendra Kumar Dixit, and A. M. Agrawal

Abstract Total Quality Management (TQM) is a systematic approach to the management of an organization. TQM focuses on improving the quality of the products of a company, including goods and services, by continuously improving organizational processes. The purpose of this paper is to study the 14 Deming's quality principles and analyze the cause-effect relationship among them to improve the TQM process. No research is reported on such a relationship in TQM. To fill this gap, DEMATEL technique is used to understand the cause-effect of the 14 Deming's principles. DEMATEL is a semi-qualitative Multi-Criteria Decision Making (MCDM) technique. By this, it can be analyzed and understand what are the principles which need more control. By controlling this cause group principle, practitioners can control effectively to the effect group principles. In the implementation of TQM, this cause-effect analysis has been recommended to the manufacturing and service industry as a new focus area.

Keywords Total quality management · Deming's principles · Multi-criteria decision making · DEMATEL · Cause-effect relationship

1 Introduction

In the twenty-first century, organizations are battling for enhancements in their stock chains. The key achievement factor is not just to improve an organization's supply chain, yet how quickly it can actualize changes contrasted with its rivals. Thus, the rivalry is not between organizations, yet between supply chains. Thus, a great manager will drive their group forward to oversee changes in all parts of the business and improve the productivity of the organization. As per Delavigne and Robertson [1], in this world, there are three kinds of changes: transformative change, progressive change and change during the time spent advancement. These kinds of changes have been contemplated by Shewhart and later by Deming.

S. Agarwal (✉) · V. Agrawal · J. K. Dixit · A. M. Agrawal
Institute of Business Management, GLA University, Mathura 281406, India
e-mail: sucheta.agrawal@gla.ac.in

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_9

An observer who went to Japan to help with the survey during World War II, Deming also urged members in prominent Japanese companies to take control of accurate procedures. So that companies can decrease costs by improving quality just as the overall market improves productivity and portion.

Japanese companies such as Honda, Panasonic, and Sony witnessed incredible achievement in the midst of implementing Deming's tactics. An output was far higher than that of competitors around the globe, and they had lower expenses. The boom in Japanese products continued–and many of these companies dominated the global market by the 1970s. American and European companies recognized that the price crisis could never be ignored again.

Deming did not receive any praise for his research until 1982, when he wrote the book, currently called "Out of the Depression." This book presented his well-known 14-point philosophy of managers. From these 14 focuses, there is a lot to gain. Many investigations of profoundly fruitful organizations show that considerable improvements are prompted by way of thinking. That is why these 14 focuses have become a standard quality management guide.

This paper is focused on assessing the cause-effect relationship among the 14 quality principles given by Deming using DEMATEL: a multi-criteria decision-making technique. The remaining this paper includes the literature review in Sect. 2, followed by Sect. 3, that is, research methodology. Further, Sect. 4 is explained in which discussion and conclusion are discussed, followed by implication, future research and limitation as Sect. 5.

2 Literature Review

Deming was an American master on quality control, and by the late fifties, he had become something of a divine being in Japan. With the conceivable special case of Douglas MacArthur, he was the most well known and most worshipped American in Japan during the after-war years [2].

Total Quality Management (TQM) is frequently used to allude to any arrangement of changes, procedures and projects that organizations decide to initiate for the sake of improvement. The word 'Absolute' passes on the possibility that all degrees of an association is to seek after quality. The word 'Quality' applies to each part of the association. TQM has developed as a reaction to the requirement for improving and guaranteeing quality in business just as in technical and managerial procedures for adequately guaranteeing, reestablishing and accomplishing clients' fulfillment.

TQM can be characterized as a comprehensive management philosophy focused on continuous improvement in all elements of an enterprise to convey services and goods in accordance with the clients' needs or prerequisites. ISO characterized TQM as "An administration approach of an association fixated on quality, in view of investment of every one of its individuals and focusing on long haul advantages to all individuals from the association and society". A few quality management researchers keep on composing, talk and know about the rule of quality crosswise over every one of the enterprises and organizations. Conspicuous among them are Juran [3] and Crosby [4, 5], and every one of them has created significant thoughts that have been acknowledged by the business. In any case, it is Deming's "quality" definition that has gotten the rule in controlling the activities of numerous supervisors. Deming's association in quality development in Japan is very much perceived in both the eastern and the western universes.

The example of overcoming adversity of Japan is somewhat credited to its appropriation, alteration and augmentation of the extent of Deming's hypothesis of 14 points of the quality management, delivering their own one of kind ideas of generation and Total Quality Management (TQM). Deming likewise asserted that up to 85% of the reasons for any slip-ups, variety, wastefulness issues and waste in any of business were the consequence of organization frameworks [6]. Deming additionally prompts that supervisory crews receive a consistent improvement in the style of "plan, do, act and afterward study," or PDAS [7]. He verbalized that hierarchical change must start with the individual, and that this originates from comprehension and usage of the significant information framework. Deming demanded that there was no "moment pudding," a few administration advisors while setting up themselves with customers suggested momentary gains rather than long haul changes [8]. Because of the craving for transient increases, process improvements and decreases in process durations become extremely famous, and now and again become a definitive target for associations. In this way, there is likewise a need to evaluate the reason impact relationship among the Deming 14 standards (Table 1).

Table 1 Deming's 14 principles

SN	Principle	SN	Principle
A1	"Create constancy of purpose for improving products and services"	A8	"Drive out fear"
A2	"Adopt the new philosophy"	A9	"Break down barriers between staff areas"
A3	"Cease dependence on inspection to achieve quality"	A10	"Eliminate slogans, exhortations and targets for the workforce"
A4	"End the practice of awarding business on price alone; instead, minimize total cost by working with a single supplier"	A11	"Eliminate numerical quotas for the workforce and numerical goals for management"
A5	"Improve constantly and forever every process for planning, production and service"	A12	"Remove barriers that rob people of pride of workmanship, and eliminate the annual rating or merit system"
A6	"Institute training on the job"	A13	"Institute a vigorous program of education and self-improvement for everyone"
A7	"Adopt and institute leadership"	A14	"Put everybody in the company to work accomplishing the transformation"

Source Modified from Petersen [8]

3 Research Methodology

Different (ISM, TOPSIS, AHP and many more) multi-criterion decision making methods are used in a different context [9–11]. The purpose of this study is to analyze the cause and effect of the 14 Deming's principles of TQM. The DEMATEL confirms interdependence between variables and helps in map creation to represent relative relationships between them, which can be used to investigate which solve complicated and entangled issues. This approach not only transforms the interdependence relationships by matrixes into a cause and effect category, but also identifies the essential factors of a complex structure network using an impact relation diagram. DEMATEL's method has gained a lot of interest over the past decade because of its benefits and versatility and many researchers have used it to solve complex device problems over different fields [12–14].

Insight taken from the literature, compared to different model, theory-driven model is more useful and successful rather than others. In this regard DEMATEL method is considered for assessing the cause—effect among the 14 Deming's principle of TQM. To examine this, the steps are as follows:

1. Initially, all 14 principles are selected as given by Deming for improving the total quality in development of products and services.
2. Apply DEMATEL to build the cause-effect relationship and draw a Network Relationship Matrix (NRM) among the Deming's 14 points.

3.1 DEMATEL

In 1971 the Battelle Memorial Association (BMA) established DEMATEL in Geneva [15]. Around the time, the method was used to evaluate and analyze dynamic problems [16]. DEMATEL is an effective tool for building and analyzing the structural model of the relationship of complex system variables between causes and effects [17]. DEMATEL combines the idea of system planning and the visual problem-solving theory. The method considers factors that facilitate understanding of their relationships in a dichotomy of cause and effect [18]. DEMATEL has been sent by Tsai and Chou [19] to select a sustainable growth management framework for SMEs. Lee et al. [20] used DEMATEL to determine the decision-making criteria around equity investments. Wu [21] also used DEMATEL to draw up a list of policies for banks. The steps of DEMATEL are as follows:

1. Compute average matrix.
2. Calculate normalized initial direct relationship matrix.
3. Calculate the total relation matrix.
4. Set a threshold value.
5. Find cause and effect relationship.

Initially, all the 14 principles given by Deming are selected and a questionnaire is prepared and circulated to the experts. Therefore, as DEMATEL uses expert advice, 9 experts, 4 from industry and 5 from academia with expertise in supply chain management, manufacturing and operations, overall efficiency, profitability, etc., were consulted for average matrix computing in the present report. The response from experts is collected through a questionnaire. A questionnaire is circulated among the 9 experts for collecting their responses. Each expert assessed the influence between two principles of TQM given by Deming by using "4 = very high influence", "3 = high influence", "2 = medium influence", "1 = low influence", and "0 = no influence".

The documentation of x_{ij} demonstrates how much the respondent accepts principle i influences factor j. For $i = j$, the corner to corner components are set to zero. For every respondent, an $n \times n$ non-negative lattice can be set up as

$$x^k = x_{ij}^k$$

where k is the quantity of respondents with $1 \leq k \leq H$, and n is the quantity of components. In this way, $X_1, X_2, X_3, \ldots, X_H$ are the networks from H respondents. To join all sentiments from H respondents, the normal framework $A = [a_{ij}]$ can be developed as pursues:

$$a_{ij} = \frac{1}{H} \sum_{k=1}^{H} x_{ij}^k$$

Calculate the standardized beginning direct-connection lattice. Standardize introductory direct-connection network D by $D = A \times S$, where

$$S = \frac{1}{\max \sum_{j=1}^{n} a_{ij}}$$

Every component in framework D falls somewhere in the range of zero and one.

Calculate the all-out connection lattice. The all-out communication network T is defined as $T = D(I - D) - 1$ (Table 2) with the same matrix as I. Characterize r and c as $n \times 1$ and $1 \times n$ vectors referring separately to complete lines and complete portions of the all-out network T. Assuming r_i to be the whole of ith push in System T, at that point r_i abbreviates both immediate and circuitous impacts provided by factor I to various elements. On the off chance that c_j denotes the entire jth segment in network T, c_j displays both immediate and backhanded impacts from various components by factor j at this point. At the point where $j = I$ the entire $(r_i + c_j)$ shows the maximum impacts given and obtained from factor i. That is, $(r_i + c_j)$ demonstrates the degree of importance that factor I plays in the entire system. The difference $(r_i + c_j)$ suddenly portrays the net impact which element I adds to the system. Especially where $(r_i - c_j)$ is definite, factor I is a net cause, whereas factor I is a net beneficiary or consequence if $(r_i - c_j)$ is negative (refer Table 3).

The values of T_{ij} being more than $\alpha = 0.7888$ (threshold value) were check from Table 2, which presented the interaction among the 14 points of Deming in TQM.

Table 2 Relative intensity matrix

	$A1$	$A2$	$A3$	$A4$	$A5$	$A6$	$A7$	$A8$	$A9$	$A10$	$A11$	$A12$	$A13$	$A14$
$A1$	0.76	0.76	0.73	0.83	0.86	0.78	0.80	0.81	0.70	0.76	0.85	0.81	0.81	0.82
$A2$	0.81	0.69	0.71	0.77	0.83	0.78	0.75	0.77	0.68	0.76	0.83	0.82	0.76	0.81
$A3$	0.91	0.85	0.73	0.89	0.94	0.84	0.85	0.87	0.75	0.81	0.95	0.88	0.84	0.90
$A4$	0.84	0.79	0.76	0.76	0.88	0.78	0.78	0.82	0.71	0.77	0.88	0.84	0.80	0.84
$A5$	0.90	0.80	0.79	0.86	0.84	0.85	0.82	0.87	0.75	0.82	0.92	0.88	0.82	0.89
$A6$	0.79	0.76	0.69	0.80	0.81	0.70	0.76	0.77	0.67	0.74	0.83	0.78	0.77	0.79
$A7$	0.83	0.79	0.74	0.82	0.87	0.79	0.72	0.81	0.70	0.77	0.87	0.82	0.80	0.83
$A8$	0.84	0.78	0.74	0.79	0.85	0.81	0.78	0.74	0.70	0.77	0.85	0.82	0.77	0.84
$A9$	0.88	0.83	0.76	0.87	0.89	0.82	0.80	0.83	0.67	0.78	0.89	0.85	0.80	0.86
$A10$	0.77	0.71	0.68	0.77	0.82	0.75	0.74	0.75	0.66	0.65	0.79	0.77	0.71	0.78
$A11$	0.83	0.76	0.72	0.84	0.87	0.78	0.78	0.80	0.70	0.76	0.79	0.82	0.78	0.82
$A12$	0.76	0.69	0.67	0.75	0.77	0.72	0.69	0.73	0.65	0.71	0.81	0.69	0.75	0.77
$A13$	0.81	0.74	0.73	0.80	0.85	0.76	0.74	0.78	0.66	0.72	0.84	0.80	0.70	0.79
$A14$	0.82	0.76	0.72	0.81	0.85	0.79	0.78	0.80	0.70	0.75	0.84	0.82	0.78	0.75

Note For better clarity values presented upto two decimal points

Table 3 The sum of given and received

T	RT	CT	$R + C$	$R - C$	Rank($R - C$)	Cause and effect
$A1$	11.0654	11.5597	22.6250	−0.4943	4	Effect
$A2$	10.7693	10.7083	21.4776	0.0610	11	Cause
$A3$	12.0014	10.1709	22.1723	1.8305	13	Cause
$A4$	11.2810	11.3688	22.6499	−0.0878	9	Effect
$A5$	11.8123	11.9264	23.7387	−0.1142	8	Effect
$A6$	10.6705	10.9525	21.6230	−0.2820	5	Effect
$A7$	11.1567	10.7785	21.9352	0.3781	12	Cause
$A8$	11.0856	11.1469	22.2325	−0.0613	10	Effect
$A9$	11.5375	9.6969	21.2344	1.8406	14	Cause
$A10$	10.3440	10.5815	20.9255	−0.2374	6	Effect
$A11$	11.0453	11.9265	22.9718	−0.8812	2	Effect
$A12$	10.1479	11.4094	21.5573	−1.2615	1	Effect
$A13$	10.7134	10.8825	21.5958	−0.1691	7	Effect
$A14$	10.9747	11.4961	22.4708	−0.5214	3	Effect

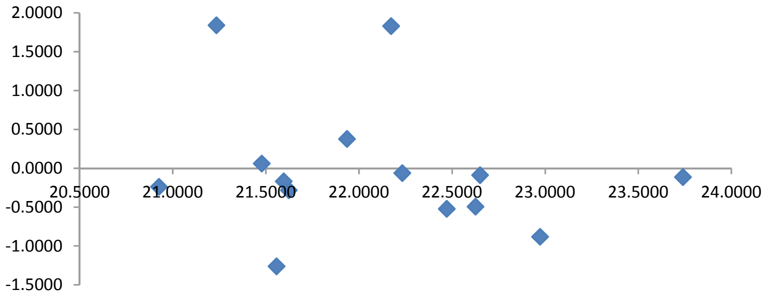


Fig. 1 Network relationship map

Set a cap an opportunity for digraph acquisition. Because Framework T provides data on how one aspect affects another, setting an edge an opportunity to sift through any unrelated impacts is important for a leader.

In doing so, it will only select the impacts that are more prominent than the edge value and appear in the digraph. The edge confidence is defined in this investigation by figuring the usual of the components in network T. You will acquire the digraph by mapping the dataset from ($r + c$, $r -$ c). Upper values show the cause factors and below the axis show the effect factor (Fig. 1).

4 Discussion and Conclusion

On the basis of the $R + C$ the importance of the 14 points of Deming principle can be determined. On this basis this 'improve constantly and forever every process for planning, production and service ($A5$)' is the most important point with the highest value 23.7387, whereas 'eliminate slogans, exhortations and targets for the workforce ($A10$)' is the least important point with value 20.8255. According to this the results are $A5 > A11 > A4 > A1 > A14 > A8 > A3 > A7 > A6 > A13 > A12 > A2 > A9 > A10$. It is clearly observed that practitioners should focus more towards on improving constantly and forever every process for planning, production and service and less on eliminating slogans, exhortations and targets for the workforce. On the basis of $R – C$ the results are $A12 > A11 > A14 > A1 > A6 > A10 > A13 > A5 > A4 > A8 > A2 > A7 > A3 > A9$.

Due to this contradiction, the 14 points are grouped into two groups, that is, cause and effect. The points with negative value are placed in the effect group, whereas the others in cause group. On the basis of this $A1$, $A3$, $A7$ and $A9$ are categorized in the cause group and remaining in the effect group. For a better understanding of the result, the network relationship map is prepared on the basis of $R + C$ and $R – C$. From Fig. 1 and Table 3, it is observed that Cease dependence on inspection to achieve quality and Improve constantly and forever every process for planning, production and service are the most affecting factor. These two points are almost affecting twelve other points. This is followed by Break down barriers between staff areas, Adopt and institute leadership, etc.

5 Implications, Limitations and Scope for Future Research

The present research presents professionals working in the field of complete quality control with some important scientific and organizational perspectives. The research argues practitioners will be more focused on more points of control. They will emphasize their quality policy in the manner in which they manufacture the product or provide services.

14 Deming principles are considered in this research for a review of causal influence in TQM. To boost the result's precision, the number of experts for data collection can be increased. All the experts came from North India alone, so the regional profile of experts can be diversified for more detailed tests. Using certain mathematical techniques, the statement can be validated. Uncertainty and vagueness can be reduced in this analysis by introducing Fuzzy MCDM (Fuzzy AHP, Fuzzy TOPSIS, and Fuzzy DEMATEL) strategies for better future test outcomes. Furthermore, the researchers will be offering more comprehensive information with a qualitative and quantitative approach in the future.

References

1. Delavigne, K.T., Robertson, J.D.: Deming's Profound Changes. PTR Prentice Hall, Englewood Cliffs, NJ (1992)
2. Halberstam, D.: The Reckoning. William Morrow, New York, NY (1986)
3. Juran, J.M.: Juran on Leadership for Quality: An Executive Handbook. Free Press, New York, NY (1989)
4. Crosby, P.B.: Let's Talk Quality. Plume, New York, NY (1990)
5. Crosby, P.B.: The Eternally Successful Organization: The Art of Corporate Wellness. Mentor, New York, NY (1992)
6. Deming, W.E.: Out of the Crisis: Quality, Productivity and Competitive Position, Cambridge University Press, Cambridge.
7. Redmond, R., Curtis, E., Noone, T., Keenan, P.: Quality in higher education: the contribution of Edward Deming's principles. Int. J. Educ. Manag. **22**(5), 432–441 (2008)
8. Petersen, P.B.: Total quality management and the Deming approach to quality management. J. Manag. Hist. **5**(8), 468–488 (1999)
9. Singh P.L., et al.: Evaluation of common barriers to the combined lean-green-agile manufacturing system by two-way assessment method. In: Shanker K., Shankar R., Sindhwani R. (eds.) Advances in Industrial and Production Engineering. Lecture Notes in Mechanical Engineering. Springer, Singapore (2019)
10. Agrawal, V., Agrawal, A.M., Mohanty, R.P.: Application of fuzzy MCDM in supplier selection of fertiliser manufacturing industry. Int. J. Bus. Perform. Supply Chain Model. **9**(2), 133–159 (2017)
11. Agrawal, V., Tripathi, V., Agrawal, A.M.: Exploring key dimensions of e-service quality: a case of Indian banking industry. Int. J. Serv. Oper. Manag. **29**(2), 252–272 (2018)

12. Aggarwal, A., Gupta, S., Ojha, M.K.: Evaluation of key challenges to industry 4.0 in Indian context: A DEMATEL approach. In: Shanker K., Shankar R., Sindhwani R. (eds.) Advances in Industrial and Production Engineering. Lecture Notes in Mechanical Engineering. Springer, Singapore (2019)
13. Agarwal, S., Agrawal, V., Dixit, J.K.: Green manufacturing: A MCDM approach. Mater. Today Proc. (2020)
14. Agrawal, V., Mohanty, R.P., Agrawal, A.M.: Identification and analysis of enablers of SCM by using MCDM Approach. Benchmarking Int. J. (Forthcoming)
15. Gabus, A., Fontela, E.: Perceptions of the World Problematique: Communication Procedure, Communicating with Those Bearing Collective Responsibility, pp. 11–18 (1973)
16. Fontela, E., Gabus, A.: The DEMATEL Observer, DEMATEL 1976 Report.Battelle Geneva Research Center, Switzerland, Geneva (1976)
17. Wu, W.W., Lee, Y.T.: Developing global managers' competencies using fuzzy DEMATEL method. Expert Syst. Appl. **3**(2), 499–507 (2007)
18. Li, C.-W., Tzeng, G.-H.: Identification of a threshold value for the DEMATEL method using the maximum mean de-entropy algorithm to find critical services provided by a semiconductor intellectual property mall. Exp. Syst. Appl. **36**(6), 9891–9898 (2009)
19. Tsai, W.H., Chou, W.H.: Selecting management systems for sustainable development in SMEs: a novel hybrid model based on DEMATEL, ANP, and ZOGP. Exp. Syst. Appl. **36**(2), 1444–1458 (2009)
20. Lee, W.-S., et al.: Analysis of decision making factors for equity investment by DEMATEL and Analytic Network Process. Exp. Syst. Appl. **38**(7), 8375–8383 (2011)
21. Wu, H.T.: Constructing a strategy map for banking institutions with key performance indicators of the balanced scorecard. Eval. Prog. Plann. **35**, 303–320 (2012)

Security in Manufacturing Systems in the Age of Industry 4.0: Pitfalls and Possibilities

Ruchika Gupta, Rakesh Kumar Phanden, Shubham Sharma, Priyank Srivastava, and Prateek Chaturvedi

Abstract The manufacturing industry is swiftly entering Industry 4.0, wherein the supply chains, operations, factories and customers are becoming digitally interconnected. This interconnection, coupled with advanced automation driven by technologies such as robotics, cloud computing, artificial intelligence and big data, makes the manufacturing systems increasingly vulnerable to cyber-attacks. The motive and impact of these attacks may vary, but all such attacks cost time and money to the manufacturers and their customers. If these challenges are not adequately addressed, Industry 4.0's true potential may never be realized. It is, therefore, imperative for the manufacturers to have a well-designed mitigation plan in place to secure their systems from such attacks. Therefore, the purpose of this study is to explore the numerous possibilities offered by these advanced technologies and also to identify the pitfalls in the existing security measures of manufacturing systems. The study also focuses on evaluating the level of awareness and preparedness for potential future cyber-attacks. Based on the findings, the study suggests several strategies to mitigate these attacks, which would possibly serve as a valuable reference for practitioners and other researchers.

Keywords Security · Cybersecurity · Smart manufacturing · Industry 4.0 · Manufacturing · Supply chain

1 Introduction

Smart manufacturing, which is conjointly mentioned as Industry 4.0, announces an era of bendable supply chains and customized items or services developed using cutting edge innovations, for example, artificial intelligence, the Internet of

R. Gupta (✉) · P. Chaturvedi
Amity University, Greater Noida Campus, Noida, Uttar Pradesh, India
e-mail: rgupta@gn.amity.edu

R. K. Phanden · S. Sharma · P. Srivastava
Department of Mechanical Engineering, Amity University, Sector–125, Noida, Uttar Pradesh, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_10

things, analytics, automation, and augmented reality. While the introduction of these advanced technologies has helped companies gain significant insights and develop the services they offer, Industry 4.0's "cyber-physical systems or smart production systems" will further revolutionize the future way of working.

Industry 4.0 also combines automation with digital technologies to reduce direct human effort and resources. Such developments effectively make the production system a "smart networked factory" in which all operations are digitally regulated and therefore, immutable [1]. As a result, resource use, both financial and content, is more productive and offers better customer satisfaction. As indicated by Capgemini [2], smart manufacturing had facilitated manufacturers to accomplish nearly 17–20% productivity gains while attaining 15–20% quality gains simultaneously. It is no big surprise then that numerous makers—with figures as high as 67% for mechanical assembling—have shrewd manufacturing plant programs and, if Capgemini's projections [2] are to be accepted, the result will be a $500 billion to $1.5 trillion advantage for the global economy throughout the following 5 years.

However, despite all the benefits, this interconnectivity amongst the supply chains, factories, customers, and operations in the "smart networked factory" also jeopardizes the system for cyber-attacks [3, 4] (Fig. 1). Incidents, such as a Stuxnet attack [5] on Iranian uranium enrichment facilities or an attack on Germany's steel company, indicate a destructive effect of cyber threats on production systems.

Recent reports [6–9] show that the manufacturing industry has been the most targeted for cyberattacks in the past year. Manufacturing Business Technology reported in March 2017 that after healthcare, manufacturing is the second-most hacked industry. According to a similar study published by NTT Security [10], 34% of all documented cyberattacks focused on manufacturing during Q2 2017. However, according to the 2019 Manufacturing and Distribution Survey [11], over the last 12 months, half of the businesses have been victims of at least one data breach.

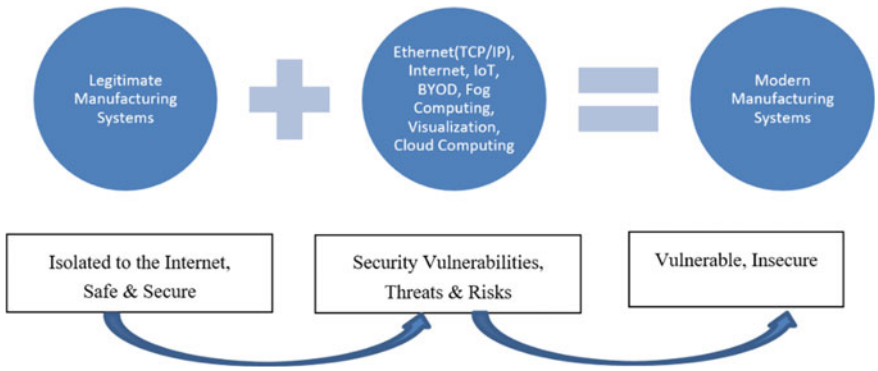


Fig. 1 Evolution from legitimate manufacturing systems to smart or modern manufacturing systems [3]

One of the main reasons behind this trend is that manufacturing processes have failed to present proper defense plans to encounter such cyber-physical attacks. Several times, production systems have been linked to Internet networks without any method of preventive protection. Hence, these weaknesses and lack of a defensive mechanism in fabrication systems make them one of the cyber-attackers' most targeted targets. The motive and impact of these attacks may vary, but all such attacks cost time and money to the manufacturers and their customers [12].

Therefore, developing a truly integrated competitive solution to cyber risk is crucial to creating value chains when they combine Industrial Technology and Information Technology—the main motivating force behind Industry 4.0. If these challenges are not adequately addressed, Industry 4.0's true potential may never be realized. Therefore, the objectives of the study are to explore the:

- Numerous possibilities offered by these advanced technologies;
- Challenges faced during the integration of smart technologies in manufacturing systems;
- Pitfalls in the existing security measures for manufacturing systems;
- Level of awareness and preparedness for potential future cyber-attacks; and
- Strategies to mitigate targeted cyber-attacks.

2 Smart Manufacturing Systems in Industry 4.0: Possibilities and Challenges

Industry 4.0 is a term used in the manufacturing sector to encompass an array of zones ranging from product design to supply chain and logistics. It is bringing in a new generation of connected manufacturers and smart factories. The National Institute of Standards and Technology (NIST) defines Smart Manufacturing as systems that are "fully-integrated, collaborative manufacturing systems that respond in real-time to meet changing demands and conditions in the smart factory, in the supply network, and in customer needs."

Smart manufacturing (SM) is a technology-driven method that tracks the production process utilizing Internet-connected machinery. SM's goal is to find the potential for automating processes and to use data analytics to improve performance in manufacturing. SM is an advanced Internet of Things (IoT) technology. For production equipment, implementations include the embedding of sensors to collect data on their operational status and efficiency. In the past, this information was typically kept on individual devices for local databases and was only used after they occurred to assess the cause of equipment failures [13].

Smart manufacturing combines data and information that can be compiled to form new approaches from multiple open and provider apps and goods. It can be extended to a single line of equipment, to a whole plant or to a network of vendors and customers. In addition, it is possible to link and integrate between and over all of these in a coordinated time. This cyber-physical and virtual domain combination unlock new arenas of innovation that will make drastic changes in the manufacturing industry works so as to make high-quality products, improve profitability, increment energy execution and guarantee more secure plant floors.

In Smart Manufacturing/Smart Factory, the devices can transmit data in real-time via a wireless Internet connection. A typical setup could include several systems that are accessed from a number of devices. A Smart Factory, for example, may have a Material Lifecycle Management (PLM) program that can relay concept details to the Manufacturing Execution Program (MES) where the material is manufactured. A Human Machine Interface (HMI) may control this, such as a control panel or even a smartphone. This method of configuration enables the smooth flow of information between computers. This can then be used to modify and improve the performance of the devices to achieve maximum output while reducing waste. It also ensures that the cycle can be streamlined, contributing to decreased downtime that can help improve efficiency and reproducibility and increase profitability. Manufacturers can have real-time monitoring and access to data through the HMI that provides information on the machinery situation remotely enabled through cloud computing technology [14, 15].

Despite the numerous benefits and opportunities of smart production platforms in Industry 4.0, Dell Technologies' 2019 survey [8] revealed that "a staggering 91% of mid-sized and larger companies are facing major obstacles to digital transition," resulting in comparatively little concrete moves toward digitalization. The various challenges faced during the integration of smart technologies in manufacturing systems are given:

- **Systems integration issues**: The manufacturing group supports firmly the "if-it-ain't-broke-don't-fix-it" idiom. For many years computers are preserved and used, well beyond a time in which parts are easy to obtain. They stay part of the environment because it would cost hundreds of thousands of dollars to remove them, an expenditure which smaller manufacturing companies find it very difficult to justify when the current system is fully working.
- **Lack of clear Return on Investment (ROI) on new technology**: The question of funding is crucial with all IoT implementations, with pro-IoT proponents within the organization demanding management to finance trials and potentially complete installations. It is hard to induce executives to fund on the grounds of the abstract advantages that are not yet demonstrable in the existing plant. Quantifying gains always have to demonstrate the connection between organizational changes and the bottom line.
- **Lack of skills required**: At this stage, the competence issue arises, precisely whether the organization has the resources in place to plan, build, execute, fine-tune and manage IoT implementation. The range of skills needed is substantial, from device engineers with detailed knowledge of manufacturing environments, system integration experts who can support the hardware's incorporation into the manufacturing environment, to data analysts.
- **Data scientists and functional managers lack trust**: Lack of trust creates a gap between data insights and strategic decision-making. This causes problems when it comes to deciding which data to use for certain business decisions. There is

also an inability to manage the volume and velocity of the produced results. To put it simply, the manufacturers cannot make the most of their results.

3 Cybersecurity Threats/Pitfalls of Smart Manufacturing Systems

Cybersecurity is no longer just an integral part of the IT department. Globally, its importance was noticed in the corporate boardrooms, and the executive interest was predicted to increase [16, 17]. New technologies in industrial environments carry with them a current kind of cyber threat, while criminals are continually looking for approaches to abuse the known and obscure imperfections of old frameworks, programming and techniques. The manufacturing sector faces many specific challenges to cybersecurity:

- **The Internet of Things (IoT) malware-infected machines**: Industry 4.0 facilities depend on robust interconnection and on constant data sharing between devices. While the IoT systems are good for automation and performance, they make manufacturers exposed to distributed denial of service (DDoS) attacks that can operate through firewalls.
- **IP theft**: The company is at risk even if the system is not regulated to the point that it is susceptible to DDoS attacks because you store or view sensitive information electronically. Your patented IP divides you from your rivals-it should be a key priority to keep it safe from cyber threats.
- **Lack of network security investments**: The move towards lean manufacturing models has contributed to an emphasis on cost reduction at all rates. As a consequence, many companies are reluctant to invest in appropriate cybersecurity infrastructure or the personnel qualified to operate and track them. This lack of investment makes businesses susceptible to attacks—particularly small and medium-sized companies.

However, the effects of cyber-attacks on a company will vary from a prolonged outage and its resultant financial loss to something larger and more sinister. A hacker, for example, might make subtle changes to your computer code that would change the software in dangerous ways. As producers know, an imperceptible variance of a few millimeters or degrees will easily risk protection or efficiency for precision materials. While such a situation may seem far-fetched, every supplier should be worried about cybersecurity by the reality that it could happen.

4 Awareness and Preparedness for Potential Cyber-Attacks

In recent years, cyber situation awareness (CSA) has drawn considerable interest from the security research community as an approach to support pre-emptive cyber protection, particularly despite focused attacks. Generally, CSA includes considering the nature of the network, projects, tools and challenges faced. It is an umbrella term for a difficult-to-measure collection of strengths and techniques. This includes the following capabilities:

- Knowing the present circumstance
- Evaluating how conditions develop
- Impact assessment of the attacks
- Assessing the actions of the intruder
- Considering the origins of present circumstances
- To be educated regarding the nature of the data gathered
- Estimating potential prospects.

Most companies are investing heavily in security safeguards to secure their device and data infrastructure. Nonetheless, most of these technological safeguards are rendered useless due to the lack of training on cybersecurity knowledge among employees. Employees take chances digitally and that greatly increases their organization's cybersecurity threats. Employees' risky activities include accessing inappropriate documents and not safeguarding sensitive information saved on or sent from their devices. The 2015 Cyber Risk Protection Research Survey [6, 7] states that workers low-security knowledge is the biggest barrier to protect themselves from cyber threats.

Low care about security scored on top of the charts resulting in underscoring the importance of planning in security training as the essential activity an affiliation can grasp to enhance their digital resistances. Workers ought to be taught with respect to great practices in digital security and perceive that they assume an urgent job in defending the computerized properties of their undertaking. Workers are supposedly the mainline of guard against digital dangers through legitimate training.

5 Security in Manufacturing Systems: The Road Ahead

In 2021, cybersecurity will continue to be an important topic in Finnish manufacturing, as industrial systems, goods and ecosystems are becoming increasingly complex, Internet-enabled and interconnected. The cybersecurity sector will continue to evolve indefinitely in 2021 and new threats will continue to appear on a daily basis, at least. Cybersecurity will be important not only to win customer trust but also to keep the critical infrastructure, people and company going. Therefore, it is essential to prioritize the key areas of manufacturing. As per a study by Deloitte [9], Digitalization, Industry 4.0, Internet of Things, and mechanical computerization security will be the most significant drivers for cybersecurity in manufacturing in 2021. Deloitte Cyber Security Framework depicts these priority topics under different categories which are- Secure, Strategic, Vigilant, and Resilient (Table 1).

Table 1 Priorities of cyber security in manufacturing in 2021 [9]

Categories	Priority topics
Secure	Security of industrial automation Ensuring availability Identity and access management
Strategic	Internet of things (IoT) Digitalization and Industry 4.0
Vigilant	Threat intelligence Vulnerability identification Security operations
Resilient	Incident management Business resilience

6 Conclusion and Suggestions

It is important in the near future that manufacturing businesses perceive cyber threats through a different lens. Instead of talking about the threats only in terms of the number of attacks or the actual value that might be destroyed, they should recognize whether improved cyber risk management will allow them to meet more consumers, retain better relationships or generate more goods.

Findings from this study reveal that the industrial sector is already afflicted by a severe lack of knowledge of the importance of cybersecurity. Increasing mobility and the need to capture and process real-time information will begin to add large quantities of mobile devices and massive volumes of data needing security. As a consequence, manufacturing companies may need to reconsider their business sustainability, disaster mitigation, and response strategies to meet the ever-increasingly dynamic and omnipresent cyber climate. These companies need to concentrate on their capacity to distinguish and react to these cyber-threats. Various strategies that could be adopted to mitigate these threats are given.

- Be ready to distinguish an assault—build up a security checking stage that can recognize an assault by the following conduct at various levels inside the business; this could be a straightforward program that delivers a caution and sends an email when suspicious movement is seen on a firewall, through a 24 × 7 × 365 Security Operations Center (SOC) observing systems, working frameworks, applications and end clients.
- Be set up to react—set up a conventional security incident management unit that has been taught in and actualizes a recorded program that is checked on at any rate yearly.
- Adopt a hazard-based coherence methodology—create recuperation methodologies (counting point by point reinforcements) for all frameworks, and advance innovation in accordance with their criticality for organization endurance.
- Add new automated safeguards—propelled current applications (for instance, robotizing Virtual Machines (VM) and Identity and Access Management (IAM)

forms utilizing explicit innovation), just as presenting reciprocal arrangements/advancements, for example, Intrusion Detection Systems (IDS), Intrusion Prevention Systems (IPS), Data Loss Prevention (DLP) frameworks and Web Application Firewalls (WAF).

- Ask and check as often as possible—direct a digital occasion preparing activity to assess the limit of your representative to deal with the response to a significant digital assault; attempt an underlying red group work out (an arranged assault by gifted moral programmers) to test your innovative capacity to distinguish and respond to refined assaults;
- Build security in the existing pattern of advancement—guarantee that digital hazard is considered in every single new item, administrations, undertakings, and so on, complete hazard evaluations as required, and oversee inside concurred chance craving.
- Increase the detection of the risks-use forward-looking information to detect and map emerging threats.

Through concentrating on the right areas, manufacturing companies can become agile enterprises that can react to new threats and attacks efficiently and proactively while being versatile to meet today's demands in the sector.

7 Limitations

Throughout this paper, we have argued that too little attention is given to the issue of security in smart manufacturing. The study is limited to evaluating the various possibilities and pitfalls only. A more detailed study is required to evaluate our preparedness against the potential threats and on the development of technological solutions to compact threats posed by the technology itself.

References

1. Trend Micro Research. Security in the Era of Industry 4.0: Dealing with Threats to Smart Manufacturing Environments (2019)
2. Capegemini Report Smart factories: How can manufacturers realize the potential of digital industrial revolution (2017)
3. He, H.: Manufacturing Informatics Centre, Cranfield University (Member of IOT Security Foundation), Security Challenges on the Way Towards Smart Manufacturing
4. Gupta, R., Agarwal, S.: A comparative study of cyber threats in emerging economies. Globus Int. J. Manag. IT **8**(2), 24–28 (2017)
5. W32.Stuxnet Dossier (Version 1.4), Tech. Rep. (2011)
6. Cyber Risk Protection Research Survey 2015
7. Cyber threat defense report 2015
8. Dell technologies 2019 survey: Measuring business digital transformation progress around the world

9. Deloitte Report: Predicting the future of Cyber Security in Finnish Manufacturing Cyber Secure Manufacturing in 2021
10. NTT Security: Cybersecurity Expertise in the Automotive Industry 2019
11. Manufacturing & Distribution Survey Report: Transforming for Tomorrow. Sikich (2019)
12. Gupta, R., Varma, S., Bhardwaj, G.: A structural equation model to assess the factors influencing employee's attitude & intention to adopt BYOD (bring your own device). Int. J. Recent Technol. Eng. **8**(3), 63030–66308 (2019)
13. Mittal, S., Khan, M.A., Romero, D., Wuest, T.: Smart manufacturing- characteristics, technologies and enabling factors. Proc. Inst. Mech. Eng. Part B J. Eng. Manuf. **233**(5), 1342–1361 (2017). https://doi.org/10.1177/0954405417736547
14. Nilufer, T.: Stephen: security of smart manufacturing systems. J. Manuf. Syst. **47**, 93–106 (2018)
15. Srivastava, P., et al.: Fuzzy methodology approach for prioritizing maintenance 4.0 attributes. In; 2020 international conference on computation, automation and knowledge management (ICCAKM), Dubai, United Arab Emirates, pp. 308–311 (2020). https://doi.org/10.1109/ICCAKM46823.2020.9051483
16. Smarter Security for Manufacturing in the Industry 4.0 Era, Tech. Rep. (2017)
17. Viega, J,, McGraw, G.: Building Secure Software: How to Avoid Security Problems the Right Way. Addison Wesley (2006). ISBN 978-0321425232.

Application of Structured Maintenance Reliability Programme in Oil and Gas Industry—A Case Study

Kumar Ratendra and Narula Virender

Abstract This paper explores the maintenance of equipment to provide optimum capabilities at minimum/reasonable cost in giant Oil and Gas Industry. The maintenance of equipment is required to increase life cycle and mitigate operational risk. Maintenance activities focus on three prime factors of any equipment viz Reliability (of equipment 100%) availability (95–99%) and maintainability. In prevailing maintenance practices RCM (Reliability centered maintenance) is very common. Reliability and availability are crucial to the success of any project as they underlie the higher order, but less tangible, project requirements for operability and maintainability. Based on literature review and input from industrial experts, this paper discusses a structured MRP (Maintenance Reliability program) that may be established by doing proper planning, scheduling, execution and auditing and also outcome of this paper establish the relationship among reliability, availability and maintainability.

Keywords Optimum capabilities · Cost · Structured · Scheduling · Reliability

1 Introduction

Oil and Gas industry is capital-intensive organization having heavy plant and machinery costing crore of rupees for example E&P Company (ONGC) having the plant and machinery of the cost of Rs. 67,000 Crore. The management of this level capital asset demands an effective and efficient equipment management system. Operation and maintenance of drilling rigs and oil installations are very complex, labor-intensive and require a higher degree of safety. Different type of

K. Ratendra (✉)
Manav Rachna International Institute of Research and Studies, Faridabad 121001, India
e-mail: ratendra_kumar@yahoo.com

N. Virender
Mechanical Engineering, Manav Rachna International Institute of Research and Studies, Faridabad 121001, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_11

maintenance strategies is in practice in Oil and Gas industries. However, preventive maintenance and corrective maintenance is in practice mainly and preventive maintenance activities are carried out according to recommendations of OEM (Original equipment manufacturer). Chances of breakdown/failure are very high, even preventive maintenance is followed.

When analyzed, it is observed that the main reasons for failure/breakdown are (1) Improper/incorrect maintenance practices, (2) Overlook of safety practices, (3) Standard operative practices (SOP) not followed, (4) Overconfidence of maintenance persons, (5) Operator and maintenance technicians do not pass information to each other, (6) poor quality of spares and (7) Poor workmanship.

Good maintenance results in minimum shutdown/breakdown, higher reliability at a low cost. Breakdown and failures are not desirable in any condition. The equipment availability and reliability, its efficiency and performance depend on its condition. What type of maintenance model is followed plays an important role in equipment availability and reliability. Generally, preventive maintenance is carried out according to the recommendation of OEM or on the basis of results from condition monitoring. Sometimes maintenance is delayed due to operational emergency of equipment or condition monitoring results. In oil and gas industry, 30% of total manpower is busy in operation and maintenance activities.

When carried out the survey, it is observed that improper maintenance causes 85% failures and safety of equipment with recordable injury <0.1%. Cost reduction in Oil and Gas industry: Operators in the oil and gas industry need to reduce their costs to remain competitive and maximum economy recovery, identifying and eliminating low-value activities.

The upper stream industry is slow to deploy new technology/Innovations, including digital advances and mobile applications. There are several reasons for it: low investment and Uncertain oil prices. The probable solution for higher equipment availability and reliability is application of total quality maintenance practices and new technology.

2 Brief of Oil and Gas Industry

Crude oil and gas come from below of earth. Main equipments/facilities used in O&G industry are Rigs, Pumps, compressors, turbines, Motors, hoisting system, storage tanks, columns, HVAC system, control and instrumentation system, Distributed control system (DCS), Emergency safety shut down system, etc.

The oil and gas industry can be classified:

Upstream/E&P Industry covers Exploration, Drilling, Production/processing of Oil and Gas, etc.

Downstream covers Refining, etc.

Midstream covers operation and processes such as transportation through pipeline, gas treatment, LNG, manufacturing of chemical products from hydrocarbon, for example, industrial chemicals, fertilizers, chemicals, etc.

In this type of industry, equipments can be classified broadly as rotary and static equipments. Pumps, compressors, engines, turbines, etc., comes under the category of rotary equipment and vessels, columns, heat exchangers, coolers, pipelines, etc., fall under the category of static equipment. Maintenance of equipments and facilities in upstream/E&P Industry is little bit difficult because our most of the operations are in Offshore, equipments move from one place to another in drilling rigs and in exploration activities, Some production platform and Sucker rod pumps are unmanned. Equipments are scattered, installed at different locations far from each other.

3 Prevailing Maintenance Practices

Maintenance is essential activity because reliability, availability and performance of equipment depend upon maintenance model. In Oil and Gas industry equipment/facilities are not at one place, Rigs and installations are located far from each other. O&M can be categories into two categories (I) for onshore (ii) for offshore.

In Onshore: (1) Routine operation and maintenance are carried out by staff deployed at Rig/installation, (2) Preventive maintenance/setting/clearances, etc., by field maintenance party, (3) Workshop/Base office: To support top overhauling/overhauling, fabrication, welding and other specialized jobs, etc.

In offshore: Routine O&M, preventive, predictive maintenances are carried out by staff deployed there. Generally, activities such as overhauling/repairing, etc., are also carried out there with the help of experts/OEM. Maintenance cost in offshore is too high so it is not easy to get support/outside services without proper justifications, so emphasis is given on skill and training to existing staff. Mostly corrective and preventive maintenance practices are followed in the oil and gas industry—shown in Fig. 1.

Specialized skills are required to carry out the maintenance job in O&G industry. Shortage of manpower, Manpower training in specialized repair in maintenance field and new investment is very low.

Most companies feel that all activities of preventive maintenance are not fruitful some of them are waste (according to statement of Mr. Benedict Hearken, Director Norway Energy Partners on cost-efficient solutions) (i) 40% of preventive maintenance cost have negligible effect on uptime failure, (ii) 30% of preventive maintenance activities are carried out too frequently and (iii) 45% of all the maintenance efforts are ineffective.

4 Today's Maintenance Strategy and Their Challenges

As stated in paragraph 3.0 majorly preventive and breakdown maintenance are carried out and nowadays TPM, TQM, BCM, RCM, etc., are also quite popular and industry is implementing these new type maintenance models slowly.

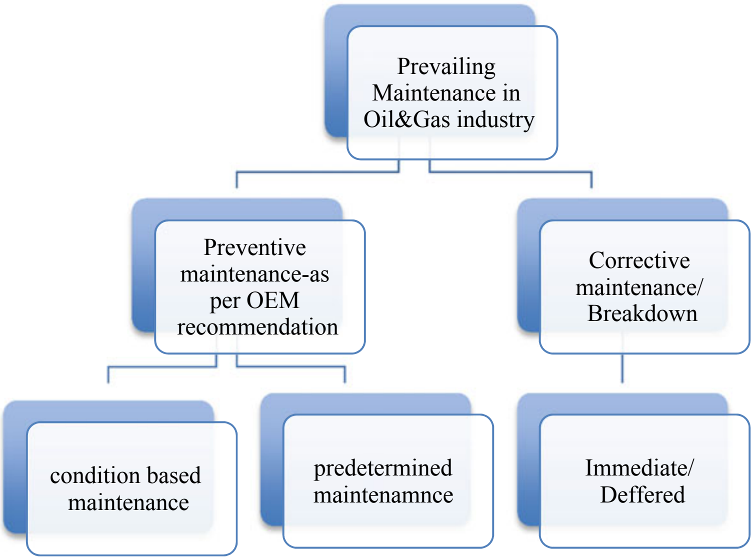


Fig. 1 Various types of prevailing maintenance practice

In present time in Oil and Gas Industry, many maintenance strategies have been formulated and applied. However, all these maintenance strategies are developed to optimize the uptime of a system by choosing a suitable maintainability plan 'believed' to enhance the availability of such system. These maintenance strategies include; Total Productive Maintenance (TPM), Business Centered Maintenance (BCM), Total Quality Maintenance (TQM), Reliability Centered maintenance (RCM) and implementation of such type maintenance is difficult.

Key performance indicators in terms of technical performance are.

(i) There is no link between maintenance KPIs and business KPIs
(ii) There was no resultant action plan-for below target
(iii) SAP base CMMS is already in use however critical information and accurate data are still not available.

Challenges:

(i) Business needs innovations due to higher maintenance cost and breakdowns.
(ii) Maintenance management is shifting from repair to reliability-focused culture.
(iii) Failure records are not documented.
(iv) Lack of management support.
(v) Maintenance manpower is not trained.
(vi) There is no proper maintenance planning and scheduling.

5 Structured Maintenance Reliability Program (SMRP)

A structured maintenance reliability program is needed for effective maintenance and reliability. Different maintenance strategies have been studied as described below to implement in industry. Every maintenance strategy has its Pros and Cons so choosing the one is very difficult. Through SMRP, we want to achieve higher availability, low maintenance cost, optimum performance of system/equipment, etc. The objective is to focus on following seven principles through "maintenance monitoring" for the reliability and availability of equipments. The primary objective is to preserve operational function of equipment and system by adhering to time-bound maintenance and overhauling of equipment, Adaption of new technology and replacement of inefficient, obsolete and unreliable equipment to get competitive advantages and environment protection, Corrective and predictive maintenance of equipment based on condition monitoring of the equipment and emphasizes on zero delay between problem creation and manifestation. Root cause failure analysis of all critical equipment is essential so that reoccurrences of failure can be arrested.

Maintenance of equipment is essential to restore its functions and efficiency to design standards. Maintenance is a risk mitigation activity and failure of equipment can pervade multiple types of risks. Maintenance monitoring envisages for alignments of resources to those activities where chances of failure is more and thereafter impact is very high. Sole purpose of maintenance monitoring is to align all resources with the help of stakeholders in achieving "vision" and "mission" of the company through equipment availability beyond 95% and system availability 100%.

Our aim is to be world class, swift, proactive, innovative and cost consciousness maintenance program. This demands an effective and efficient management by keeping in mind Concept of life cycle management and Concept of TPM-emphasizing.

SMRP is developed by improving maintenance management system consisting of following factors:

- Critical equipment identification
- Equipment and system availability
- Failure analysis
- Preventive maintenance program implementation and compliance
- Spare parts identifications and inventory control
- Choosing the option whether the activity should be carried out in-house or outsourcing by analyzing properly.
- Identification of maintenance bottlenecks and seek solutions to improve availability.

Identification and eliminating low-value activities are also essential because this is also a way of cost-saving. Ex of low-value activities are

(i) Maintaining redundant equipment.
(ii) Carrying out maintenance and inspection of machinery too frequently.

(iii) Carrying out maintenance and inspection manually that could be done online.
(iv) Deployment of excessive manpower.
(v) Over storing of inventory.

Proposed maintenance strategy in Cairn India Ltd (M/s Vedanta): performance management/maintenance management their philosophy is: Implementation of Asset performance system to digitalize maintenance processes by critically analysis, reliability centered maintenance, risk-based inspection, monitoring health of assets and changing maintenance strategies. Three maintenance models are found to be popular (1) TPM, (2) CBM and (3) RCM (Reliability centered maintenance). Reliability-based structured maintenance program will reduce downtime and increase profitability.

5.1 Maintenance Planning and Scheduling

Planning: means activities are documented. Resources are allocated to execute the task. Requirement of material and consumables are identified and provided. Safety concerns are also identified and eliminated.

Scheduling: The aim of scheduling is flow less and efficient maintenance execution that will ensure optimum equipment availability and optimum production. Planning and Scheduling go hand in hand and involvement of all stockholders are also essential. Breakdown can be avoided if inspection and maintenance are done judiciously with proper planning and scheduling.

During designing of SMRP first, we should focus on planning and scheduling then execution that will ensure proper and effective maintenance of equipment and machinery and minimize breakdown. If we plan properly, requirement of manpower will be less, and it can be assured that preventive maintenance is done on time and all safety rules are followed.

At this stage:

(i) Develop a maintenance policy
(ii) Develop a maintenance strategy
(iii) Implement a maintenance management framework
(iv) Allocate maintenance resources
(v) Develop a maintenance program/plan
(vi) Outline a maintenance plan
(vii) Develop a basis for maintenance performance measurement.

5.1.1 Reliability Centered Maintenance (RCM)

Reliable components/equipment makes the system reliable. "To develop an effective RCM program, knowledge of reliability and maintainability of the system and its components are required" [2]. MTTR (Mean time to repair), failure rate of facilities, MTBF (Mean time between failure) are some basic parameters required to calculate reliability of system. Nowadays so much software are available in the market that can calculate reliability directly. Application of RCM benefits in the form of effective maintenance program in accordance with operational and economic optimization, safety, environment, etc.

Reliability is a critical issue in capital-intensive operations. In RCM, asset to fulfill its intended function in best operating condition, part of the machinery to perform in the intended way. The main objectives of RCM are (i) To find out maintenance requirement (ii) Low-cost maintenance. Reliable equipment means working on optimum capabilities at low cost. It is assumed that production facilities produce optimally.

Reliability reduces the issues, leading to reduced breakdown maintenance and more uptime. The seven basic questions which entail the RCM method are given here by Anon [1]: (i) present operating condition and performance standard of the system, (ii) why it is unable to perform, (iii) failure causes against each function, (iv) result and consequences of failure, (v) effect of each failure in terms of operational and economic parameter, (vi) prediction or prevention method against each failure and (vii) Remedial measures after findings. Figure 2 shows the relation with correctness and reliability.

Another role of reliability engineer is to manage risk and to reduce risk.

(i) Preliminary hazard analysis (PHA)
(ii) Failure modes and effect analysis (FMEA)
(iii) Criticality analysis (CA)
(iv) Simplified failure modes and effects analysis
(v) Analysis of fault tree
(vi) Analysis of event tree
(vii) Maintainability information.

Important capabilities of reliability engineers are

- To manage asset life cycle
- Asset planning in best way
- To minimize cost of labor force- both in house and outsourcing.

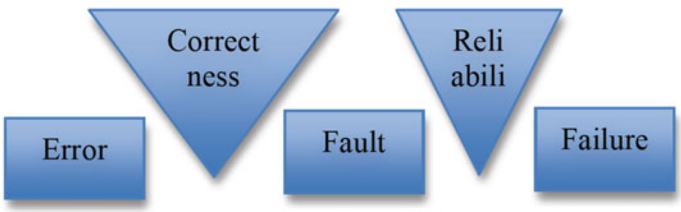


Fig. 2 Relation with correctness and Reliability

5.1.2 Performanme-Based Maintenance (PBM)

Performance of equipment after maintenance is very much essential that effect production and profitability of company. Here performance reliability is assured based on assessing the condition of system and requirement of processes, past data. Important components of plant-based maintenance (PBM) are (i) trained manpower, (ii) properly designed maintenance system and processes, (iii) consistent orientation toward organization and maintenance objectives and (iv) maintenance quality and time. PBM is also alternate way of outsourcing maintenance and it is observed that condition-based maintenance is not suitable for degraded system. May be that system works normally even if the health of machinery indicates failure thresholds. PBM model can reduce maintenance costs as compared to condition-based maintenance and preventive maintenance. PBM can be modified into TPM (Total productive maintenance). Benefits of PBM are (i) minimum shutdown, (ii) low maintenance cost, (iii) maximum life cycle of equipment, (iv) better information management system and (v) performance degradation can be arrested by applying proactive actions or measures.

PBM is just like a contract when performance up to mark or higher is rewarded otherwise penalty for lower performance. Sometimes it works as combo of preventive and proactive maintenance.

5.1.3 Business Centered Maintenance (BCM)

There is no business culture in the area of maintenance. Maintenance is associated with cost, production loss, sales, etc., that makes maintenance a business center. This is a cost-effective model with taking care of all safety requirement. BCM align maintenance function with business house objectives or business objectives can be translated into maintenance objectives. Main disadvantages of BCM are (i) complexity and (ii) extensive need for data. Main principles are "Greater autonomy to operator. This is developed from TPM. Profitability is key parameter of BCM. Elements of this technique are proactive actions, preventive maintenance, skilled manpower on job, etc., TPM, TQM, RCM are also the part of BCM. This method is difficult to implement practically.

5.1.4 Repair Policy

Failure cannot be avoided even preventive maintenance is done religiously. There may be so many reasons for failure such as improper operations, overloading, substandard material, unskilled manpower, etc., therefore in SMRP it is required to frame repair policy. That may be different for different equipment. If equipment is of critical then repair policy should be displayed on equipment so quick action can be taken. Repair policy has so many parameters/components (1) Requirement of sub-contractor? (2)

In house or outsource/OEM repair? (3) Whether equipment should be repaired immediately or later on? (4) Requirement of cranes/logistics/tools/tackles and (5) Repair or replacement. Generally, OEM provides repair methods/SOP for all critical equipment. In oil and gas industry there is a concept of standby machines where ever it is possible so pressure of immediate repair is reduced to some extend and get some limited time to get the help of experts and operations go continuously without any interruption.

5.1.5 Replacement Policy

Every equipment/machine has certain life so after completion of life it is required to replace or sometimes due to technical advancement it is also required to replace. Accident/damage of equipment also may be one of the reasons for replacement. Government regulations also advice some time to replace the machinery. Replacement can be extended on the basis of condition monitoring recommendations. Replacement requires huge cost so business objectives, future of business, new technology, balance sheet, etc., are considered before replacement. Replacement policy cannot be same for all type businesses for ex life of engine is fixed 15 years and life of firefighting equipment is fixed 10 years.

5.1.6 Turnaround Maintenance

In order to guarantee or at least maximize safety, oil installation is shutdown to maintain machines that cannot be properly inspected, repaired, replaced or overhauled during normal operation/running of the plant. This type of maintenance is called “Turnaround”.

5.1.7 Inventory Management

Inventory affects the working capital of the company so small quantity of spare parts stock is always desirable. Inventory stock depends upon criticality of spares. To keep the right stock XYZ and EOQ methods should be followed. Providing right material at the right time without blocking large amount of money and idle stock for prolonged time is not desirable.

Higher inventory means blockage of money so it is never desirable other side inventory (spares + consumables) are required to maintain the facilities so a balanced way should be adopted. Ordering of spares parts and consumables for future failure/requirement/breakdown require high skill and experience otherwise there will be fear of over inventory or under inventory.

5.1.8 Computerized Maintenance Management System (CMMS)/SAP System

CMMS-is a maintenance cost control tool

Computers are used for storing data/history/plan/analysis of data in e-form. These details are basic requirement for implementation of SMRP. CMMS has been replaced by SAP and this is uniformly applied to all installations/rigs, etc., in whole organization. This is a plethora of statistical data. Accurate statistical data and performance reports are maintained. CMMS will enable to look all things such as maintenance work and cost, overall performance level of maintenance team, which assets are costing the most and why, which one of location (facility is performing the best or worst and why).

5.2 CMMS Capabilities

(i) Work order generation
(ii) Prioritization and tracking of equipment/components
(iii) Tracking of work orders
(iv) Tracking of scheduled/unscheduled activities
(v) Sorting of maintenance procedure
(vi) Real-time report of ongoing activities.

5.2.1 Drone Inspection

New advances in artificial intelligence has taken place and nowadays Drones and Robots are playing active part in modern maintenance Around 80–90% of the assets used in Oil and Gas and Petrochemical industry is static—that is, tanks, columns, heat exchangers, coolers, pipeline for transportation, flare line, valves, etc., it is obvious that chance of failure of static equipment also there that can be prevented by regular inspection and monitoring through drone. Drone is also used for acquisition of data that can be used for different studies and this data are also useful for maintenance team to decide and act of maintenance activities according to SMRP to arrest failures. There are so many benefits of drone-based inspection and maintenance.

(i) No human error
(ii) Quick and fast result in shorter time
(iii) Accurate result in data collection
(iv) Easy access of object where technician cannot go
(v) Versatile and flexible
(vi) Decreasing shutdown of equipment
(vii) Identify the defects and the rate of failure
(viii) Improved safety and minimum no accidents

(ix) Improve facility/equipment reliability.

Low-cost operation

5.2.2 Energy Audit and Technical Audit

Auditing is also essential to know whether we are achieving objectives or maintenance excellence. Energy audit and technical audit contribute to its vision of equipment life cycle management with focus on operation and maintenance of equipment and compliance to approved policies of the company. Each audit has its unique scope, coverage to collect various information from oil installation, its interpretation and result in the form of observation.

Energy Audit

The scope of audit included: efficient use of energy in any form, undertake energy conservation campaign and activities, use of waste heat recovery systems, encourage use of nonconventional sources of energy, use of energy-efficient equipment/devices, etc.

Technical Audit

Technical audit has emerged as one of the most effective tools for management to monitor the health, performance and efficiency of equipments and initiate necessary action in time for corrective action.

Type of observations: repair/replacement**, safety, overhaul, preventive** maintenance**, test** and inspection**, corrosion** and painting**, housekeeping, documentation** and others.

5.2.3 Life Cycle Management and Cost

Life cycle of equipment is considered from the day of installation to the last of functioning. The definition of life cycle cost as per U.S. Department of Energy is as follow:

"The sum of all direct, indirect, recurring, nonrecurring, and other related costs incurred in the planning, design, development, procurement, production, operations and maintenance, support, recapitalization, and final disposition of real property over its anticipated life span for every aspect of the program, regardless of funding source."

Life cycle costs have two components ownership and operating cost. Sometimes it is cost-effective to replace the equipment rather than repair. New equipment solution: If maintenance cost is more than 50% of equipment cost then it is better to replace the equipment. This condition is called BER (Beyond economic repair). Life cycle costing is an analytical tool that can be used in minimizing waste and energy. The interest rate, fuel price volatility, etc., impact on life cycle cost. Life cycle cost also depends on equipment reliability and maintenance type selected.

Component of Labor cost has the maximum contribution in maintenance cost of oil field equipment and facilities because most of the operations are in offshore even in onshore equipment are scattered. It is seen that

(I) Proportion of time spends on preventive maintenance: 70%.
(II) Proportion of time spends on corrective maintenance: 30%.

This cost can be reduced by proper training of departmental candidates.

6 Best Maintenance Practices

To be followed for reliability and reducing cost of maintenance. Following technics should be part of best maintenance practices.

- Digitization and use of latest IT tools for economy and efficiency/Intelligent control for improved reliability and greater precision.
- Referencing and use of SOP (Standard operating practices).
- Video conferencing and feedback.
- Online adoption of national/international codes/standards.
- Interactive sessions: for formulation of specifications, norms, policies and guidelines.
- Use of advanced material that can perform for longer time without deterioration.
- Highly skilled manpower/multidisciplinary knowledge persons can give best result.

Organizations such as ISO, API, ANSI, ASME and CSA with regards to developed standards, specifications, guidelines and recommended procedures for design, operation, inspection and maintenance of Oil and Gas static assets such as piping, valve assemblies, tanks, communication towers as well as moving assets such as tankers, vessels and cylinders. These guidelines enable the operators of these static and moving assets to achieve reliable and sustainable facility operations while taking care of the regulatory and obligatory requirements.

Maintenance KPI is essential to judge the best maintenance practices.

- Life cycle cost/replacement value
- Average inventory value
- Preventive maintenance time/total time for maintenance
- Total maintenance cost/total turnover
- Break down and repair time/total time for maintenance
- Planned maintenance time/total time for maintenance
- Running hrs of equipment/total available hrs
- Overall performance of equipment

OUTCOME: From the experience and according to statement of Mr. Benedict Hearken, Director Norway Energy Partners on cost-efficient solutions, following type savings are possible through SMRP.

(i) Reduction in maintenance cost up to 25%
(ii) Elimination of breakdowns up to 60%
(iii) Reduction in downtime upto 40%
(iv) Reduction in unplanned/outages upto 40%
(v) Reduction in capital investment by 3–5%
(vi) Total spend on preventive maintenance can be reduced upto 40%.

Total preventive maintenance hours can be reduced.

7 Conclusion and Findings

Operation in Oil and Gas industry is of continuous nature and safety is of prime importance. In an oil installation, major equipments are storage tank, heater treater, air and gas compressors, oil dispatch pumps, DG set, fire pump, turbines, etc. There are many factors to consider while considering life cycle management and cost reduction in maintenance. This paper presents the key issues of maintenance, prevailing and present style of maintenance and prescribed methodology follow in justifying importance of life cycle management and cost reduction in maintenance. Key business driver should be:

(i) Improve availability of Assets (downtime reduction)
(ii) Increase operational efficiency
(iii) Cost-effectiveness to meet cost reduction.

7.1 Findings

The findings of equipment failure on an oil installation can be divided in two parts.

Technical Aspects

Oil Dispatch pump is a critical equipment in Oil and Gas industry and failure/stoppage of pump means no or less dispatch that means Refinery cannot work on full capacity and obligation of agreement cannot be fulfilled and from available data/past history, it is observed that only 18% pumps have an age-related failure and 82% failure appear randomly. The data collected is for the period of 2015–2018.

Total population of pumps are 200 and sample data of 40 pumps were collected and observed 16 No's repair incidences. The MTBF would be 40/16 = 2.5 years. According to preface of pump user's handbook (ISBN 0-88-173-575-5) of the 2006 alludes to pump failure statistics. For a well-managed and reasonably reliability focused of US refinery with 2400 installed pumps and 312 failure repair incidences in a year and the MTBF would be 2400/312 = 7.7 years.

During data analysis, it is observed that oil dispatch pump failure was the highest however stand by pump is available and pump run one by one and change over takes place after every 12 h. so further study was carried out with the help of Pareto chart and it was observed that 75% of the defects causes due to bearing failure, mechanical seal leakage and poor material of components.

Financial Aspects

After compilation of result for one pump, financial aspect of the matter was investigated, and it was found that

- cost of bearing failure in a year Rs. 28,000/-
- cost of seal failure in a year Rs. 6.00 lakhs
- cost of material failure in a year Rs. 4.0 lakhs
- cost of other type failure Rs. 2.8 lakhs.

cost of pump is approximately Rs. 80.00 lakhs and Rs. 39.00 lakhs has been spent since commissioning in the last 03 years and life of the pump is 15 years. Hence there is a need to review the maintenance strategy and follow the SMRP. Here maintenance methods were reviewed and structured, focused on online monitoring of pump parameters and immediate corrective action in case of any deviation and technicians were given special training for seal fitment. After that obtained higher reliability and reduction in maintenance cost.

References

1. Anon, M.A.: CMMS Online (Aug 2015) retrieved from https://www.maintenanceassistance.com/about-us/our-history [Accessed 2 August 2015].
2. Moubray, J.: Butterworth heinemann, reliability centered maintenance, quality and reliability engineering international, **8**(1), 75(1991)

Six Sigma with Optimization and Probability Models in Healthcare Management

S. Madhura Mokana and O. S. Deepa

Abstract A population of rapid growth, a place of the booming economy, whistle-stop urbanization along with disease escalation requires persistent improvement in healthcare services. However, delays, medical errors, measurement errors and variability weaken the coherence of healthcare, which increases the pressure in redesigning the process for quality improvement. In this paper, Six sigma is implemented for selecting the parameters in health care management. Then optimization based on nonlinear programming is performed for minimizing the total cost in bed scheduling, where the constraints depend on the budget spent, types of doctors, the technicians, the medical equipment, etc. It also aims to minimize the total cost associated with packaging medications and emergency department allocation. Optimized results showed that the emergency department has to be taken care in order to gain a superlative performance of healthcare maintenance. Hence the usage of probability models based on Poisson regression has been imposed on bed occupancy of the emergency department by considering the number of arrivals and the number of departures of patients on specific days. The results are then examined using DMAIC techniques and are found to be under control using an exponentially weighted moving average chart. The computational behavior, the efficiency of the proposed model and the practical applicability is exemplified by a case study. This novel methodology of integrating six sigma with optimization techniques and probability models has gained a strong potential success related to cost reduction, increase in patient satisfaction and enables continuous monitoring of health care service, thereby promoting economic sustainability.

Keywords Six sigma · DMAIC techniques · Nonlinear programming · Emergency department and probability models

---

S. Madhura Mokana · O. S. Deepa (✉)
Department of Mathematics, Amrita School of Engineering Coimbatore, Amrita Vishwa Vidyapeetham, India
e-mail: os_deepa@cb.amrita.edu

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_12

1 Introduction

To lend a hand in reducing waste and improving quality care, several hospitals use Six Sigma tools. SS is an efficient data-driven procedure with the intention of dropping down the process variation. Process variation naturally reduces energy consumption, reduces cost, reduces defect, reduces workflow variability and reduces scrap which in turn leads to eco-friendly environment. Six sigma has been a powerful management strategy across all services. It also focuses on rapid and robust improvements. Six sigma concentrates on the performance of the process and process flow improvement. There is much increasing pressure on the health care industry due to competitive priorities and resource constraints, which has made researchers focus on continuous improvement practices throughout the globe [1–4]. Only a few documented research was done integrating optimization and six sigma in health care, and hence this paper tries to fill in the gaps by providing a case study, thereby increasing patient satisfaction and an overall improvement in health care performance. This paper identifies the key performance measures like efficacy in public health service, expanding public health challenges and optimizing resources utilization, including the waiting time, length of stay, increased capacity, increased staff morale, patient satisfaction, patient-centric service levels, medical quality and cost reduction. Leading private hospitals are acknowledged as world-class hospitals and are considered as one of the competitors and are expected to increase their performance by the usage of six sigma with the combination of optimization and probabilistic models together [5–7]. Control charts are used to check whether the system is in control or not. Control charts have been extensively used in an attribute sampling plan and variable sampling plan and are most commonly used in industries to monitor the production process [8–12]. The fuzzy Interpretive Structural Modelling (FISM) approach has been used to analyze the interrelationships among health care factors. Information on the health care system in Germany with a focus on mental health care in people with intellectual disabilities was studied. The study of assessing the availability of health services and the prevalence of chronic conditions among MSFWs in Indiana was done recently [13]. Even bid data analysis technologies have been made for the evaluation methods of physical and mental quality of middle school students, for personalized exercise programs and for the implementation of physical and mental quality monitoring [14, 15]. A large-scale study has been made for Cyprus and Greece, exploring the level of satisfaction among third-country nationals (TCN) in relation to their health care needs [12]. The application of lean six sigma has been used to reduce medication errors [8]. Even health care studies have been made in Germany based on their intellectual disabilities [3], the lean manufacturing process has been done in the emergency department [2], six sigma has been implemented to improve medical tourism [14], enhancing service quality of a healthcare organization through lean six sigma methods, improving the hospital discharge process with six sigma methods [16–22].

There are few challenges that raised the implementation of six sigma with the probability models and optimization is:

1. Nonexistence of resources to meet the demands of the patients
2. Increase in population growth

3. Insufficiency of hospital infrastructure
4. Decrease in medical storage
5. Probable wastage of storage
6. Supply chain with a high level of system uncertainty
7. Collective cost of logistics increasing rapidly
8. Limited access to technological resources in hospitals.

So, the DMAIC methodology has been implemented to find the root cause of the problems arising in the health care system.

1.1 Define

The hospitals which are taken for our case study are defined, such that comprises all the necessary details to be given for solving. All the necessary data are collected from the doctors and the laborers of the hospital. The objective functions are modeled and data collected is analyzed by the usage of optimization.

1.2 Analyse

Few hospitals are chosen in Coimbatore City in such a way that it has all the necessary equipment's and the patients are not to be subjected to relocation. The doctors in these hospitals were consulted and the following four objective functions are modeled. In this paper, two major departments, namely the orthopedic department and gynecology department, are taken.

1.3 Measure

1. *Minimizing total cost (emergency department bed schedule)*

$$\min \text{ total cost } \sum_{i\in I} c_{d_i}(\mathrm{ND}_i + \mathrm{NDA}_i) + \sum_{i\in I} c_{n_i}(\mathrm{NN}_i + \mathrm{NNA}_i) + \sum_{i\in I} c_{t_i}\mathrm{NT}_i + \sum_{i\in I} c_{b_i}(\mathrm{NB}_i + \mathrm{NBA}_i) + \sum_{i\in I} c_{w_i}\mathrm{NBA}_i + \sum_{i\in I} \mathrm{cm}^i\mathrm{NM}^i$$

such that

$$\mathrm{ND}_i + \mathrm{NDA}_i \le \mathrm{md}_i, \quad i \in I$$

$$\mathrm{NN}_i + \mathrm{NNA}_i \leq \mathrm{mn}_i, \quad i \in I$$

$$\mathrm{ND}_i + \mathrm{NDA}_i \geq \mathrm{NT}_i, \quad i \in I$$

$$\mathrm{NB}_i + \mathrm{NBA}_i \leq \mathrm{mb}_i, \quad i \in I$$

$$\sum_{i \in I} c_{d_i} \mathrm{ND}_i + \sum_{i \in I} c_{n_i} \mathrm{NN}_i + \sum_{i \in I} c_{t_i} \mathrm{NT}_i + \sum_{i \in I} c_{b_i} \mathrm{NB}_i + \sum_{i \in I} c_{w_i} \mathrm{NBA}_i + \sum_{i \in I} \mathrm{cm}^i \mathrm{NM}^i \leq f_i, \quad i \in I$$

where $\mathrm{ND}_{i,}$, NDA_i, NN_i, NNA_i, NT_i, NB_i, NBA^i, NM_i denotes the number of: doctors, added doctors, nurses, added nurses, technicians, beds, added beds, medical equipment in department $i \in I$ respectively.

c_{d_i}, c_{n_i}, c_{t_i}, c_{b_i}, c_{w_i}, cm^i denote the cost of: doctors, nurses, technicians, beds, waiting cost of doctors, operate medical equipment in department $i \in I$ respectively.

md^i, mn^i, mb^i denotes the maximum number of doctors, nurses, beds could be allocated for a department $i \in I$.

f_i denotes a maximum fund that is available for a department $i \in I$.

2. *Minimizing total cost (Operation Room allocation)*

$$\min \alpha \sum_{i \in I} a_i + \beta \sum_{i \in I} b_i + \gamma \sum_{i \in I} d_i + \delta \sum_{i \in I} v_i + \sum_{i \in I} u_i$$

such that

$$\sum_{i \in I} x_i \geq \sum_{i \in I} (e_i - y_i + a_i + b_i)$$

$$\alpha \sum_{i \in I} a_i \leq \sum_{i \in I} n_i$$

$$\beta \sum_{i \in I} b_i \leq \sum_{i \in I} m_i$$

$$\gamma \sum_{i \in I} d_i \leq \sum_{i \in I} n_i$$

$$\delta \sum_{i \in I} v_i \leq \sum_{i \in I} m_i$$

$$\sum_{i \in I} k_i - t\left(\sum_{i \in I}(n_i + m_i)\right) = o_i - u_i$$

$$\sum_{i \in I} x_i \leq c_i$$

$$y_i \leq e_i$$

where

- x_i denotes the number of operating rooms allocated to a department "i"
- y_i denotes the amount of department "i"'s emergency surgery demand to be met in the emergency operating room
- a_i and b_i denote department "i"'s inpatient and outpatient demand postponed from day to the next day, respectively
- d_i and v_i denote department "i"'s unmet inpatient and outpatient demand
- k_i denotes the amount of idle time of operating room allocated for a department "i"
- t denotes the total amount of idle time of non-emergency operating rooms
- c_i and e_i denote the maximum and daily number of the emergency operating room for a department "i" in a day, respectively
- n_i and m_i denote total inpatient and outpatient arrivals approximately, respectively
- o_i and u_i denote oversupply and undersupply of operating room hours for a department "i", respectively

$$\alpha : \begin{cases} 1, & \text{if no side effects of postponement} \\ 0, & \text{otherwise} \end{cases}$$

$$\beta : \begin{cases} 1, & \text{if no side effects of postponement} \\ 0, & \text{otherwise} \end{cases}$$

$$\gamma : \begin{cases} 1, & \text{if no side effects of postponement} \\ 0, & \text{otherwise} \end{cases}$$

$$\delta : \begin{cases} 1, & \text{if no side effects of postponement} \\ 0, & \text{otherwise} \end{cases}$$

3. *Minimizing the deviations from target hours*

$$\min \sum_{j \in J} \frac{s_j}{h_j}$$

such that

$$s_j \leq u_j$$

$$\sum_{i \in I} \sum_{j \in J} x_{ij} \leq a_i$$

$$s_j \geq h_j - \sum_{i \in I} \sum_{j \in J} d_i x_{ij}$$

where

- s_j denotes the number of under-allocated hours in department "*j*"
- x_{ij} and a_i denote the number of types of room "*i*" assigned to a department "*j*" and available in a day, respectively
- u_j denotes the maximum number of under-allocated hours allowed in a department "*j*"
- h_j denotes ideal target hours for a department "*j*"
- d_i denotes the duration of availability (in hours) of room type "'*i*" in a day.

4. *Minimizing total cost which is associated with packaging medications*

$$\min \sum_{a \in A} \sum_{m \in M} c_m^a \left(\frac{n_m}{d_m^a} \right) x_m^a + \sum_{m \in M} n_m y_m + \sum_{a \in A} i^a x^a + \sum_{a \in A} 52 l t^a$$

such that

$$y_m^a \leq x^a$$

$$\sum_{m \in M} x_m^a \leq c \sum_{m \in M} \sum_{a \in A} \frac{n_m x_m^a b_m^a}{d_m^a} + \sum_{a \in A} 52 t^a x^a \leq 3000E$$

where

- n_m and $d_m{}^a$ denote the average number of packages of medications "*m*" that is needed for a year and repackaging using an alternative "*a*" for medication "*m*," respectively
- l denotes labor amount for a pharmacy technician for an hour
- E and c denote the total number of employees available for repackaging and containers available for the storage of medications, respectively
- t^a and $b_m{}^a$ denotes time spent in maintaining the alternative "a" per week (in hours) and packaging the medication batch using an alternative "*a*," respectively
- x^a, i^a and $c_m{}^a$ denote cost of: alternative used for the medication, infrastructure initially invested for alternative and package of medications "*m*" using an alternative "*a*" (in hours), respectively.

$$x_m^a : \begin{cases} 1, & \text{if hospital uses alternative} \\ 0, & \text{otherwise} \end{cases}$$

$$y_m : \begin{cases} 1, & \text{if hospital invests in alternative} \\ 0, & \text{otherwise} \end{cases}$$

The above optimization model is a general case. The constraints can be increased according to the needs of hospital management. As a case study, the data has been collected from a hospital for a period of four months and the model is solved. The data and optimization results may vary from hospital to hospital and the authors have restricted to a hospital with two major departments, namely the orthopedic department and the gynecology department. By solving and upon consultation with the doctors and hospitals, it is found that the bed schedule in the emergency department needs to be taken extra good care. Thus, Poisson regression is done since it is a generalized linear model form that is used to model count data, and in this case study, the dependant variables are count.

2 Poisson Distribution for Arrivals and Departures in an Emergency Department

The multiple linear regression model with age, type of the room used, gender are the variables considered:

$$Y_j = \beta_0 + \beta_1 X_{j1} + \beta_2 X_{j2} + \beta_3 X_{j3} + \varepsilon_j, \quad j = 1, 2$$

where

- ε: random error
- X_{j1}: age of the patient
- $X_{j2} : \begin{cases} 1, & \text{if patient uses general room} \\ 0, & \text{if patient uses IMCU room} \end{cases}$
- $X_{j3} : \begin{cases} 1, & \text{if patient is female} \\ 0, & \text{if patient is male} \end{cases}$
- β_0: y-intercept
- $\beta_1, \beta_2, \beta_3$: coefficient value measuring a unit of the patient changes.

where X_{j1}, X_{j2}, X_{j3} changes with the age, room and gender

- E_{nr}: emergency department bed occupancy at day "n" for the department "r"
- a_{nr} and d_{nr}: number of arrivals and departures on a day "n" for the department "r"
- c_{nr}: net increase or decrease in emergency department bed occupancy during a day "n" for the department "r".

$$E_{nr} = E_{(nr)-1} + a_{nr} - d_{nr}$$
$$= E_{(nr)-1} + c_{nr}$$

E_{nr_0}: emergency department bed occupancy at the start of the day

$$E_{nr_1} = E_{nr_0} + c_{nr_1}$$

$$E_{nr_2} = E_{nr_0} + c_{nr_1} + c_{nr_2}$$

$$E_{nr_3} = E_{nr_0} + c_{nr_1} + c_{nr_2} + c_{nr_3}$$

$$E_{nr_n} = E_{nr_0} + \sum_{i=1}^{n} c_{nr_i}$$

$$c_{nr_i} = \begin{cases} > 0, a_{nr} > d_{nr} \\ = 0, a_{nr} = d_{nr} \\ < 0, a_{nr} < d_{nr} \end{cases}$$

$$P\left(c_{n_i r_i} = 0\right) = \left[P\left(a_{n_i r_i} = 0\right) \times P\left(d_{n_i r_i} = 0\right)\right] + \left[P\left(a_{n_i r_i} = 1\right) \times P\left(d_{n_i r_i} = 1\right)\right] + \cdots$$

$$= \sum_{i=1}^{2} \sum_{k=0}^{\infty} \left[P\left(a_{n_i r_i} = k\right) \times P\left(d_{n_i r_i} = k\right)\right]$$

$$P\left(c_{n_i r_i} = 1\right) = \left[P\left(a_{n_i r_i} = 1\right) \times P\left(d_{n_i r_i} = 0\right)\right] + \left[P\left(a_{n_i r_i} = 2\right) \times P\left(d_{n_i r_i} = 1\right)\right]$$
$$+ \left[P\left(a_{n_i r_i} = 3\right) \times P\left(d_{n_i r_i} = 2\right)\right] + \cdots$$

$$= \sum_{i=1}^{2} \sum_{k=1}^{\infty} \left[P\left(a_{n_i r_i} = k\right) \times P\left(d_{n_i r_i} = k - 1\right)\right]$$

$$P\left(c_{n_i r_i} = 2\right) = \left[P\left(a_{n_i r_i} = 2\right) \times P\left(d_{n_i r_i} = 0\right)\right] + \left[P\left(a_{n_i r_i} = 3\right) \times P\left(d_{n_i r_i} = 1\right)\right]$$
$$+ \left[P\left(a_{n_i r_i} = 4\right) \times P\left(d_{n_i r_i} = 2\right)\right] + \cdots$$

$$= \sum_{i=1}^{2} \sum_{k=1}^{\infty} \left[P\left(a_{n_i r_i} = k\right) \times P\left(d_{n_i r_i} = k - 2\right)\right]$$

$$P\left(c_{n_i r_i} = m\right) = \sum_{i=1}^{2} \sum_{k=m}^{\infty} \left[P\left(a_{n_i r_i} = k\right) \times P\left(d_{n_i r_i} = k - m\right)\right], m = 1, 2, \cdots \quad (1)$$

$$P\left(c_{n_i r_i} = -1\right) = \left[P\left(a_{n_i r_i} = 0\right) \times P\left(d_{n_i r_i} = 1\right)\right] + \left[P\left(a_{n_i r_i} = 1\right) \times P\left(d_{n_i r_i} = 2\right)\right] + \cdots$$

$$= \sum_{i=1}^{2}\sum_{k=1}^{\infty}\left[P\left(a_{n_i r_i} = k-1\right) \times P\left(d_{n_i r_i} = k\right)\right]$$

$$P\left(c_{n_i r_i} = -2\right) = \sum_{i=1}^{2}\sum_{k=2}^{\infty}\left[P\left(a_{n_i r_i} = k-2\right) \times P\left(d_{n_i r_i} = k\right)\right]$$

$$P\left(c_{n_i r_i} = -l\right) = \left[P\left(a_{n_i r_i} = 0\right) \times P\left(d_{n_i r_i} = 1\right)\right] + \left[P\left(a_{n_i r_i} = 1\right) \times P\left(d_{n_i r_i} = l+1\right)\right] + \cdots$$

$$= \sum_{i=1}^{2}\sum_{k=l}^{\infty}\left[P\left(a_{n_i r_i} = k-l\right) \times P\left(d_{n_i r_i} = k\right)\right], l = 1, 2, \cdots \quad (2)$$

The arrivals and departures are assumed to follow Poisson distributed and here, μ is the mean arrival of the patients and ρ is the mean departure of the patients. Hence,

$$P(m \text{ arrivals}) = \frac{e^{-\mu t}\mu t^m}{m!}, \quad m = 0, 1, 2, \ldots \quad (3)$$

$$P(l \text{ departures}) = \frac{e^{-\rho t}\rho t^l}{l!}, \quad l = 0, 1, 2, \ldots \quad (4)$$

Here, the mean μ and ρ is obtained from Eqs. 5 and 6 taking the concept of multiple linear regression as there is more independent variables in the health care system.

$$\mu = t\exp\left(\beta_1 X_{j1} + \beta_2 X_{j2} + \beta_3 X_{j3}\right) \quad (5)$$

$$\rho = t\exp\left(\beta_1 X_{j1} + \beta_2 X_{j2} + \beta_3 X_{j3}\right) \quad (6)$$

The multiple linear regression model with age, type of the room used, gender are the variables considered:

$$Y_j = \beta_0 + \beta_1 X_{j1} + \beta_2 X_{j2} + \beta_3 X_{j3} + \varepsilon_j, \quad j = 1, 2$$

where

- ε: random error
- X_{j1}: age of the patient
- $X_{j2} : \begin{cases} 1, & \text{if patient uses general room} \\ 0, & \text{if patient uses IMCU room} \end{cases}$
- $X_{j3} : \begin{cases} 1, & \text{if patient is female} \\ 0, & \text{if patient is male} \end{cases}$
- β_0: y-intercept

Table 1 Mean arrivals and departures

Days	Arrivals (μ)	Departures (ρ)
Monday	2.53	2.47
Tuesday	2.62	2.93
Wednesday	2.45	2.61
Thursday	2.39	2.54
Friday	2.56	2.87
Saturday	2.61	2.28
Sunday	2.65	2.16

- β_1: coefficient value measuring a unit change where X_{j1} changes, that is when the gender of the patient changes
- β_2: coefficient value measuring a unit change where X_{j2} changes, that is when the usage of the room by patient changes
- β_3: coefficient value measuring a unit change where X_{j2} changes, that is when the gender of the patient changes.

Table 1 shows the mean arrivals and departures. Taking the coefficients, variables into consideration and in discussion with the doctors in the hospital, the mean arrival and discharge rates for the patients on each day of a week is calculated as follows:

The maximum number of arrivals and departures of patients for the bed occupancy in the emergency department in the hospital is given to be 9 (approximately) by the doctors in the hospital.

For instance, the value of arrival on Saturday is given to be 2.6. This is because the data collected from the hospital shows that, the arrival of patients on Friday is 2, 3, 4, 3 and 2 in a month, which has been recorded. Thus, by taking the mean of all the five values (five Fridays in the month where our record is taken) 2.6 is obtained. A similar calculation holds for all the values.

$$P\left(c_{n_i r_i} = 0\right) = e^{-(\mu+\rho)}\left(h_{0,0} + h_{0,1} + h_{0,2} + \cdots\right), \quad \text{where } h_{0,n} = \frac{(\mu\rho)^n}{n!n!}, \quad n = 0, 1, 2 \ldots \tag{7}$$

Using the data collected, (7) equation is used and upon calculation, Fig. 1 shows the change in bed occupancy of the emergency department.

Thus, an increase in the bed occupancy might happen on Saturday, Sunday and Monday and a decrease might happen on Tuesday, Wednesday, Thursday and Friday.

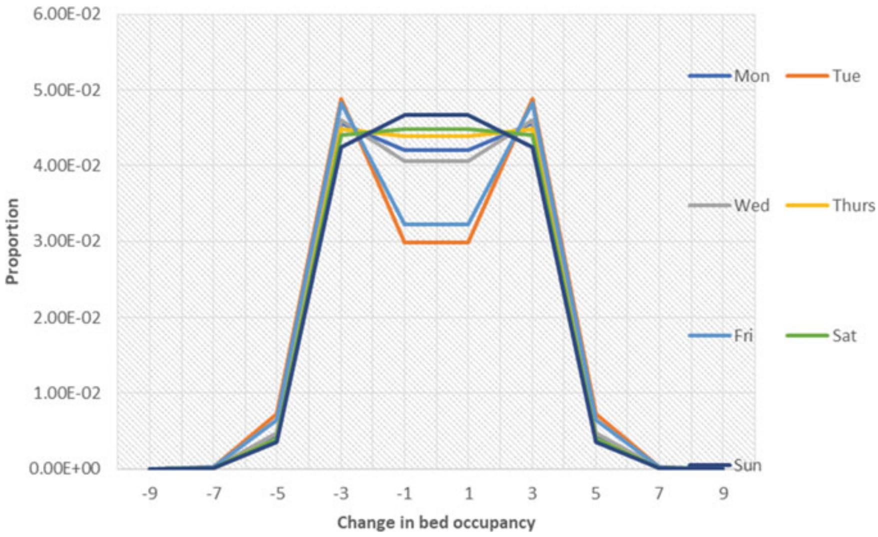


Fig. 1 Change in bed occupancy of the emergency department

2.1 Improve Phase

The arrivals and departures of the patients influence the smooth routine of the hospital. The authors and the doctors have discussed the improvement of various factors with regard to the optimization and probabilistic models.

2.2 Control Phase

The control phase is done by two methods (i) X bar chart and R chart (ii) EWMA chart. Table 2 shows the mean arrival of patients and shows the Values of the Control Limits.

(i) ***X bar chart and R chart***

The X bar chart and R chart are plotted for arrivals and departures of the patient.

Table 2 Mean arrival of patients

Week	Mon.	Tue.	Wed.	Thurs.	Fri.	Sat.	Sun.	$\overline{X}$	Range
1	2.53	2.62	2.47	2.32	2.55	2.64	2.64	2.53	0.32
2	2.52	2.65	2.43	2.37	2.57	2.63	2.63	2.54	0.28
3	2.54	2.6	2.42	2.35	2.51	2.61	2.68	2.53	0.33
4	2.51	2.63	2.45	2.33	2.56	2.66	2.65	2.54	0.33

Table 3 Values of the control limits

Standard deviation	0.005758756
CL	2.538214286
UCL	2.555490552
LCL	2.520938019

(a) *For arrivals*

A record of 4 months is collected as data from the hospital. Here, for instance, the arrival data for Monday in 4th week is given as 2.5. This is because all the Mondays of the 1st week of the 4 months is taken, that is, 1st Monday of June, 1st Monday of July, 1st Monday of August and 1st Monday of September are collected from the hospital and the data shows that the number of arrivals of patients are 2, 3, 4 and 1 on the 1st Monday of June, July, August and September, respectively. Similarly, all the values given in Table 2, are obtained.

By using the above data, calculations are done and the control charts Table 3, namely *X*-bar chart (Fig. 2) and moving range of *R* chart (Fig. 3) is obtained using SPSS software, showing that the arrivals in the hospital are under control. Table 4 shows the mean Departure of Patients and Table 5 shows the Values of the Control Limits. Figure 4 shows $\overline{X}$ chart for departures and Fig. 5 shows *R* chart for departures.

The two charts, namely $\overline{X}$ chart and *R* chart is plotted using SPSS software.

(b) *For Departures*

The values of the control limits are used to plot the graph.

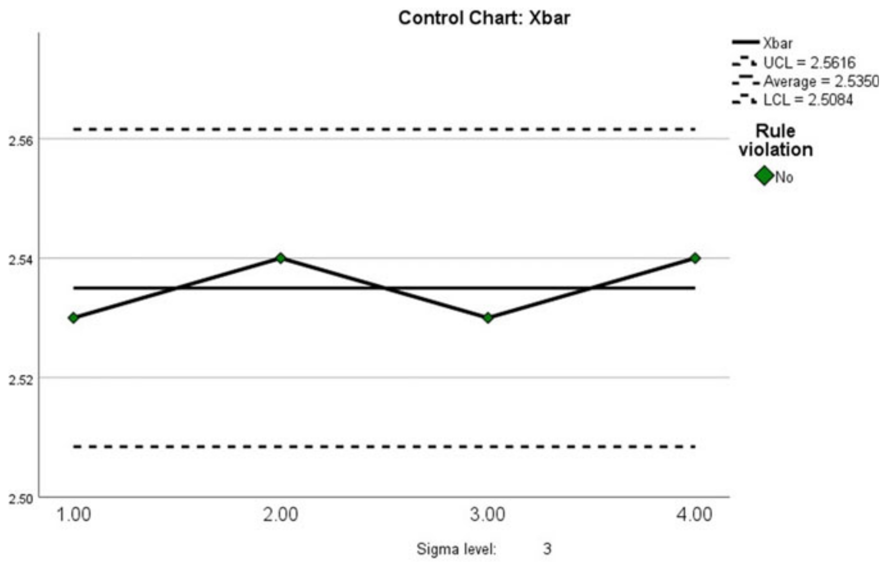


Fig. 2 *X*-bar chart

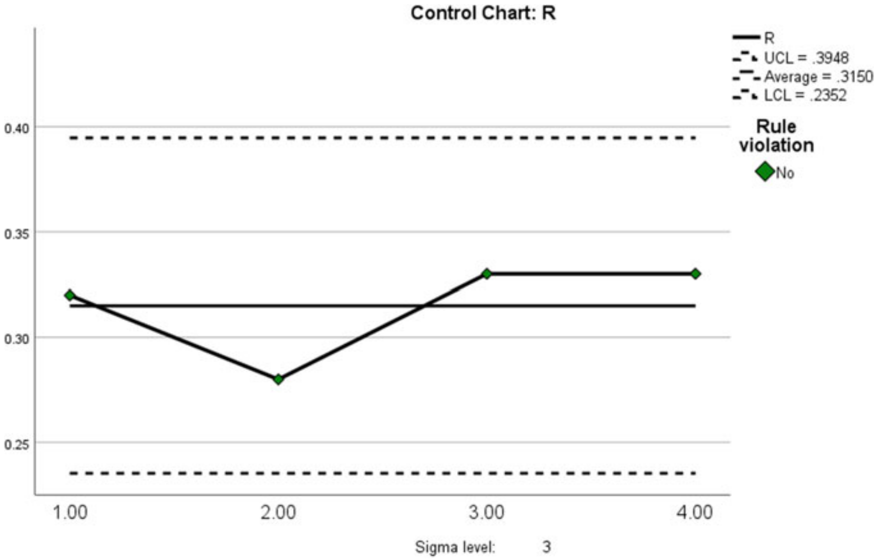


Fig. 3 *R* chart

Table 4 Mean departure of patients

Week	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.	$\overline{X}$	Range
1	2.45	2.91	2.63	2.51	2.82	2.21	2.12	2.52	0.79
2	2.43	2.98	2.61	2.53	2.88	2.28	2.16	2.55	0.82
3	2.47	2.93	2.66	2.52	2.89	2.26	2.19	2.56	0.74
4	2.41	2.96	2.68	2.54	2.87	2.24	2.1	2.54	0.86

Table 5 Values of the control limits

Standard deviation	0.016781914
CL	2.544285714
UCL	2.594631458
LCL	2.493939971

(ii) ***Exponentially Weighted Moving Average Chart***

The exponentially weighted moving average (EWMA) control charts find good applications in the field of healthcare, where it is very helpful in detecting small changes in any process.

The EWMA statistic is calculated by:

$$\text{EWMA}_t = \alpha Y_t + (1 - \alpha)\text{EWMA}_{t-1},\ \text{for time } 't' \tag{8}$$

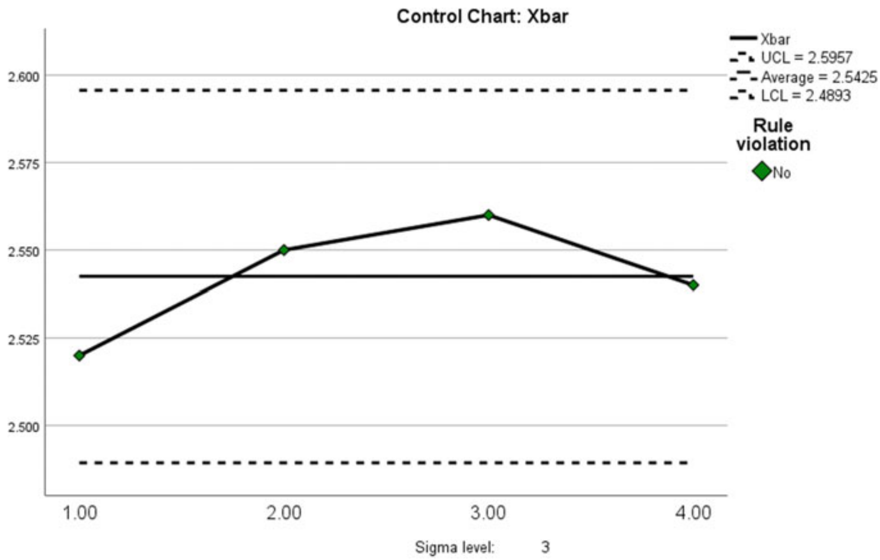


Fig. 4 $\overline{X}$ chart for departures

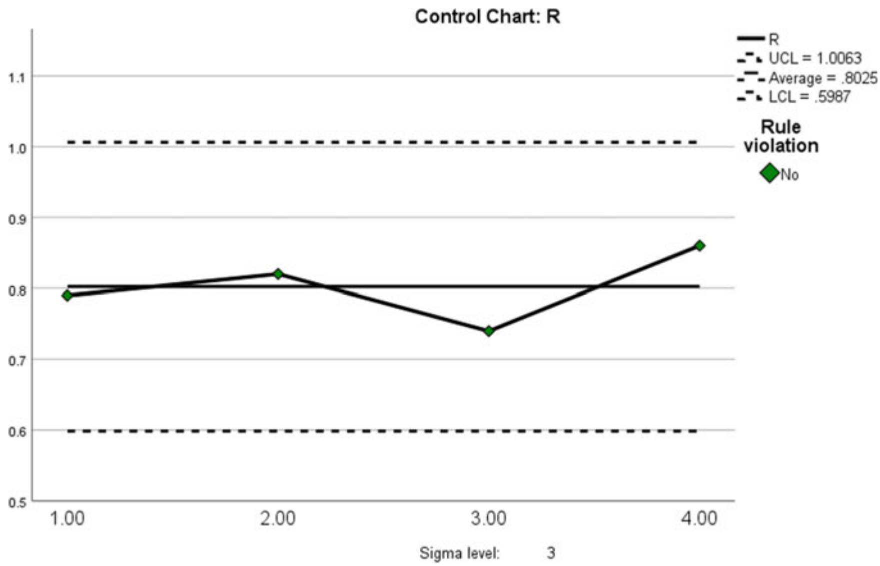


Fig. 5 R Chart for departures

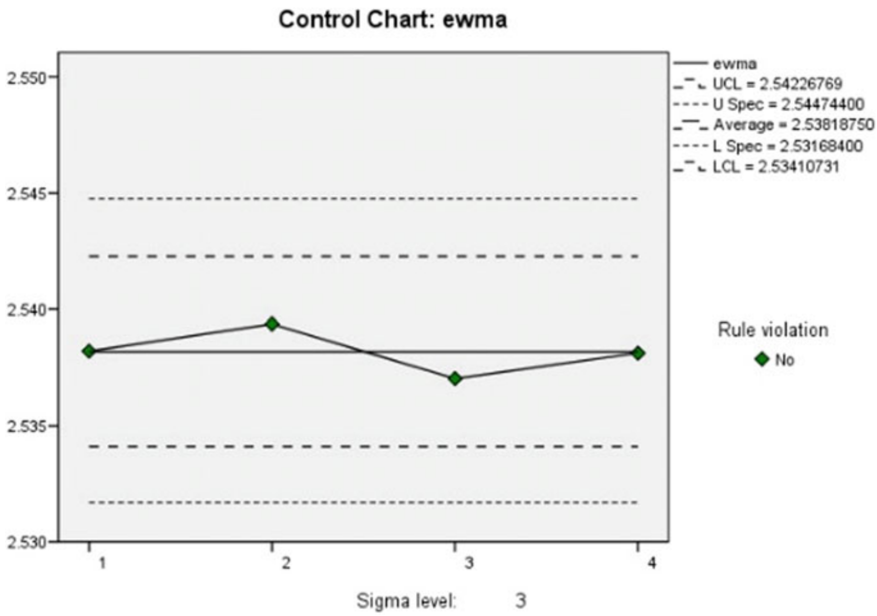


Fig. 6 EWMA chart for arrivals

where

- α is the smoothing constant (we take 0.25)
- EWMA_0 is the mean of our data
- Y_t are the observations.

The calculations are done using the data in Tables 2 and 4 and are applied in Eq. (8). The EWMA control chart is plotted using SPSS software. In the following two figures, Fig. 6 shows the EWMA chart of arrivals and Fig. 7 shows the EWMA chart of departures and thus are found to be under control.

3 Conclusions

Measuring the performance of any organization in a typical manner is a challenging job and is important for any organization in meeting the demands of the present scenario. Here, in this paper, optimization has been done for four different cases as minimizing total cost (emergency department bed schedule) minimizing total cost (Operation Room allocation) minimizing the total cost (packaging of medications) and minimizing the deviation from target hours weekly. It was found that care has to be given to the emergency department and hence on discussion with experts in the hospital, it was proposed to check whether the number of arrivals and departures

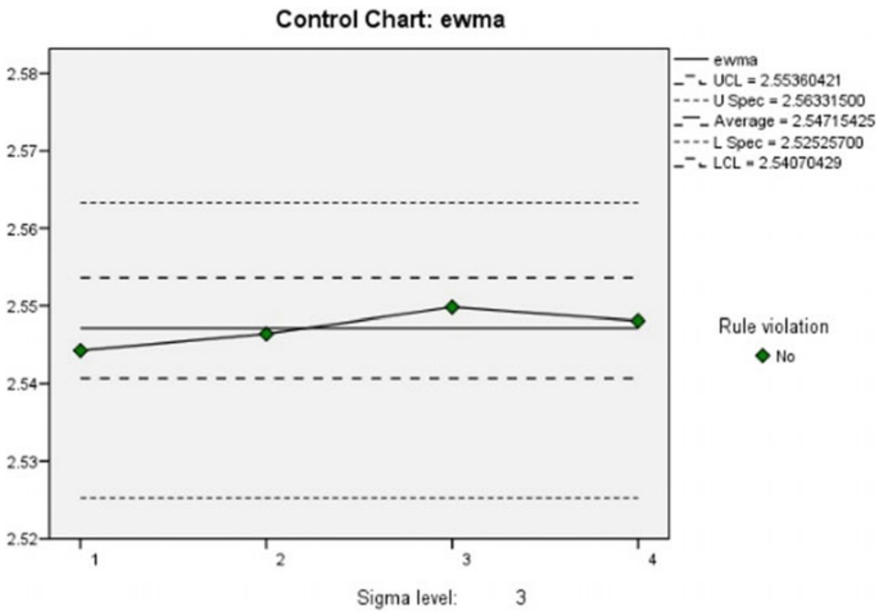


Fig. 7 EWMA charts for departures

in the bed occupancy affects the emergency department. This leads to the usage of probabilistic models using Poisson regression. Thus, it was found that there is an increase in the bed occupancy on Saturday, Sunday and Monday and a decrease on Tuesday, Wednesday, Thursday, and Friday based on the hospital data taken for the case study. Hence betterment in the section of the emergency department enhances the service quality of the hospitals. The data collected was used in calculating the arrivals and departures in the emergency department and tested the process to be in control using EWMA chart. Hence DMAIC methodology with optimization model, probabilistic model, multiple linear regression model and EWMA control charts has been explained in this paper using a hospital case study. Persistent maintenance of these proposed methodology will gain satisfaction and contentment of the patients, thereby creating a continuous improvement of the quality in healthcare.

Acknowledgements We would like to convey our hat tip to Dr. R.T. Vinod Rajkumar, Dr. SGR Hospital, for the guidance regarding data collection from the hospital.

References

1. Chen, J., Lyu, Z., Liu, Y., et al.: A big data analysis and application platform for civil aircraft health management. In: IEEE Second International Conference on Multimedia Big Data, Taipei (2016)

2. Dickson, E., Singh, S., Cheung, D., Wyatt, C., Nugent, A.: Application of lean manufacturing techniques in the emergency department. J. Emerg. Med. **37**(2), 177–182 (2009)
3. Elstner, S., Theil, M.: The health and social care of people with disabilities in Germany . Adv. Mental Health Intel. Dis. **12**(3/4), 99–104 (2018)
4. Heuvel, J.V.D,, Does, R.J.M.M,, Verver, J.P.S,: Six Sigma in healthcare: lessons learned from a hospital. Int. J. Six Sigma Compet. Adv. **1**(4), 380–388 (2005)
5. Ken, L.R., Huq, B.A.: Integrating Six Sigma and CQI for improving patient care. TQM Mag. **16**(2), 105–113 (2004)
6. Li, X., Li, Y.: Monitoring and evaluation of physical and mental quality of middle school students based on big data analysis. Electron. Sci. Technol. **32**(4), 85–90 (2019)
7. Linderman, K., Schroeder, R.G., Zaheer, S., Choo, A.S.: Six Sigma: a goal-theoretic perspective. J. Oper. Manag. **21**(2), 193–203 (2003)
8. Miglani, P.: Application of lean six sigma in reduction of medication errors. J. Multidisc. Res. Healthc. **2**(1), 55–72 (2015)
9. Deepa, O.S.: Application of acceptance sampling plan in green design and manufacturing. Int. J. Appl. Eng. Res. **10**(2 Special Issue), 1498–1499 (2015)
10. Deepa, O.S.: Optimal production policy for the design of green supply chain model. Int. J. Appl. Eng. Res. 10(2 Special Issue), 1600–1601 (2015)
11. Yan, P.: Thoughts and enlightenment of data mining application of Chinese students' physical health test. Sci. Technol. Inf. **15**(22), 199–200 (2017)
12. Phanden, R.K., Ferreira, J.C.E.: Biogeographical and variable neighborhood search algorithm for optimization of flexible job shop scheduling. In: Advances in Industrial and Production Engineering, pp. 489–503. Springer, Singapore (2019)
13. Phanden, R.K., Saharan, L.K., Erkoyuncu, J.A.: Simulation based cuckoo search optimization algorithm for flexible job shop scheduling problem. In: Proceedings of the International Conference on Intelligent Science and Technology, pp. 50–55 (2018)
14. Panagiotopoulos, C., Apostolou, M., Zachariades, A.: Assessing migrants' satisfaction from health care services in cyprus: a nationwide study. Int. J. Migr. Health Social Care **16**(1), 108–118 (2019)
15. Parasuraman, A., Zeithaml, V.A., Berry, L.L.: SERVQUAL: a multi-item scale for measuring consumer perceptions of service quality. J. Retail. **64**(1), 12–40 (1988)
16. Nair, R.P., Paul, G.: Lean Six Sigma as a panacea to improve service quality in medical tourism. Int. J. Acad. Res. Dev. **4**(6), 495–499 (2017)
17. Sandoval-Rosario, M., Hunter, T., Durnham, A., Holt, A., Pontones, P., Perry, G.: Chronic conditions and barriers to care: exploring the health of migrant and seasonal farmworkers in Indiana . Int. J. Hum. Rights Healthc. **9**(4), 229–234 (2016)
18. Hinchageri, S., Patil, N.R., Teli, S.: Application of lean six sigma approach in indian hospitals to improve patient care. World J. Pharm. Med. Res. **4**(1), 45–53 (2018)
19. Shruthi, G., Deepa, O.S.: Average run length for exponentiated distribution under truncated life test. Int. J. Mech. Eng. Technol. (IJMET) **9**(6), 1180–1188 (2018)
20. Krishnan, S.M., Deepa, O.S.: Control charts for multiple dependent state repetitive sampling plan using fuzzy poisson distribution. Int. J. Civ. Eng. Technol. (IJCIET) **10**(1), 509–519 (2019)
21. Saha, S., Nazmul Ahsan, A.M.M., Imran Mahmud, M., Bhowmick, T., Roy, H.M.: Enhancing service quality of a healthcare organization through lean six sigma methods. Int. J. Sci. Eng. Res. **4**(8) (2013)
22. Allen, T.T., Tseng, S.-H., Swanson, K., McClay, M.A.: Improving the hospital discharge process with six sigma methods. Qual. Eng. 22 (2010)

Study on Important Techniques and Processes for the Management of Waste Electrical Wires

Abhishek Kumar Gupta, Anand Kumar, and Vinay Pratap Singh

Abstract With the expansion of modern and communication industries, a diversity of metal wires and cables are used in a variety of applications, simultaneously wastes in the form of wire are also increasing which is also responsible for environmental pollution. The disposal of this type of waste is a worldwide problem. Therefore, recycling is very important for economic savings and a positive effect on the environment. Earlier, recycling techniques involved burning of the plastic layer of wire and then recovery is done for copper, aluminium and steel but this process is highly harmful to the environment because it releases toxic gases. In this study, various types of important techniques and processes for recycling of waste electrical wires are discussed which are less harmful to the environment.

Keywords Metal wires · Environment · Economic savings · Recycling · Important techniques

1 Introduction

Currently, proper waste management is one of the major environmental problems in the world so proper waste management system are used to recover and recycle valuable waste in order to prevent health and environmental problems and to conserve natural resources, minimize the production cost of many products such as metals, and plastics [1]. Waste is also in the form of Electrical and Electronic Waste which is commonly known as WEE. The use of electrical and electronic products has increased rapidly in the last decade and by this generating of large quantities of waste electrical and electronic equipment at the end of its life. The production of waste electrical and electronic equipment worldwide is approximately 20–50 Mt/year [2]. There are some global policies that deal with the management of waste electrical and electronic equipment (WEEE) in which 1989 Basel convention is the most significant which aimed to minimize the movement of hazardous materials around the world [3]. One of

A. K. Gupta (✉) · A. Kumar · V. P. Singh
Department of Mechanical Engineering, Harcourt Butler Technical University, Kanpur, India
e-mail: abhishekgupta.hbtu@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_13

the commonly known wastes in Waste Electrical and Electronic Equipment (WEEE) is an electrical cable, which is composed of a conductor, mostly a copper with PVC-insulated cover. Copper is obtained from two sources: extracting and processing of raw materials which are known as primary production and recycling of end of life products, known as secondary production, which is transformed by some physical and chemical process and can be reintroduced in the production process which improves economy and also minimizes environmental problems [4]. Due to its properties such as conductivity, malleability, and copper is considered one of the most important industrial metals, with about 70% of global copper being used for various electrical applications [5].

In the last decades, mining production of copper worldwide has increased by 3.2% per annum to 20 million tonnes in 2017 and Chile was the largest producer of copper around 5.6 million tonnes. The total global requirement of copper was nearly 25 million tonnes and the largest consumer of copper was China (12 million tonnes) [4]. Nowadays, various separation processes have been developed to recover valuable metal and non-metal from electrical and electronic waste. In this study, the separations of copper and plastic from waste electrical cables with the help of mechanical or physical methods to be utilized have been discussed.

2 E-waste Management, Disposal, and Its Impact on the Environment

Almost every electrical and electronic products that have reached their life are considered as e-waste such as cameras, radios, printer machine, cellophanes, TVs and computer motherboard. E-waste also affects human health such as liver damage, tumours, kidneys and behavioural changes. So, recycling of these types of waste is very important because it impacts negative effects on the environment. Currently, the disposal of e-waste is done with incineration, acid baths and landfills method [6].

3 Methods of Separation

Mechanical/physical separation process includes shredded method, Eddy current separation, gravity separation, sensor-based separation, density-based separation, thermal-based separation, magnetic-based separation and melting process. There are also some chemical processes used for separation of metallic parts. Magnetic-based separation is mostly used for separation of ferromagnetic metal from non-ferromagnetic metal and other non-magnetic objects.

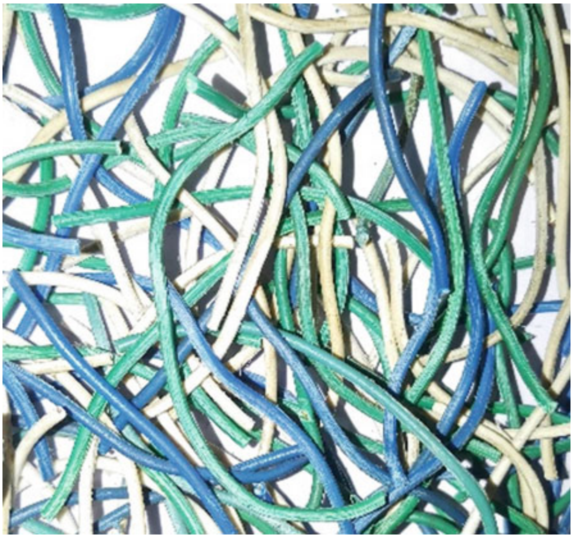


Fig. 1 Waste copper wire

3.1 Shredded Method

Cansu Celik et al. 2019 experimentally studied that about 13 kg of waste electrical cables of different shapes, diameters and length are used. The diameters of waste cable are varying between 0.5–2.5 cm and waste cables are shredded first to decrease its size and then separation is done by gravity and electrostatic separation techniques. In this process, size deduction, Mozley table and electrostatic test are applied. Mozley table is used for separation because there is a high difference between densities of copper and plastics (the density of pure copper is 8.9 g/cm^3 and density of plastics is 1.5 g/cm^3). In the middling's of Mozley table, electrostatic separation test was applied in four steps: when copper is separated from waste then melting is done for the production of pure copper. Thus, by this process, 99.6% of refined copper can be obtained [1]. Figures 1, 2, 3 and 4 present waste copper wire, shredded waste cables, separation of copper and refined copper, respectively.

3.2 Eddy Current Separation

Eddy current is a significant method for the separation of non-ferrous metals. According to Faraday's Law, an electric current is generated in the conducting metal when it is cut off by changing magnetic flux. In the material, these currents make close circuits which are known as eddy current and due to this eddy current, magnetic field occurs in the materials in accordance with Ampere's Law by which separation forces are generated and by this force, the material is thrown out from scrap flow [7]. Recently, one of the authors has developed a new mechanism for the separation

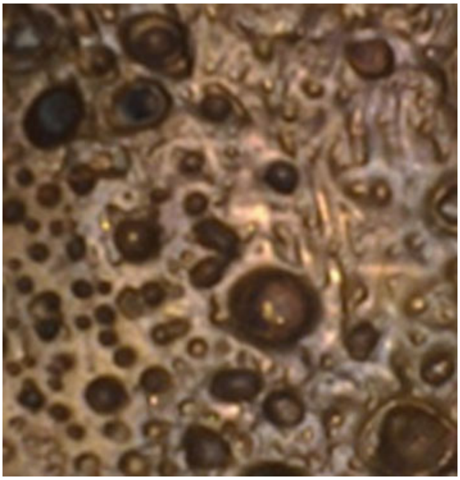
Fig. 2 Shredded waste cables [1]

Fig. 3 Separation of copper [1]

of small non-ferrous metals based on eddy current torque [8]. Ahmet Fenercioglu et al. 2015 have reported that by using eddy current separator (ECS), copper and aluminium can be separated from a shredded mixture which is known as granule cable waste (mixture of PVC particles of insulation). ECS systems are machines which are designed for separation of non-ferrous metals from scrap cables. Magnetic drum and conveyor band are used in ECS. This drum rotates at a very high speed around 3000 rpm under conveyor band and by the force which occurs due to eddy current, non-ferrous metals moved toward the drum and fall into a separate container as shown in Fig. 5 [7]. Figure 6 shows the Mixture of waste granule cable with PVC.

For recycling, 1.5–2 mm diameter and 4–5 mm length wire was shredded, and for non-ferrous metal the repellent force (Fr) in eddy current separator is given by Eqs. (1) and (2) [9]. Finally, copper and aluminium waste was separated via repellent

Fig. 4 Refined copper [1]



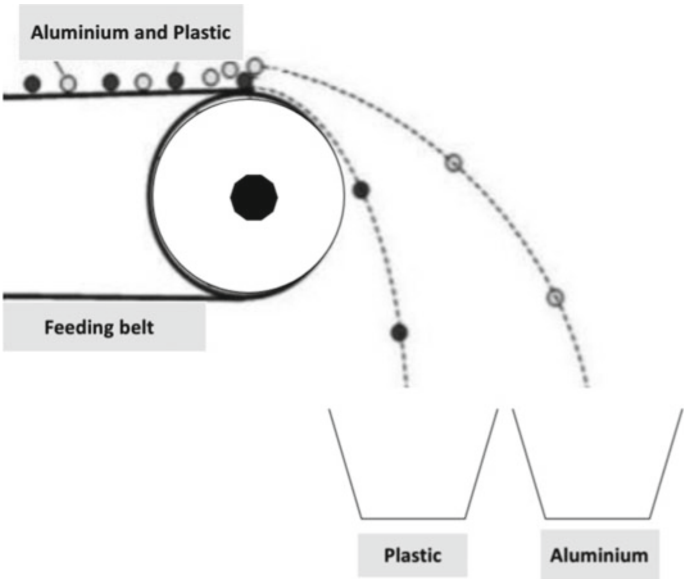


Fig. 5 ECS principle diagram [7]

force by eddy current and by this process, 94.7% of copper and 99.5% of aluminium are recovered [7]. In this method, separation cost is higher because high energy consumption is required.

$$\mathrm{Fr} = H^2 f \times (m\sigma/\rho s) \quad (1)$$

Fig. 6 Mixture of waste granule cable with PVC [7]

$$f = np/120 \tag{2}$$

where
H = magnetic field, (A/m)
f = eddy current frequency, (Hz)
m = material's mass, (kg)
n = speed of drum, (rpm)
p = number of drum poles
s = shape coefficient
ρ = density, (g/cm^3)
σ = conductivity, (S).

3.3 Gravity Separation

According to Fernando Pita and Ana Castilho 2018, copper can be separated from waste electrical cables with the help of jigging and shaking table and also from froth flotation techniques. Jigging and shaking table help effectively to remove copper from plastic layer and the separation with the help of shaking table is controlled by many parameters such as waste water flow rate, feed water flow rate, inclination, frequency, the amplitude of table and movement. In each test, around 2.5 kg of waste material was used and the position of splitters was kept constant during all experiments. By this process, about 97% of copper can be recovered and the separation by froth flotation has lower efficiency, i.e., 85% because plastics are hydrophobic in nature and copper also have some hydrophobic behaviour [4].

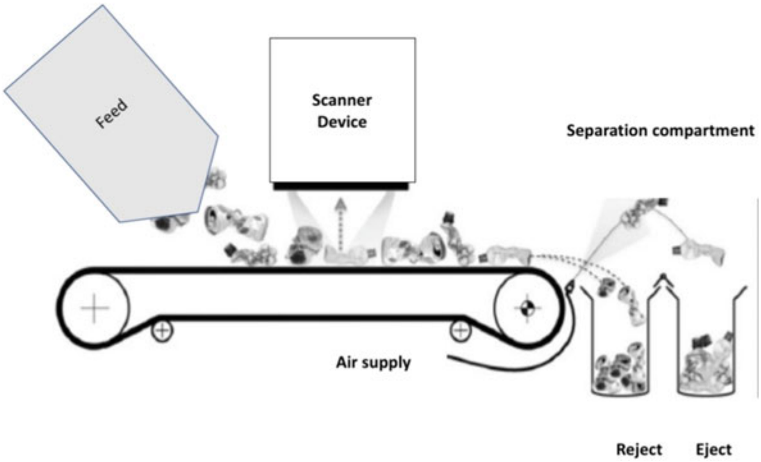


Fig. 7 Schematic of sensor-based sorting system [2]

3.4 *Sensor-Based Separation of Waste Electrical and Electronic Equipment (WEEE)*

Jakub Hlosta, et al. studied that Copper can be separated from mixed cables waste with the help of sensor-based separation. In this process, air jets are used to eject particular types of materials from the mixture. Near-Infrared (NIR) technique detects an infrared spectrum which is unique for each type of materials. In this method, if the sensor detects objects which is needed to be eject from the mixture, then computer activates the air jets' system and the chosen part from the waste is blown out at the end of belt conveyor and unwanted materials fall into the rejected box [2].

Kavya Balakrishnam et al. have studied the technique of automatic waste segregation (AWS). The process is cheap and easy to use for separation of waste. Three variety of waste is separated which are metallic, organic and plastic. For making it more efficient, the ultrasonic sensor is used for monitoring the waste [10]. Figure 7 shows the schematic of sensor-based sorting system [2].

3.5 *Density-Based Separation Technique*

There are many separation techniques used based on shape or densities of materials and in some process, the wet technique is also used in which water involved for the separation process and the wide range of objects sizes varies from 1 to 150 mm are used generally. In density separation technique, waste parts flow with water across a perforated bed and the lighter objects fall at the end of bed via an overflow and the heavier objects are captured by another plate [2]. Due to hygroscopic properties, density separation of plastic waste is completed. Plastic waste can be used as a fuel source which results in the positive effect on the environment and also economic saving [11].

3.6 Thermal Separation Method

Vadim M. et al. 2011 have found that copper can be separated from the plastic layer with the help of two rotating rollers in which copper is passed between these two rotating rollers and the surface of one roll is heated below the melting temperature of the insulator and the surface of other rolls remain cold. By passing cables between rollers, the plastic insulator of cables break after thermal different and finally, copper can be separated [12]. In the thermal method, waste cable with single-core is placed between two rotating rolls as shown in Fig. 8. Due to difference in the coefficient of thermal expansion of insulation substance metals, metal conductor remains undamaged and free from an insulating material. Different length, diameter and material of waste wire can be used in this technique.

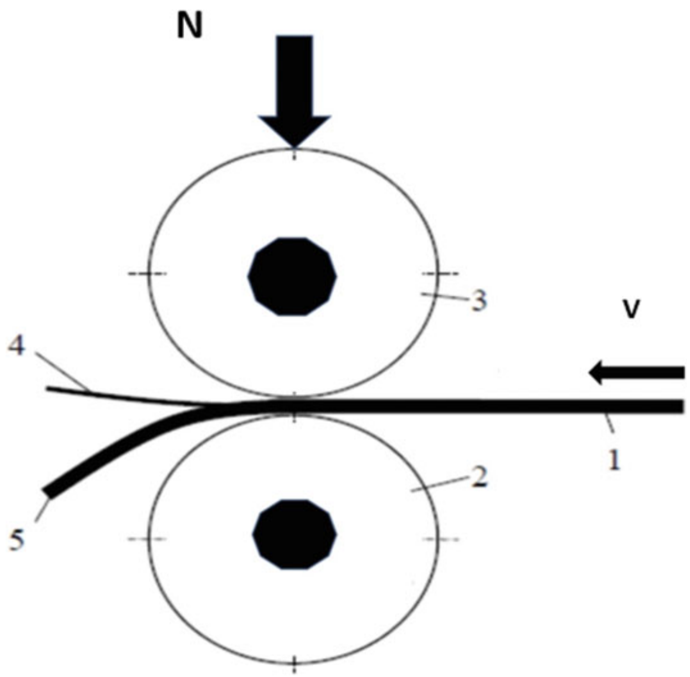


Fig. 8 Schematic of removing the insulator from metal conductor: 1—cable; 2—cold roll; 3—hot roll; 4—metal core(conductor); 5—plastic insulator; *v*—peripheral speed of rolls and linear speed of the cable; *N*—load [12]

Sa Xiao et al. 2015 have studied to solve the domestic wire waste with some technique such as stripping machine technology, mechanical crushing sorting technology, high-pressure water jet recycling technology, chemical treatment technology, cryogenic processing technology, heat recycling technology and ultrasonic separation and recovery technology. The waste wire can be separated from insulating material by using these techniques [13]. Vijaya Agarwal et al. 2014 have studied the various recycling techniques which is used for recycling of metallic and non-metallic electronic waste. These techniques include pyrolysis method, hydrometallurgical method, air classification method, mechanical recycling and bio metallurgical separation method [14].

3.7 Melting Process

Vasile Basliu et al. 2015 have experimentally found that by using the melting process, high quality of secondary copper can be obtained in which copper is separated from waste PVC-insulated copper wire. There are basically four steps involved such as Scrap pre-treatment, Smelting, Alloying and Casting. Pre-treatment basically involved cleaning of waste for smelting and smelting involves heating and treating of waste for separation of valuable materials. Alloying consists the addition of one or more other materials to copper to obtain desirable quality and preparation of combined materials. The copper waste can be recovered with minimum losses and low energy consumption and by melting process, costs are relatively low [15].

In this method, waste cables with variable shapes and diameters are used and uncoated copper wire and rod are obtained by removing insulator cover. Electric Tilting Crucible Furnace (ETCF) is used for melting of copper waste. Waste copper wire was melted to obtain pure copper and this copper was mixed with brass waste to obtain a casting of Cu–Zn alloy [15]. Celso Roman Jr et al. 2014 have studied to develop recycling methods to minimize the amount of pvc which is stored in landfills [16].

With the help of Table 1, percentage of copper and aluminium separated from PVC-insulated waste cables by using various separation techniques and processes are shown, which can be further re-used in various industries which results in economical saving and also a positive effect on the environment due to reduction in waste wire. Figures 9, 10 and 11 show PVC-insulated waste copper wires, uncoated copper wires and ETCF for copper melting, respectevely.

4 Conclusion

Waste electrical wires are very important raw materials due to its properties and non-ferrous metal content which can be re-used in many industries. Therefore, the recovery of this metallic content is very necessary for economic growth and also to

Table 1 Comparison of the percentage of copper and aluminium recovered from various methods

S. No.	Authors	Methods of separation	Percentage of copper	Percentage of aluminium
1	Cansu Celik et al. [1]	Shredded method	99.6	
2	Ahmet Fenercioğlu et al. [7]	Eddy current separator	94.7	99.5
3	Fernando Pita et al. [4]	Gravity separation	97.0	
4	Jakub Hlosta et al. [2]	Sensor and density-based separation	53.7	
5	Vadim M. et al. [12]	Thermal separation	83.9	61.33
6	Vasile Basliu et al. [15]	Melting process	86.87	

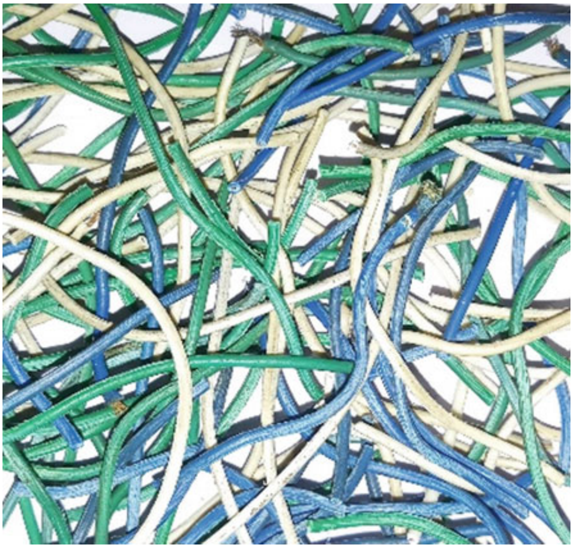


Fig. 9 PVC-insulated waste copper wires

minimize environmental problems. So various separation methods for the management of waste electrical wires have been discussed by which pure form of copper and aluminium can be achieved by using some useful techniques and processes. Thus, this study showed that non-ferrous metal such as copper and aluminium can be separated from scrap cables very effectively.

Fig. 10 Uncoated copper wires

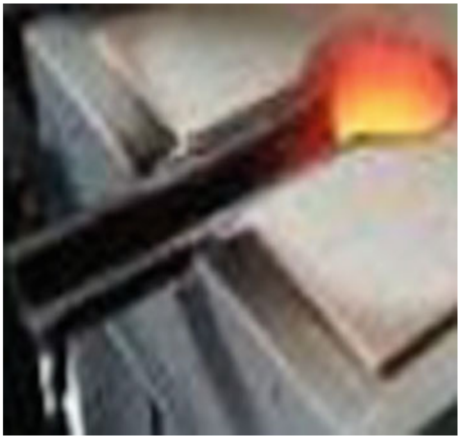


Fig. 11 ETCF for copper melting [15]

References

1. Celik, C., Arslan, C., Arslan, F.: Recycling of waste electrical cables. Med Crave Mater. Sci. Eng. **3**(4), 107–111 (2019)
2. Hlosta, J., Zurovec, D., Kratochvil, M., Botula, J., Cablik, V.: WEEE sorting processes and separation of copper wires with support of DEM modelling. Inzynieria Mineralna (2017)
3. Long, E., Kokke, S., Lundie, D., Shaw, N., Ijomah, W., Kao, C.-c.: Technical solutions to improve global sustainable management of waste electrical and electronic equipment (WEEE) in the EU and China. J. Remanuf. 15–0023-6 (2016)
4. Pita, F., Castilho, A.: Separation of copper from electric cable waste based on mineral processing methods: a case study. MDPI Min. **8**, 517 (2018)
5. Anastassakis, G.N., Bevilacqua, P., De Lorenzi, L.: Recovery of residual copper from low-content trailing derived from waste electrical cable treatment. Elsevier Int. J. Min. Process. **143**, 105–111 (2015)

6. Sivaramanan, S.: E-waste management, disposal and its impacts on the environment. Univ. J. Environ. Res. Technol. **5**, 531–537 (2013)
7. Fenercioğlu, A., Barutcu, H.: Separation of granule non-ferrous metals in shredded cable waste with eddy current separator. In: Proceedings of the World Congress on Mechanical, Chemical, and Material Engineering (MCM) (2015)
8. Settimo, F., Bevilacqua, P., Peter, R.E.M.: Eddy Current Separation of Fine Non-ferrous Particles from Bulk Streams, vol. 13, pp. 15–23. Taylor and Francis (2004)
9. Wang, Q., Zhao, Y., Jiao, H., Zhang, H.: Effects of operation parameters of eddy current. In: 7th World Congress on Recovery, Recycling and Re-integration (2005)
10. Balakrishnan, K., Rosmi, T.B., Swathy Krishna, K.J., Sreejith, S., Subha, T.D., Aleena, V.J.: Automatic Waste Segregator and Monitoring System. www.stmjournals.com, V 3 (2016)
11. Gent, M.R., Menendez, M., Toraño, J., Diego, I.: Recycling of Plastic Waste by Density Separation: Prospects for Optimization (2009). https://www.sagepub.com. https://doi.org/10.1177/0734242X08096950
12. Moksin, V., Striska, V., Tetsman, I.: Method of removal of the plastic insulator from waste cables by passing them between two rotating rolls that have different surface temperatures. In: The 8th international conference, ilnius Gediminas Technical University, Environmental Engineering. ISSN 2029-7092 (2011)
13. Xiao, S., Xiong,W., Wang, L., Ren, Q.: The treatment technology of recycling scrap wire and cable. 4th ICSEEE (2015)
14. Agarwal, V., Gupta, S., Modi, G., Saini, R.: A review on various electronic waste recycling techniques and hazards due to its improper handling. Int. Ref. J. Eng. Sci. (IRJES) **3**(5), 05–17 (2014)
15. Basliu, V., Ciocan, A., Tudor, B.: Recovery of copper from waste cables used in electrical applications. The annals of "Dunarea De Jos" University of Galati. Metal. Mater. Sci. 1453–083X (2015)
16. Celso R., Jr., José Zattera, A.: Study on the recycling of waste pvc compounds from electrical wires. In: AIP Conference Proceedings vol. 1593, pp. 52 (2014)

A Case Study of Manpower Productivity Improvement in Moulding Section of Automotive Industry by Using Man Machine Chart

Tarun Kumar Verma and Niraj Gupta

Abstract Nowadays all companies want to increase their output without increasing the input so that their productivity will improve and profit will increase. This paper discusses time study methodology using Man Machine Chart through which the work study has been successfully implemented. It provides the case study of manpower productivity improvement in moulding section of automotive industry. From our study in moulding section shots/hour increased and there is reduction in manpower in terms of saving/month.

Keywords Manpower productivity · Time study · Man machine chart · Moulding · Automotive industry

1 Introduction

Nowadays all companies want to increase their output without increasing the input (manpower, cost, reduce waste and decrease idle time of machine and worker) so that their productivity will improve and profit will increase [1, 2]. In industries, the manpower productivity affects the overall productivity so when we improve the manpower productivity and decrease idle time of machine and worker then the overall productivity increases. Productivity is defined as the amount of result (output) an organization gets for a given amount of inputs such as labour and machinery [3]. The benefit of productivity includes such as (a) higher wages, larger bonuses and better benefits for workers, (b) greater competitiveness and higher profitability for companies, (c) cheaper and better-quality goods and services for customers. There are various productivity improvement techniques which are technology, employee, material, process, product and management based. In our study, we have used work study technique like Man Machine Chart [4–6].

T. K. Verma (✉) · N. Gupta
Faculty of Mechanical Engineering, Shri Ramswaroop Memorial University, Barabanki, India
e-mail: nirajcom@yahoo.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_14

2 Production Flow

The case industry manufactures different type of product like sealing system, anti-vibration, fluid system, boots and bellows, air intake and other moulded hoses, etc. The process flow followed at case Industries rights from the incoming raw material to the value addition at various steps have been depicted in Fig. 1.

This section is dividing into two parts: (a) Compound store: in this store comes the rubber sheets and piece and (b) BOP store: In this store comes the metal Brought out parts (BOPs). In the moulding there are two types of machines, i.e. Injection Moulding and Compression Moulding machine which are used in manufacturing all rubber and rubber metal parts. Rubber parts like as gasket head cover, O-ring, duct-L-cover, etc. Rubber and metal parts like Mehta bush, engine hanger bush, etc. Flash removal process comes under deflashing which is performed in quality room

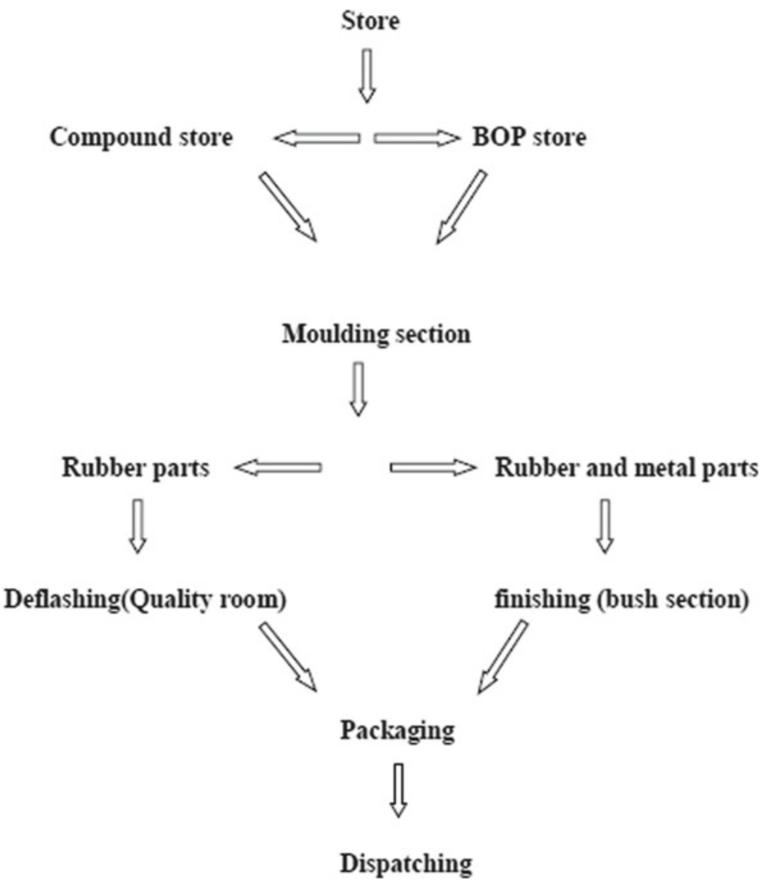


Fig. 1 Process flow chart at automotive industry

and online deflashing is performed in the moulding section. Finishing process like buffing, grinding, rimming, ID checking and OD grinding is done in the bush section. After packaging finished good is dispatched to customers [2–4].

3 Objective of Study

In moulding section, the following were objectives of study.

(1) To achieve the higher productivity without increasing the cost.
(2) Minimizing the idle time of machines and workers.
(3) Increase the shots (Number of cycle) per hour.
(4) Minimizing the rejection in production.
(5) Improve the workers efficiency by providing the dexterity training.
(6) Improve overall productivity of moulding section.

4 Methodology

Time study can be performed by the following methods, depending upon the accuracy required:

(1) Stopwatch Method.
(2) Motion Picture Camera.

In our study, we have used both the methods [1, 3]. We selected the part which consume the maximum manpower per month, and which is running more than 25 days. We selected more than 95 parts which come in the above condition. Table 1 shows the summary sheet of video shooting and Table 2 shows the timing and Operators Details.

5 Procedure of time study

(1) Select the machine for time study.
(2) Select operator to be studied if there are more than one operator doing the same task.
(3) Check properly the machine pressure, curing time, injection time and shots/hrs according to the standard.
(4) If all above are right, then we record the video of three to four cycle continuously.
(5) After recording the video, we brake the video into small work element like as loading the BOP in bottom plate, demoulding the part, loading the cut rubber

Table 1 Summary sheet of video shooting

Summary sheet of video shooting	
Machine no	IM-11
Part name	Rubber Bush Engine Hanger (M-1)
Type of moulding	Injection
Standard cavity	60
Running cavity	60
Old shots/hour	8
New shots/hour	8.07
Operator-1 name	Devilal (Tarun-417)
Operator-2 name	Not required

Note Second cycle is skipped because 2nd cycle time is more so the shots/hrs is 6.69 which is very less than the tanderd shots/hrs (8) so we consider 1st and 2nd cycle
Moulding-IM-11-Rubber Bush Engine Hanger

in the top ejector, machine curing time, inner and outer BOP loading in outer fixture.

(6) Divide the operation into reasonable small elements and record them in the Time Study (element study example) observation sheet and then make MMC.
(7) After making MMC, we calculate the idle time of operator and machine.
(8) Determine allowances for fatigue and various delays.
(9) Determine standard time of operation.
(10) Standard time = Normal time + allowances
(11) Select the trained operator; if the operator is not properly trained for working on the machine then they go through the dexterity training, and when the operator improves his working speed and is properly trained then they go on the machine.
(12) In the dexterity training we trained the worker for loading fixture for inner and outer, loading unloading part, rubber cutting, etc.
(13) We suggested new ways to reduce the idle time of operator and machine.
(14) Implement the new methods to reduce the idle time of operator and machine.

6 Results

From our study in moulding section shots/hour increased and there is reduction in manpower in terms of saving/month (Rs.1,59,037/-). Reduction of manpower and shots/hour increased in moulding section is shown in Table 3.

Table 2 Timing and operators details

Element study of man machine chart (MMC)
Part name = Engine hanger bush
Machine no. = IM-11

Sr.no	Machine—IM-11	Timing (in second)	Operator -1 Devilal (tarun-417)	Timing (in second)
1	Top ejector downward	22–27	Push the button	22–27
2	Idle	27–42	Flash removing	27–37
3	X		Rubber loading in top ejector plate	32–42
4	Top ejector upward and ram moving upward	42–50	Push the button	42–50
5	Moulding cycle time	50–378	Loading inner and outer BOP in outer fixture	50–180
6	X		Part checking visually and rubber remove from inner of part	180–381
7	Ram moving downward	378–381	X	X
8	Bottom ejector upward	381–384	Push the button	381–384
9	Idle	384–423	Clean die with air	384–397
10	X		Loading inner BOP in die	397–423
11	Bottom ejector downward	423–427	Push the button	423–427
12	Idle	427–462	Demoulding the part	427–442
13	X		Loading outer BOP in bottom ejector plate	442–462
14	Top ejector downward	992–998	Push the button	992–998
15	Idle	998–1023	Flash removing	998–1017
16	X		Rubber loading in top ejector plate	1017–1023
17	Top ejector upward and ram moving upward	1023–1030	Push the button	1023–1030
18	Moulding cycle time	1030–1358	Loading inner and outer BOP in outer fixture	1030–1154

(continued)

Table 2 (continued)

Element study of man machine chart (MMC) Part name = Engine hanger bush Machine no. = IM-11				
Sr.no	Machine—IM-11	Timing (in second)	Operator -1 Devilal (tarun-417)	Timing (in second)
19	X		Part checking visually and rubber remove from inner of part	1154–1360
20	Ram moving downward	1358–1360	X	
21	Bottom ejector upward	1360–1363	Push the button	1360–1363
22	Idle	1363–1410	Clean die with air	1363–1377
23	“		Loading inner BOP in die	1377–1414
24	Bottom ejector downward	1410–1414	Push the button	1410–1414
25	Idle	1414–1448	Demoulding the part	1414–1428
26	X		Loading outer BOP in bottom ejector plate	1428–1448

7 Conclusions

The following conclusions are drawn from this study:

- Idle time of operator/machine reduced.
- Shots/hour improved.
- By reducing idle time productivity in moulding section improved.
- Increased manpower efficiency.
- Reduced the overheads worker.

Table 3 Saving per month in Rs

Sr. no	Part name	Days required to complete the monthly Schedule		Shots/hrs		Increase shots/hrs	Manpower saving	Saving/month (Rs.)
		Before	After	Before	After			
1	Rubber Seal Breather	26.35	21.96	5	6	1	1	19,185
2	Seal Shroud	26.16	23.24	8	9	1	–	11,571
3	Gasket Cylinder Head Cover	11.68	10.51	18	20	2	–	11,571
4	Rubber Bush Rear Fork Pivot	7.3	6.39	7	8	1	–	3975
5	Clamper Fuel Hose	12.08	9.06	6	8	2	–	13,198
6	Dust Seal Green	18.26	16.23	8	9	1	–	8871
7	Rollar Cam Chain Tensioner	16.28	14.11	13	15	2	–	18,966
8	Hose Drain (YSD RH)	36.09	40.09	10	9	–	1	12,500
9	Dust-L Cover	14.4	16.32	17	15	–	1	7200
10	Dust-L Cover	7.2	8.16	17	15	–	1	3600
11	Door Grommet Left/Right	6.9	6.9	8		–	1	3450
12	Grommet Door CDT	6.1	6.1	8		–	1	3050
13	Grommet	8.8	8.8	7		–	1	4400
14	Damper Rear Wheel	80.5	80.5	6		–	2	25,000
15	Rubber Bush Engine Hanger and Mehta Bush	35.5 42.3	35.5 42.3	8		–	1	12,500

(continued)

Table 3 (continued)

Sr. no	Part name	Days required to complete the monthly Schedule		Shots/hrs		Increase shots/hrs	Manpower saving	Saving/month (Rs.)
		Before	After	Before	After			
Total								159,037

References

1. Azid, I. A., Ani, M. N. C., Hamid, S. A. A., Kamaruddin, S.: Solving Production Bottleneck Through Time Study Analysis And Quality Tools Integration. Int. J. Indus. Eng. **27**(1) (2020)
2. Schuh, G., Potente, T., Wesch-Potente, C., Weber, A.R., Prote, J.P.: Collaboration Mechanisms to increase Productivity in the Context of Industrie 4.0. Procedia Cirp **19**, 51–56 (2014)
3. Available at: https://nptel.ac.in/courses/112/107/112107142/
4. Sable, S. R.: Stop watch time study and most: work measurement techniques (2017)
5. Murali, C.S., Prabukarthi, A.: Productivity improvement in furniture industry using lean tools and process simulation. Int. J. Product. Qual. Manage. **30**(2), 214–233 (2020)
6. Singh, S., Singhal, S.: Productivity improvement by reduction of cycle time through implementing clustering: a case study. In: Advances in Simulation, Product Design and Development (pp. 735–752). Springer, Singapore (2020)

Lean Tool Selection in a Die Casting Industry: A Fuzzy AHP-Based Decision Support Heuristic

Sanatan Ratna and B. Kumar

Abstract As the government of India has recently put a lot of focus on its new policy, i.e., "Make in India," the Indian manufacturing sector has been looking forward to be on the cusps of being the manufacturing hub on the globe. And hence, a large number of manufacturing organizations are looking forward to implementing lean philosophy in their units in order to cut down the various wastes and gain sustainable advantages over the competitors in the global market. The problem arises when the tools which are to be implemented are vast in number and the need to select the tools when lean philosophy implementation arises. The lean tools need to be ranked as per their efficiency based on a number of criteria and then implemented in the manufacturing organizations. The current research work deals with the selection of lean tool for a die casting industry using Fuzzy AHP. FAHP makes use of a triplet of triangular fuzzy numbers (TFN) to include the ambiguity in the priorities during pair-wise comparisons. The lean tools under consideration are Poka Yoke, value stream mapping (VSM), Heijunka (Level Scheduling), SMED (Single minute exchange of dies), and Kaizen. These lean tools are to be evaluated on the basis of three criteria, i.e., material, time, and energy. The tools are evaluated using Fuzzy AHP and ranked accordingly. The lean tool with the best rank is chosen for implementation in the die casting industry.

Keywords Lean tools · AHP · Fuzzy AHP · MCDM · Poka yoke · Value stream mapping · Heijunka single minute exchange of dies & kaizen

1 Introduction

In today's competitive world, customers consistently look forward to demand higher quality product in a shorter delivery time and at a lower price. So, the organization

S. Ratna (✉)
Amity University Uttar Pradesh, Noida, India
e-mail: sanatan_ratna@yahoo.co.in

B. Kumar
Sunrise University, Alwar, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_15

struggles to continuously improve their organization. The aim of obtaining better quality products at low price and in a minimum lead time is possible by applying lean tools such as Poka Yoke, value stream mapping (VSM), Heijunka (Level Scheduling), single minute exchange of dies (SMED), and Kaizen. However, there is a need to identify the best tool among an amalgam of options available. This selection of the best lean tool can be done by using Fuzzy AHP methodology. Bayou and de Korvin [1] defined manufacturing leanness as a unifying concept, and second to develop a systematic, long-term measure of leanness. The leanness measure utilized the fuzzy-logic methodology since lean is a matter of degree. They applied the measure to compare the production leanness of Ford Motor Company and General Motors; the paper selects Honda Motor Company as the benchmarking firm. Grewal [2] described the implementation of VSM in a small manufacturing firm as a lean manufacturing improvement initiative. This involved mapping the activities of the firm, identifying opportunities for improvement, and then undertaking with the firm an improvement program. Choudhury et al. [3] developed an integrated fuzzy-based decision support system for the selection of lean tools in a steel manufacturing industry. Adarsh Kumar Singh et al. [4] made use of grey-based decision-making approach for lean tool selection from a set of 5 alternatives evaluated along 12 attributes. Behrouziet al. [5] used fuzzy-logic approach for lean performance evaluation of manufacturing system. Houshmand et al. [6] developed axiomatic modeling with use of process variables. The process variables comprised of tools, methods, and resources required for implementing a lean production system. Shah et al. [7] analyzed the impact of three contextual factors, plant size, plant age, and unionization status for possible implementation of 22 lean principles grouped under four “lean bundles.” The result depicted the importance of plant size as the major factor for lean production.

2 Proposed Methodology

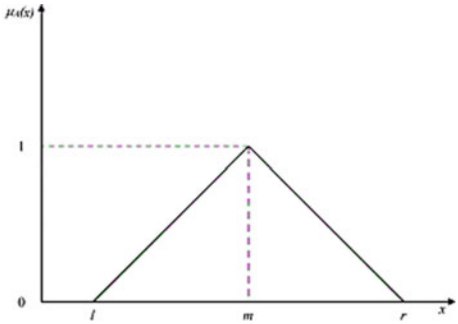
Fuzzy AHP is a multi-criteria decision-making tool or MCDM tool. It is more a useful tool as compared to AHP as it can handle ambiguity and imprecision of human judgement. In AHP, the rating scales used in pairwise comparison of criteria or alternatives is crisp numbers which is against the imprecision or vagueness of human judgement. Fuzzy AHP accommodates this imprecision and partial truth in the input data. Hence, a hybrid of fuzzy logic with conventional AHP becomes a more effective MCDM tool to handle the subjective and linguistic inputs from the survey or feedback. FAHP makes use of a triplet of triangular fuzzy numbers (TFN) to include the vagueness in the priorities during pairwise comparisons. A typical set of TFNs that can be used in FAHP application is given in Table 1.

A TFN provides a varying membership value at different inputs as depicted in Fig. 1. A linguistic expression “weakly important” is represented by the TFN (2 3 4) with zero membership for 2 and 4 at the extremes and highest membership of 1 for 3 at the middle. In general, membership for any TFN (l, m, n) can be obtained using the following expressions:

Table 1 Set of TFNs

Level of importance	Satty's scale	TFN
Equally important (EI)	1	(111)
Weakly important (WI)	3	(234)
Fairly important (FI)	5	(456)
Strongly important (SI)	7	(678)
Absolutely important (AI)	9	(999)
Intermittent important	2,4.6,8	(123) (345) (567) (789)

Fig. 1 Triangular fuzzy number (TFN)



$$\mu(x) = \begin{cases} (x-l)/(m-l) \; x \;\; \in [l, m] \\ (u-x)/(u-m) \; x \;\; \in [m, u] \\ 0, otherwise \end{cases} \tag{1}$$

3 Lean Tool Selection Problem

The current problem deals with the selection of best lean tool from five alternatives based on three criteria. The lean tools under consideration are Poka Yoke (T1), value stream mapping (VSM) (T2), Heijunka (Level Scheduling) (T3), single minute exchange of dies (SMED) (T4), and Kaizen (T5). These lean tools are to be evaluated on the basis of three criteria, i.e., material, time, and energy. The tools are evaluated using Fuzzy AHP and ranked accordingly. Several approaches are available to find the crisp relative weights for the decisions in FAHP like Chang's fuzzy extent analysis, least square priority method, preference programming method, α cut method, etc., but the Buckley's geometric mean method is adopted here for its simplicity. The pairwise comparison of the criteria using TFN is given in Table 2.

Table 2 Pairwise comparison of criteria using TFN

	Material	Time	Energy	GM for l	GM for m	GM for u
Material	(1 1 1)	(6 7 8)	(4 5 6)	2.88	3.27	3.63
Time	(1/8 1/7 1/6)	(1 1 1)	(1/4 1/3 1/2)	0.314	0.362	0.437
Energy	(1/6 1/5 1/4)	(2 3 4)	(1 1 1)	0.693	0.843	1.00
	Total			3.887	4.475	5.067
	Reciprocal			0.257	0.223	0.197
	Ascending order			0.197	0.223	0.257

The Buckley's geometric mean (GM) for each of the three numbers l, m, and u in the TFN for each criterion is calculated as follows:

$$\widehat{r_i} = \left(\prod_{j=1}^{n} \widetilde{d_{ij}} \right)^{1/n} \quad (2) \tag{2}$$

where, $\widetilde{d_{ij}}$ is the TFN and n is the number of criteria/alternatives. For the material criterion, the triangular GM for the three numbers is (2.88, 3.27, 3.63) and so on. The sum of GMs corresponding to each triangular number are then raised to the inverse power of (-1) and the results are set in ascending order as shown in Table 2. Then the relative fuzzy weights for each criteria can be found by the product of their three GMs with the corresponding ordered reverse vector. For material, the fuzzy weight is calculated as

$$\begin{aligned} \widehat{W}_{\text{material}} &= (2.88 \times 0.197,\ 3.27 \times 0.223,\ 3.63 \times 0.257\ ) \\ &= (0.567,\ 0.729,\ 0.932) \end{aligned}$$

Similarly, $\widehat{W}_{\text{time}}$ and $\widehat{W}_{\text{energy}}$ are found as (0.061, 0.08, 0.112) and (0.136, 0.187, 0.257), respectively. These fuzzy triangular weights are the de-fuzzified using center of area method in which the average of the three values is found. The de-fuzzified relative weights for the three criteria and their normalization are given in Table 3.

Then similar procedure is repeated for pairwise comparison of all the five alternative lean tools with respect to each of these three criteria. When the criteria "Material"

Table 3 Normalized crisp weights for criteria

Criteria	De-Fuzzified weight	Normalized weight
Material	0.742	(0.742/1.019) = 0.728
Time	0.084	0.082
Energy	0.193	0.189
	Total 1.019	

Table 4 Fuzzy decision matrix of lean tools for material criteria

Options	T1	T2	T3	T4	T5	GM for l	GM for m	GM for u
T1	(1 1 1)	(6 7 8)	(2 3 4)	(2 3 4)	(4 5 6)	2.49	3.15	3.77
T2	(1/8 1/7 1/6)	(1 1 1)	(1/4 1/3 1/2)	(1/6 1/5 1/4)	(2 3 4)	0.48	0.49	0.60
T3	(1/4 1/3 1/2)	(2 3 4)	(1 1 1)	(2 3 4)	(4 5 6)	1.31	1.71	2.16
T4	(1/4 1/3 1/2)	(4 5 6)	(1/4 1/3 1/2)	(1 1 1)	(2 3 4)	0.87	1.10	1.43
T5	(1/6 1/5 1/4)	(1/4 1/3 1/2)	(1/6 1/5 1/4)	(1/4 1/3 1/2)	(1 1 1)	0.28	0.33	0.43
			Total			5.43	6.78	8.39
			Reciprocal			0.184	0.147	0.119
			Ascending order			0.119	0.147	0.184

is considered, the fuzzy decision matrix for the alternatives can be formed as in Table 4 based on the expert opinions. It is important to note that here when a number of expert opinions are collected in linguistic terms known as group MCDM, the average numerical values for the TFN or the geometric mean (GM) are to be used.

Then fuzzy relative weights ($\widehat{W}_{T1}$, $\widehat{W}_{T2} etc.$) for each alternative (lean tools) are calculated and tabulated in Table 5. At the end, the normalized relative weights of the five alternative lean tools for the material criterion are found. Similar exercise is repeated for the rest of the two criteria (Time and Energy) to find the normalized crisp weights as given in Table 6.

Next, the fuzzy relative weights ($\widehat{W}_{T1}$, $\widehat{W}_{T2} etc.$) for each alternative (lean tools) are calculated and tabulated in Table 7. At the end, the normalized relative weights of the five alternative lean tools for the material criterion are found. Table 8 shows the normalized crisp weights of the Energy criteria. Next, the normalized crisp weights of alternatives for "Energy" are calculated and tabulated as shown in Table 9.

After finding the normalized crisp weights for all the five alternatives with respect to the three criteria separately, the aggregate weights for each alternative is calculated by adding the product of weight of criteria with individual weights. The total weights

Table 5 Normalised crisp weights of alternatives for material

Lean tools	Fuzzy Weights $\widehat{w}_i$			De-Fuzzified weights	Normalized weights
T1	0.296	0.463	0.693	0.484	0.457
T2	0.057	0.072	0.110	0.079	0.074
T3	0.155	0.251	0.397	0.267	0.252
T4	0.103	0.161	0.263	0.175	0.165
T5	0.033	0.048	0.079	0.053	0.050

Table 6 Fuzzy decision matrix of lean tools for time criteria

Options	T1	T2	T3	T4	T5	GM for l	GM for m	GM for u
T1	(1 1 1)	(4 5 6)	(2 3 4)	(2 3 4)	(4 5 6)	2.29	2.95	3.65
T2	(1/6 1/5 1/4)	(1 1 1)	(1/4 1/3 1/2)	(1/4 1/3 1/2)	(2 3 4)	2.16	1.71	0.75
T3	(1/4 1/3 1/2)	(2 3 4)	(1 1 1)	(2 3 4)	(2 3 4)	1.14	1.55	2.00
T4	(1/4 1/3 1/2)	(2 3 4)	(1/4 1/3 1/2)	(1 1 1)	(2 3 4)	0.75	1.00	1.31
T5	(1/6 1/5 1/4)	(1/4 1/3 1/2)	(1/4 1/3 1/2)	(1/4 1/3 1/2)	(1 1 1)	0.30	0.37	0.50
			Total			6.64	7.58	8.21
			Reciprocal			0.15	0.13	0.12
			Ascending order			0.12	0.13	0.15

Table 7 Normalized crisp weights of alternatives for time

Lean tools	Fuzzy weights $\widehat{w}_i$			De-Fuzzified weights	Normalized weights
T1	0.274	0.383	0.547	0.401	0.400
T2	0.259	0.222	0.112	0.197	0.196
T3	0.136	0.201	0.300	0.212	0.211
T4	0.090	0.130	0.196	0.138	0.137
T5	0.036	0.048	0.075	0.053	0.052

Table 8 Fuzzy decision matrix of lean tools for energy criteria

Options	T1	T2	T3	T4	T5	GM for l	GM for m	GM for u
T1	(1 1 1)	(6 7 8)	(4 5 6)	(2 3 4)	(6 7 8)	3.10	3.74	4.33
T2	(1/8 1/7 1/6)	(1 1 1)	(1/4 1/3 1/2)	(1/4 1/3 1/2)	(1/4 1/3 1/2)	0.28	0.35	0.46
T3	(1/6 1/5 1/4)	(2 3 4)	(1 1 1)	(2 3 4)	(2 3 4)	1.05	1.40	1.74
T4	(1/4 1/3 1/2)	(2 3 4)	(1/4 1/3 1/2)	(1 1 1)	(2 3 4)	0.75	1.00	1.31
T5	(1/8 1/7 1/6)	(2 3 4)	(1/4 1/3 1/2)	(1/4 1/3 1/2)	(1 1 1)	0.43	0.54	0.69
			Total			5.61	7.03	8.53
			Reciprocal			0.178	0.142	0.117
			Ascending order			0.117	0.142	0.178

Table 9 Normalized crisp weights of alternatives for energy

Lean tools	Fuzzy weights $\widehat{w}_i$			De-Fuzzified weights	Normalized weights
T1	0.362	0.531	0.770	0.554	0.526
T2	0.032	0.049	0.081	0.054	0.051
T3	0.122	0.198	0.309	0.209	0.198
T4	0.087	0.142	0.233	0.154	0.146
T5	0.05	0.076	0.122	0.082	0.077

Table 10 Aggregate weights of alternatives and their ranks

Criteria	Weight	T1	T2	T3	T4	T5
Material	0.728	0.457	0.074	0.252	0.165	0.050
Time	0.082	0.400	0.196	0.211	0.137	0.052
Energy	0.189	0.526	0.051	0.198	0.146	0.077
	Total	0.464	0.079	0.238	0.158	0.055
	Rank	1	4	2	3	5

for alternatives and ranking based on it are given in Table 10. From this Fuzzy AHP (FAHP) exercise, the lean tool T1, i.e., Poka Yoke with rank one emerged as the best option for the given MCDM problem.

4 Conclusion

The Fuzzy AHP methodology has been used for the current MCDM problem for finding the best suited tool among five alternatives to be implemented in a die casting industry. The criteria for tool selection are material, time, and energy. The fuzzy AHP method is useful in the sense that it takes into account the imprecision, partial truth, and vagueness of human judgement in the input data. The tools are evaluated on the basis of the three criteria, i.e., material, time, and energy. It is found that the tool T1, i.e., Poka Yoke emerges as the best ranked tool among the five tools under consideration. The lean tool Poka yoke is selected for implementation in the die casting industry which is under study.

References

1. Bayou, M.E., Korvin, A.: Measuring the leanness of manufacturing systems—a case study of Ford Motor Company and General Motors. J. Eng. Technol. Manage. **25**, 287–304 (2008)
2. Grewal, C.: An initiative to implement lean manufacturing using value stream mapping in a small company. Int. J. Manuf. Technol. Manage. **15**(3), 404–417 (2008)

3. Singh, R.K., Choudhury, A.K., Tiwari, M.K., Maull, R.S.: An integrated fuzzy-based decision support system for the selection of lean tools: A case study from the steel industry. Proc. IMechE Vol. 220 Part B: J. Eng. Manuf. **220**(10), 1735–1749 (2006)
4. Singh, A.K., Vinodh, S., Vimal, K.E.K.: Application of grey based decision making approach for lean tool selection. AIMTDR 2014. 106–112 (2014)
5. Behrouzi, F., Wong, K.Y.: Lean performance evaluation of manufacturing systems: A dynamic and innovative approach. Procedia Comput. Sci. **3**, 388–395 (2011)
6. Houshmand, M., Jamshidnezhad, B.: An extended model of design process of lean production systems bymeans of process variables. Robotics and Computer-Integrated Manufacturing **22**, 1–16 (2006)
7. Shah, R., Ward, P.T.: Lean manufacturing: Context, practice bundles, and performance. J. Oper. Manage. **21**, 129–149 (2003)

Comprehensive Study of Artificial Intelligence Tools in Supply Chain

Manish Kumar Ojha, Bal Krishna Sharma, Rajat Rana, Sumit Kumar, Sumit Gupta, and Poonam Ojha

Abstract The global supply chain has become more complex in recent years, and the advent of artificial intelligence tools is set to improve the functioning of supply chain. This paper examines the effect of artificial intelligence tools on key parameters of supply chain such as cost, quality, pace, reliability, and sustainability. The Blockchain, the internet of things, the big data technologies, and the machine learning are the new potential enablers of sustainable manufacturing supply chain. This study reviews the current state-of-art research efforts and provides a systematic overview of the current and potential research directions to recognize the market trend in the adoption of these new technologies and some of the challenges as well.

Keywords Supply chain management · Blockchain · Internet of things (IOT) · Smart contracts · Machine learning

1 Introduction

There is a huge investment of time to make a payment between a maker and a supplier, a vendor and a wholesaler or a customer and a retailer. Every contractual agreement requires assistance from law and financial stakeholders that further increases cost and time. Sometimes when required it is hard to trace back the products and parts back to the downstream of the supply chain. The product we get at our doorstep has been gone through various operations in its journey from raw materials to final product that collectively forms a supply chain. The market demand of any product is dependent on the efficient functioning of its supply chain. In the past years, many efforts have been made to increase the efficiency of the supply chain, and a lot of investment has been made on the methods to improve the efficiency of the supply chain. Most of these business problems could have a single possible answer and that is Artificial

M. K. Ojha (✉) · B. K. Sharma · R. Rana · S. Kumar · S. Gupta
Department of Mechanical Engineering, Amity University Uttar Pradesh, Noida, India
e-mail: mkojha@amity.edu

P. Ojha
Graphic Era Hill University, Bhimtal Campus, Bhimtal, Uttarakhand, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_16

Intelligence tools, which can be an integration of blockchain, Internet of Things (IoT) and machine learning. Now, the industrial fourth revolution (I4.0) has made all the industries to move toward Artificial Intelligence. AI is the future of the upcoming generation and AI tools are expected to be employed at each and every stage of the Supply chain. This paper is focusing on the adoption and integration of AI tools like Blockchain Technology (BT), Internet of Things (IOT), and Machine Learning (ML). Blockchain is the most popular technology of I4.0 and can be used in any field like medical, govt. policies, Cybersecurity, food industries, manufacturing industries, and so on. There is a huge hike in digital currencies from 2017 and have a total market value of near about $ 135 billion [1, 2]. Though Blockchain Technology (BT) has been used as many cryptocurrencies like Bitcoin, itBit, Coin-base, etc., it can be very useful in the supply chain in maintaining a decentralized ledger for each transaction either in the form of money or in the form of information. Machine Learning is the second AI tool which can be best fitted in the Supply Chain Risk Management (SCRM) as it can perform across a variety of metrics using both black box and interpret-able machine learning techniques [3–11]. In recent years, many machine learning algorithms have been developed for the purpose to forecast production for the new batches using previous data, production history, and some graphical maps in inputs [12–31]. Machine learning can also play an important role in making workflows more efficient and consistent by using surface quantitative interpretation techniques [25, 32, 34]. This paper is reviewing the current state of art about AI tools and their potential for integration in supply chain.

2 Artificial Intelligence (AI) Tools

Blockchain technology can be integrated into the supply chain architecture to create a reliable, transparent, authentic, and secure system and also reduces any chance of corruption, fraud, and tampering in supply chain [3]. BT can function as a connector for the transfer of data between on-chain and off-chain systems by maintaining the flow of transactions smoothly and transparently to increase the efficiency of the company to achieve more flexible, efficient, and effective business operations and information sharing [32]. Blockchains have many industrial uses in Supply Chain Management, such as automotive supplier payment, transaction traceability, contract bids and execution, cold chain monitoring, and IoT project [28]. The current state of art suggests seven uses of Blockchains in SCM, such as community registry, EDI replacement, lineage/track and trace, safe and secure supply chains, tracking social responsibility goals, supply chain finance, and document sharing [29]. Private Blockchains are regarded as more suitable for Business-to-Business (B2B) applications when privacy concerns, such as identity anonymity, business competition, are considered [5]. Apart from the manufacturing supply chain, the various AI tools are taking other supply chain sectors to a great extent like the agriculture supply chain. Recently many examples have been seen that improve the efficiency of the agriculture supply chain by using AI tools. The internet of things, the Blockchain, and big data technologies are potential enablers of sustainable agriculture supply chains [6]. Apart from the uses of BT in SCM, the research has been seen that this technology is sustainable and environment friendly too. Karen Czachorowski suggested special interest in the maritime industry and represents the perspectives of the utilization of BT in improving the environmental efficiency of the maritime industry [4]. The technology has a broad range of applicability, allowing connecting the supply chain more efficiently, providing the exchange and visibility of time-stamped proofed data, decreasing the industry operational costs with intermediaries and increasing security. BT is used in the supply chain of composite materials to facilitate the certification process of components made of carbon fiber employed in the aerospace sector and to investigate the feasibility of adopting BT in the supply chain of live seafood [12]. Adopting changes are sometimes good but it is better to know the pros and cons of any method before making any changes, therefore, it is better to discuss the potential and barriers to the implementation of BT in SCM [18]. Blockchain is not suitable for every scenario. It is better to check the adaptability and suitability of Blockchain before applying it to any particular case [16]. Based on the various research papers studied some key characteristics have been identified that can be useful for making a sustainable and efficient supply chain. These factors are *Transparency (TP)*, *Security (S), trustworthiness (TW), Confidentiality (C), Authentication (A), and Repudiation (R)* (Table 1).

2.1 Blockchain

A Blockchain is the peer-to-peer network where the central server is absent; the sharing of data is between one peer to another peer or with the peer that is included in the chain. Blockchain is a decentralized ledger, therefore, it is highly secured network as any modification or tempering of data can be detected instantly and each member of the chain will know about the tempering of data. This is done by the concept of HASHING, which is a process of generating a simple KEY which is known as HASH.

KEY by using different algorithms like MD5, SHA-256, and SHA-512. Suppose someone gives an input as in Fig. 1. irrespective of the length of input data, a single word alteration in the input data will change the entire generated HASH KEY. Thus, the HASH KEY can be used as a thumbprint. If a person is changed the thumbprint will also get automatically changed (Hash key) and if the key is changed that simply means that someone has tempered the data. How this hashing is useful in Blockchain can easily be understood by the diagram in Fig. 2. If someone modifies the data in Block-B, then the key associated with Block-B (K2) gets changed and the key stored in Block-C (K2) is different so this will alarm that someone has tempered the data. In addition to security purposes, BT has many advantages like *confidentiality* (if A sends a message to B so C cannot see the Message), *integrit*y (that means the data did not modify in between), *non-repudiation* (if A sends a message to B and after some time A said that I don’t send you the message so there must be a proof that A

Table 1 Key characteristics of AI tools in supply chain

S. no	Author: Research Article	TP	S	TW	C	A	R
1.	Hockey Min.: Blockchain technology for enhancing supply chain Resilience. Business Horizons 62, 35–45 (2019)	✓	✓	✓			
2.	Bhavya Bhandari.: Supply Chain Management, Blockchains and Smart Contracts	✓	✓	✓			
3.	Rita Azzia., Rima Kilany Chamouna., Maria Sokhnb.: The power of a blockchain-based supply chain (2019)	✓	✓	✓		✓	✓
4.	O'Byrne.: Blockchain Technology is Set to Transform the Supply Chain, (2017)	✓		✓			
5.	Lora Cecere.: Moving Blockchain Forward: Seven use cases for hyperledger in supply chain, (2017)	✓				✓	
6.	Shuchih Ernest Chang, Yi-Chian Chen, Ming-Fang Lu.: Supply chain re-engineering using blockchain technology (2019)	✓	✓			✓	
7.	Frank Kottler.: Potential and Barriers to the Implementation of Blockchain Technology in Supply Chain Management	✓		✓		✓	
8.	Adrian E. Coronado Mondragon, Christian E. Coronado.: Investigating the Applicability of Distributed Ledger/Blockchain Technology in Manufacturing and Perishable Goods Supply Chains (2019)			✓			✓
9.	Pradip Kumar Sharma, Neeraj Kumar, Jong Hyuk Park.: Blockchain-based Distributed Framework for Automotive Industry in a Smart City (2018)					✓	
10.	Xiaxia Niu, Zeping Li.: Research on Supply Chain Management Based on Blockchain Technology. IOP Journal of Physics 1176 (2019)	✓		✓			
11.	Tommy Koens, Erik Poll.: The Drivers Behind Blockchain Adoption: The Rationality of Irrational Choices, Radboud University, The Netherlands (2018)		✓			✓	
12.	Sachin S. Kamblea, Angappa Gunasekaran, Shradha A. Gawankar.: Achieving sustainable performance in a data-driven agriculture supply chain (2019)		✓			✓	
13.	Li Da Xu, Senior Member, IEEE, Wu He, and Shancang Li:Internet of Things in Industries: A Survey, 2014	✓	✓	✓			
14.	Shancang Li, Li Da Xu, Shanshan Zhao: 5G Internet of Things: A survey, 2018		✓	✓		✓	
15.	Oscar Novo "Blockchain Meets IoT: an Architecture for Scalable Access Management in IoT". 2018		✓			✓	✓
16.	Shancang Li, Li Da Xu, Shanshan Zhao: Journal of industrial information integration. 2018	✓		✓			

(continued)

Table 1 (continued)

S. no	Author: Research Article	TP	S	TW	C	A	R
17.	EmilianoSisinni, Member, IEEE, AbusayeedSaifullah, Member, IEEE, Song Han, Member, IEEE Ulf, Member, IEEE and Mikael Gidlund, Senior Member, IEEE “Industrial Internet of Things: Challenges,Opportunities, and Directions”, 2018		✓		✓	✓	
18.	Ishan Mistry, Sudeep Tanwar, Sudhanshu Tyagi, Neeraj Kumar: Blockchain for 5G-enabled IoT for industrial automation 2020		✓		✓	✓	
19.	Abderahman Rejeb, John G. Keogh and Horst Treiblmaier: Leveraging the Internet of Things and Blockchain Technology in Supply Chain Management	✓	✓	✓		✓	
20.	Manavalan E., Jayakrishna K.: A review of Internet of Things (IoT) embedded sustainable supply chain for industry 4.0 requirements. 2019		✓				
21.	Falak Nawaz, Naeem Khalid Janjua, Omar Khadeer Hussain: Predictive complex event processing and reasoning for IoT-enabled supply chain. 2019	✓	✓				
22.	Alfonso Panarello, Nachiket Tapas, Giovanni Merlino, Francesco Longo and Antonio Puliafito “Blockchain and IoT Integration: A Systematic Survey”. 2018	✓	✓		✓	✓	✓
23.	Deloitte: Continuous interconnected supply chain with Blockchain and Internet of Things in supply chain traceability	✓	✓		✓	✓	
24.	GeorgeBaryannisa, SamirDanib, Grigoris Antonioua, Predicting supply chain risk using machine learning:The trade-off between performance and interpretability (2019)		✓				✓
25.	QCao, R.Banerjee,S.Gupta, J.Li, W.Zhou, B.Jeyachandra, Schlumberger: Data-driven production forecast using machine learning (june 2016)	✓		✓			
26.	Ehsan Zabihi Naeini, Ikon Science: A machine learning approach to quantitative interpretation	✓	✓	✓			

has to send the message), *authentication* (If B receives a message in the name of A, then what is the guarantee it is actually sent by A, not by C or C have actually sent a message in the name of A so this problem of Authentication must be solved which is solved by Cryptography which is a process of encryption or decryption of data).

2.2 Internet of Things

IoT is basically a worldwide neural network or infrastructure of interconnected objects that is connecting every machine from a small one to a big one in order to share data. It refers to “connecting the unconnected”. The five major IoT technologies

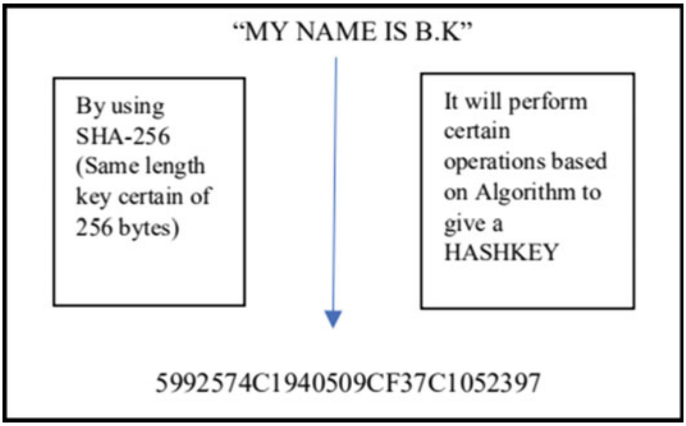


Fig. 1 An example of hash key

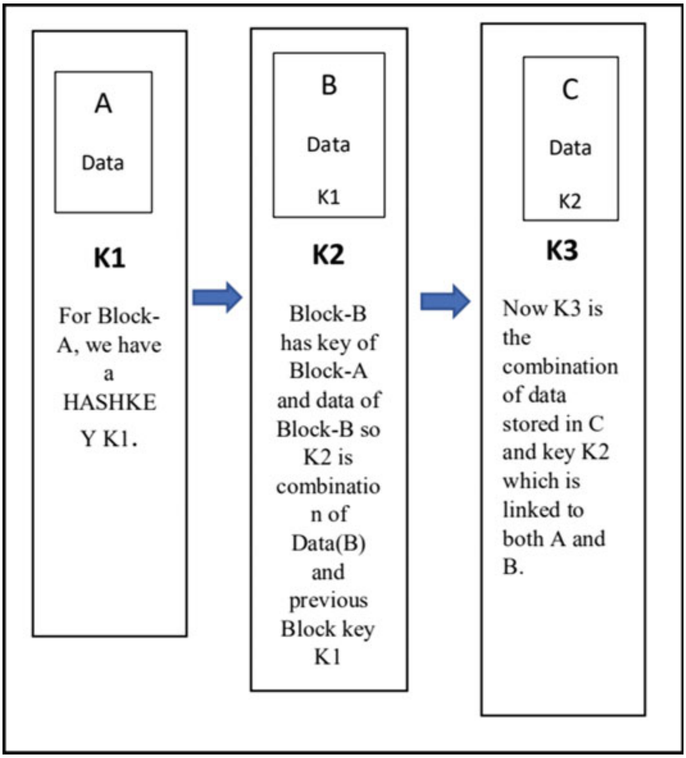


Fig. 2 Record keeping through hashing

used in the supply chain are Radio Frequency Identification (RFID), Wireless Sensor Network (WSN), cloud computing, middleware, and IoT application in software [23]. Radio Frequency Identification (RFID) and Wireless Sensor Network (WSN) are the two most important pillars of IoT [33]. *Cloud computing* provides a relationship between hardware and software to deliver information across the network. It's very easy to scale up or scale down any data anytime from anywhere [20]. Another component is *Availability of large connection*, which plays a very important role in IoT as the communication among different devices is through the internet only [19]. IOT being a worldwide network involves massive data transfer after every single minute so there is a possibility of data complications, and there might be communication fluctuations also which poses a great hurdle in the data transfer route and that needs to be eliminated [22]. 5G will provide a great speed internet that will resolve all the problems arising in a 4G generation as it includes massive input and massive output which helps to achieve network capabilities [1]. Next component is *big data;* IoT completely relies on sensors, real-time ones. These are the only materials that sense the quantity, matter, and input and provide the data for further analysis [21]. Sensors are available in every single node of IoT.

2.3 Machine Learning

Machine learning is a statistical language that uses the scientific study of algorithms and statistics models to resolve and perform complex and specific task with the help of a computer system without using any external or human instructions. It is generally relying on data, patterns, and inference and considered to be a subset of artificial intelligence. In this, some mathematical models are created or build on the basis of simple and previously provided data called training data using machine learning algorithms. After building the mathematical blocks and models, models help to make predictions and decisions without being externally programmed to perform the task. ML is a sub-field of analytic and computer science that uses pattern recognition to build models, and its main work is to convert the raw data into useful information and knowledge through designed algorithms. Using machine learning we can mitigate some of the limitations of using humans to categorize results including Humans uses intuitions and experience, Limited by memory and time, Hard on large scale to replicate, adjust to improve predictions, Explicit and direct outcomes. Data mining is one of the main fields of machine learning to study to focus on the analysis of data through unsupervised learning.

3 Present Challenges in SC

The supply chain has now been more complex with increasing demand and high growth in the industrial sector. It should be managed efficiently to maximize profit and maintain the reputation of the company and quality of product. The issue begins with the measure of paperwork or deskwork that goes into each exchange that the players go into. It is noted that the documents exchanged between the parties will dictate the terms and conditions of the contract between them, a vital issue to consider in case a dispute arises between the parties at a later stage. This huge flow of information between various supply chain stakeholders may be the reason behind the dangerous "paperwork battle". Hence, we can say that most of the problems in the supply chain exist because of this massive information flow [15]. Parties must rely on each other to relay the correct information promptly, and each must reconcile it at their end. Many companies choose to outsource the reconciliation and verification of their records to a neutral third party, which is a very expensive process that has not yielded the necessary results because each company has their own secrets, and they will not disclose their confidentiality and could not trust the other party to tell them what is owed to them so companies incur considerable costs in employing professionals to audit the records on their behalf [16]. Nevertheless, this entire process of having to crosscheck such massive amounts of data in an attempt to synchronize them is redundant and inefficient. Another most important challenge for asset management is to analyze a large amount of data in a short period to provide information for decision making in a timely fashion [34]. The rapid proliferation of sensing and data systems after combined with cheap data storage is resulting in the age of "BIG DATA". This leads to a rise in adopting new strategies and workflow for the supply chain models. Another most important issue in existing supply chain is the payment issue. According to the survey of EY, it has seen that most of the fortune 100 companies have 60 days of sales outstanding in the market at any point in time [14]. In today's competitive market, it is very difficult to outstand the payment of sale for this much longer period. Next issue is detecting fraud when it occurs, which is as difficult as detecting the source of any other inconsistencies in the data transferred over today's overly complex supply chains. Another major issue in SC comes to assure the quality of the product that the company claims. How the customer will know what are the components or raw materials that the manufacturer used to make a product. Are the raw materials claimed by the manufacturer actually used or not? There is always a sort of confusion in the customer mind. Tracing the source of goods is quite difficult to know for the customer in today's SC management system. Another issue is tracking the goods and forecasting the inventory shortages and demand which is also very difficult in ordinary SC management [5]. Hence, there is a need of sort of improvement in existing supply chain and to improve its efficiency.

3.1 Blockchain in Supply Chain

Blockchain finds a key role in SC for smart contracts, asset tracking, secure and error-free order fulfillment, cyber security. Payment delay can be a barrier to the supply chain as today's supply chain system is a paper-based system and it takes a lot of time and human effort, which includes lots of checkpoints that waste a lot of time. BT can resolve this problem as it can automate the systems and transactions by identifying all stakeholders (SC and Trading), creating process map (Transaction and Information flows), identifying risks associated with SC (categorized it in high, medium and low risks), develop immediate response for these risk management, using IoT or other AI devices to manage above tasks [26]. The characteristics of the BC (safe, secure, trustworthy, traceable, auditable, and collaborative) are the ideal feature that an SC management required. When supplier, retailer, and manufacturer use a common, combined, and decentralized ledger for transaction of data and information, this makes the SC stronger. The data or information's they share is saved on the single decentralized server, and there is no need of extra invoice, regular reminders, traceability of goods, record of inventory, receipts, shipment notification, and many more not required activities can be easily eliminated from the SC by using the tools of AI [30]. One of the main advantages of BC in SC is that BC is scalable so it can take up any length based on the retailer, supplier, and manufacturer without making it more complex and hectic [20]. As the BC is transparent to all the members so the trust issue of the parties is eliminated from the SC. The parties need not bother about trust, honesty, and accuracy. The decentralized ledger maintains each flow of information and alerts all the parties connected in the chain when any tempering is done with information or transaction and makes it transparent to every member connected in the chain [29]. BC eliminates the extra paperwork, unnecessary manpower, frauds, errors, lead time, unnecessary inventory storage, forecasting demand and increases transparency and trust between the parties. By using BT, a complete information collection and delivery process can be recorded which solves the problem of delay in information transfer and also increase traceability [8].

3.2 Internet of Things in Supply Chain

Supply chain is a very large network that faces several challenges including cost, complexity, global competition, vulnerability. To overcome such problems, the Internet of Things (IoT) is integrated with the supply chain to provide it a better environment [26]. IoT leads to enhance management of inventory, maximizes the transparency of logistics. RFID plays a vital role in the supply chain (warehouse, transportation, etc.) Cloud computing facilitates online access to the shared pool of information. IoT facilitates real-time information exchange. It completely revolutionizes the supply chain effectively and efficiently. Technological advances such as IoT and Industrial 4.0 and automation help to optimize the effectiveness of operations across the supply chain partners [9]. In context to the centralized supply chain where orders from online customers are delivered independently, a new delivery strategy based on synthetically disposed orders is proposed to decrease the outbound delivery cost [10].

3.3 Machine Learning in Supply Chain

Machine learning makes it possible to discover new and different patterns in supply chain data by depending on the algorithms of machine learning. These algorithms quickly pinpoint and catch the most influential factors to a supply network's success while constantly learning the process. The automatic ML platform is suitable for smart cities that need sensitive info [7]. ML holds great promise for lowering service and product costs, serving better and speeding up the processes of industry recognized as an important application of technology development, gaining momentum across industries. The new patterns in supply chain data have the energy and potential to revolutionize any business [27]. Machine learning algorithms are finding a new way in supply chain data on a daily basis with the greatest predictive accuracy and some of the key factors for the same are inventory level, supplier quality, demand forecast, procure to play, production planning, order-to-cash, transportation management, etc. [13].

3.4 Smart Contracts: An AI-Based Application

A smart contract is a program based on the decentralized system which is actuated by some assets or currency, and it runs the code automatically. This contract performs its predefined conditions like transfer the assets from one person to the other person. Assets are like money, information, data, etc., which actuates the self-executing contract and then the program will generate a receipt and store it in virtual contract in which a virtual key will be generated and recorded for the decentralized ledger [30]. When the program is actuated it will hold the receipt and key for a specified date. On specified date both the parties get their assets. If the key is transfer to the person, the owner is supposed to be paid and the program will automatically transfer the particular assets to the owner. If the key is not transferred, the program will generate refund for the same. The program will automatically get canceled after the specified date and any alteration with that contract will generate message for each person that is connected to that Blockchain [5]. The adaptation of this concept leads SC to a smart ecosystem. In the automotive industry of smart cities, trusted suppliers in the supply chain life cycle are carefully selected, managed, audited, and certified to deliver reliable, consistent, quality services [17]. The smart contract can take care of whole SCM system, i.e., from raw material sources and manufacturing up to their maintenance and recycling phase in the supply chain lifecycle.

4 Discussion: Challenges and Possible Solutions

There are many flaws in the existing SC that can be avoided using the modern technology. We have discussed above some of these challenges which a supply chain management system is facing in today's competitive market. To overcome these flaws the AI tools like BC, IOT devices, Machine Learning, Cloud computing, etc., can be implemented in SCM. When BC, IOT, and ML are implemented together to SC, it can make many changes to the SCM and can make it more transparent and flexible. Major challenges faced by the proper functioning of supply chain are trust and sharing of information [26]. These challenges must be tackled through the combination of BC and IoT. It brings *continuity of information* with the immutable nature of Blockchain, sharing of information among different people involved in supply chain will be a key to ensure traceability, and a link between physical and information flows. IoT made it possible as the data linked to IoT devices can be transformed physically into outputs [23]. It also improves a*ccessibility of Information* by making the whole supply chain fast and transparent by adopting decentralized ledger techniques, i.e., Blockchains with IoT and also provides necessary access to information to leverage upon large data produced along the supply chain [24]. When the BT with other AI tools is implemented the problem of outstanding sales in the market can be solved by which the company should not wait for days to get paid and restart their manufacturing [23]. Apart from this by increasing the transparency in SC, customer satisfaction and assurance can be achieved easily. The customer can easily know the raw materials claimed by the company are actually used in the product [12] and with help of IoT devices can easily track the live location of the product.

Machine Learning is another AI tool which plays a major role in increasing the efficiency of SC by making the machines smarter and more sustainable. The ML increases the efficiency of inside plant of the industry which ultimately increases the efficiency of SC. When the ML is implemented various types of risks are avoided. When the machine starts learning by previous data drives that is transferred through IoT and start making models and patterns by choosing the correct algorithm and matrices then SC can make better predictions based on previous data line comes with a better and convenient way to react further. Machine learning algorithms and other AI tools integration is able to handle and analyze large and wide data sets easily and very fast and this empowered SC would be more efficient with improved demand forecast accuracy, improved supplier delivery performance, risk minimization, reduced freight cost, and also provide collaborative chain networks. It also enables SC to maintain and inspect all physical assets across an entire network making the supply chain more effective, more transparent, more reliable, more sustainable, and ease in execution and thus gaining a greater adoption in logistics. Smart Contract is the major solution to the problem that existed in SC. It can combine all the tools of AI together and can give us the desired result. Many of the companies like DuPont, Dow Chemical, Tetra Pack, Port Houston, and Rotterdam Port Community System Port base, the Customs Administration of the Netherlands, and the U.S. Customs and Border Protection have tried to implement these tools and are getting better results.

In spite of this many companies are trying to collaborate with the consulting firms like EY, Accenture, and IBM for finding out the better solution to implement this on SC.

When the smart contract is actuated it is responsible for the functioning of the contract by its own. It contains all the do's and don'ts and all the possibilities of outcomes and certain fixed condition to deal with these outcomes. The only thing the management does is to actuate the smart contract by various means. IOT devices can be used for that. It can transfer the flow of information from one point to another point using the internet source and can be operated from any area irrespective of specific location. A manufacturer can operate its machine and can able to control it from anywhere. Sudden flaws and shutting down of plant can also be avoided from this device.

In India, SC is not using these tools as there are many problems to implement these tools practically. To implement these tools people should have a better understanding of IT sector which is quite not possible for most of the developing countries. The adaptability of this new technology is also very slow because of the mentality and unawareness of the people. Increasing unemployment due to recession and lack of required skill set is also a barrier. The company cannot directly implement this new technology without the new required skilled staff and fired the old staff due to a lack of skills as per the norms and ethics of the company. High-speed Internet connectivity is the backbone of AI without which the whole system is useless. The availability of such high-speed connections takes time and will be expensive in its initial days due to which many industries are not willing to invest in these technologies. This technology is a future-based technology and will take some time to be implemented in developing countries like India.

5 Conclusion and Future Research Directions

The current state of art illustrates that both IOT and Blockchain play an important role in creating a secured and fast happening world. With this growing world and technology, security issues also arise. Major threat for IOT is the malware or hacker interference. By integrating Blockchain with IOT, security issues can be resolved [24]. Blockchain being a third-party removal system will automatically remove the unwanted interferences hence allow the data to float freely with proper fluidity. The impact of Blockchain and IOT integration leads to decentralization and scalability, reliability, security, autonomy, identity [1]. By using AI tools-based smart contracts, transaction fees can be reduced by avoiding the third-party contract, instead of payment delay immediate payment can be done and fair distribution of payment would be done as every agreement is bound by the contract [15]. Some of the major advantages of this concept are *autonomy* (reduce rely on brokers), *trust, safety, backup, accuracy, savings, speed.* There is a huge range of application of smart contracts in various sectors like *government* (voting system), *healthcar*e (insurance claim), *real estate* (remove middlemen like brokers), *management* (increase accuracy, transparency, and automate the system and reduce the lead time wasted in approvals). Nowadays most of the business and trade sectors are looking forward for adapting this concept in their existing supply chain. There are still some challenges to this new concept as if the code has some bugs or not executed properly, how government should regulate these contracts, how government should tax these smart contracts transactions.

References

1. Mistry, I., Tanwar, S., Tyagi, S., Kumar, N.: Blockchain for 5G-enabled IoT for industrial automation: A systematic review, solutions, and challenge. Mech. Syst. Sign. Process. **135** (2020)
2. Blockchain technology for enhancing supply chain Resilience: Hockey Min. Bus. Horiz. **62**, 35–45 (2019)
3. Azzia, R., Kilany Chamouna, R., Sokhnb, M.: The power of a blockchain-based supply chain. Comput. Indus. Eng. **135**, 582–592 (2019)
4. Czachorowski, K., Solesvik, M., Kondratenko, Y.: The application of Blockchain technology in the Maritime Industry. Springer Nature Switzerland AG (2019)
5. Chang, S.E., Chen, Y.C., Lu, M.F.: Supply chain re-engineering using blockchain technology: A case of smart contract-based tracking process. Technol Forecast Soc Change **144**, 1–11 (2019)
6. Kamblea, S.S., Gunasekaran, A., Gawankar, S.A..: Achieving sustainable performance in a data-driven agriculture supply chain: A review for research and applications. Int. J. Prod. Econ. **219**, 179–194 (2019)
7. Lee, M.L., Yoo, J., Kim, S.W., Lee, J.H., Hong, J.: Autonomic machine learning platform. Int. J. Inf. Manage. **49**, 491–501 (2019)
8. Niu, X., Li, Z.: Research on Supply Chain Management Based on Blockchain Technology. IOP J. Phys. **1176** (2019)
9. Manavalan, E., Jayakrishna, K.: A review of Internet of Things (IoT) embedded sustainable supply chain for industry 4.0 requirements (2019)
10. Nawaz, F, Janjua, N. K., Hussain, O.K.: Predictive complex event processing and reasoning for IoT-enabled supply chain (2019)
11. Baryannisa, G., Danib, S.: Grigoris Antonioua, Predicting supply chain risk using machine learning. Thetrade-off between performance and interpretability (2019)
12. Coronado Mondragon, A. E., Coronado, C.E.: Investigating the applicability of distributed ledger/blockchain technology in manufacturing and perishable goods supply chains. In IEEE 6th International conference on Industrial Engineering and Applications (2019)
13. Settemsdal, S., Siemens:Machine Learning and Artificial Intelligence as a Complement to Condition Monitoring in a Predictive Maintenance Setting (2019)
14. Bhandari, B.:Supply Chain Management, Blockchains and Smart Contracts. NYU School of Law (2019)
15. Mushtaq, A., Ul Haq, I.: Implications of Blockchain In Industry 4.O. Pakistan Inst. of Engineering and Applied Sciences (PIEAS) (2018)
16. Koens, T., Poll, E.: The Drivers Behind Blockchain Adoption: The Rationality of Irrational Choices, Radboud University, The Netherlands (2018)
17. Sharma, P.K., Kumar, N., Park, J. H.: Blockchain-based distributed framework for automotive industry in a smart city. IEEE Trans. Indus. Inf. (2018)
18. Kottler, F.: Potential and barriers to the implementation of blockchain technology in supply chain management. University of Hamburg (2018)

19. Li, S., Xu, L.D., Zhao, S.:5G Internet of Things: A survey IEEE (2018)
20. Novo, O.: Blockchain Meets IoT: An Architecture for Scalable Access Management in IoT (2018)
21. Li, S., Xu, L.D., Zhao, S.: J. Indus. Inf. Integr. (2018)
22. Sisinni, E., Saifullah, A., Han, S., Mikael Gidlund, U.: Industrial Internet of Things: Challenges, Opportunities, and Direction. IEEE (2018)
23. Rejeb, A., Keogh, J.G., Treiblmaier, H.: Leveraging the Internet of Things and Blockchain Technology in Supply Chain Management. (2018)
24. Panarello, A., Tapas, N., Merlino, G, Longo, F., Puliafito, A.: Blockchain and IoT Integration: A Systematic Survey (2018).
25. Zabihi Naeini, E.: A machine learning approach to quantitative interpretation. Ikon Science (2018)
26. Deloitte.: Continuous interconnected supply chain with Blockchain and Internet of Things in supply chain traceability (2018)
27. Ball, K., Energy, D., Arbus, T., Odi, U., Sneed, J.: The Rise of the Machines, Analytics, and the Digital Oilfield: Artificial Intelligence in the Age of Machine Learning and Cognitive Analytics (2017)
28. O'Byrne.: Blockchain Technology is Set to Transform the Supply Chain (2017)
29. Cecere, L.: Moving Blockchain Forward: Seven use cases for hyperledger in supply chain (2017)
30. Rosic, A.: Smart Contracts: The Blockchain Technology That Will Replace Lawyers. Blockgeeks (2016)
31. Cao, Q., Banerjee, R., Gupta, S., Li, J., Zhou, W.: B, Jeyachandra. Data driven production forecast using machine learning, Schlumberger. (2016)
32. Weber, I., Xu, X, Riveret, R., Governatori, G., Ponomarev, A., Mendlin, J.: Untrusted Business Process Monitoring and Execution Using Blockchain, School of Computer Science and Engineering, UNSW, Australia (2016)
33. Xu, L. D., He, W., Li, S.: Internet of Things in Industries: A Survey: Transaction on Industrial Informatics IEEE (2014)
34. Subrahmanya, N., Peng, X.U., El-Bakry, A., Reynolds, C.: Advanced machine learning methods for production data pattern recognition (2014)

Industry 4.0 Technologies and Ethical Sustainability

Dhairya Garg, Omar A. Mustaqueem, and Ravinder Kumar

Abstract Industry 4.0 technologies are finding applications in many industrial sectors. But industrial development is societal, ethically sustainable only when the technologies used are cleaner and ethical sustainable. In this research paper, authors have shortlisted eight technologies that act as major pillars of Industry 4.0 (I4.0). These technologies have been critically examined on aspects of ethical sustainability considering Indian micro and small enterprises. For this study, authors have reviewed 55 research papers from different sources such as science direct, emerald insight, Taylor and Frances. The authors have also developed a framework, which reveals the ten major contributors toward ethical sustainable manufacturing in the digital era. Contributors or enablers such as availability of better software /hardware, reduction in e-wastage and manufacturing cost, and awareness on government policies and supports help to enable ethical sustainable manufacturing in the modern digital era.

Keywords Industry 4.0 · Ethical Sustainable Manufacturing. · Concept paper

1 Introduction

Industry 4.0 stands for the fourth industrial revolution which is another trending topic and is discussed in both professional as well as academic areas [1–55]. According to B Sezen et al., "Industry 4.0 can be regarded as a new business mindset that will help businesses and communities move towards sustainable development" [38]. According to Aquilani et al., "The Fourth Industrial Revolution—i.e., Industry 4.0-, today involves the majority of firms and institutions and emerges as a new logic for business models focused on innovation, technology and sustainability" [24]. Smart manufacturing and smart production can be termed as synonyms for the term Industry 4.0, which consists of many technologies used for the development of the value chain resulting in the reduction of lead time, improvement of product quality and efficiency [2]. Because of an insightful availability between assembling frameworks, logistics

D. Garg · O. A. Mustaqueem · R. Kumar (✉)
Department of Mechanical Engineering, Amity School of Engineering and Technology, Amity University, Noida, Uttar Pradesh 201313, India
e-mail: rkumar19@amity.edu

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_17

frameworks, and items/administrations, Industry 4.0 considers progressive new plan, manufacturing, activity, and production frameworks [13]. Also, Industry 4.0 has become another theme for researchers and top managers. Combining systems such as CPS with I4.0 brings in further new features via networking with collaborators in both horizontal and vertical aspects [10].

On the other hand, ethical sustainability, also known as sustainable development, is the "ability to sustain ethically" or "manufacture safe products safely" [15]. The prime focus of sustainability is to meet the present demands without jeopardizing the needs of future generations [35]. Maintaining a sustainable environment has not only become important but essential in the past decades due to the ongoing industrial trends [18]. Sustainability can also be understood as the utilization of resources while considering their depletion and/or how they adversely affect the environment [32]. The significant sustainability issues from the manufacturing point of view include energy utilization, scrap generation, water consumption, and the impact of the manufacturing process on the environment [32]. For coping with the challenges being faced by the industry in meeting the global demand for capital and consumer goods, the industrial value chain ought to be oriented toward sustainability [1]. It, however, pertains to SMEs as the carbon footprint of the poor cannot be factored into the aspects of sustainability, while the MNCs have enough resources and funds to reduce their carbon footprint to an acceptable standard [14, 15, 44].

In this paper, authors have summarized the observations from the literature review done on industry 4.0 and the sustainability of its practices. Finally based on observations authors have developed a framework that reveals the ten major contributors toward sustainable manufacturing in the digital era. Section 2 of the research paper will discuss the literature review. Section 3 will discuss methodology and Sect. 4 will discuss observations of the study. Section 5 will conclude and propose a framework (developed by authors in the current study) on ethical sustainable manufacturing in the digital era of I4.0. This framework highlights the enablers which gives an edge to ethical sustainable manufacturing in the modern era of I4.0. Observations and implications of the study could be beneficial for the manufacturing industries of developing economies.

2 Literature Review

Industry 4.0 has made new changes and vulnerabilities that must be regulated and administered to emphatically affect both business and society [6]. A major transformation can be observed in the way companies are producing goods after the digitalization of manufacturing [8]. The point is to incorporate the maximum number of industries as possible and adjust and upgrade the current innovations to give the necessities of advanced assembling a better fit [11]. The new concept situation originates from the intermingling of various rising advances that permit the progress to a digitized time that presents in the manufacturing plants a keen domain where machines, gadgets, and items are interconnected to adjust, be adaptable, and react rapidly to showcase changes [5].

Industry 4.0 is based upon technologies that can again be classified in many ways. In this paper, the authors have identified eight major technologies, such as Internet of Things (IoT), cloud computing, flexible manufacturing, additive manufacturing, big data analytics, augmented reality (AR), cyber-physical system (CPS), and autonomous robots from review of literature of more than 55 papers. Technologies can be divided into two categories of front and base end technologies. Front end technologies were those which plays a major role such as smart supply chain, smart product, smart manufacturing, and smart work, whereas the base technologies were the supporting ones like IoT, Cloud, Big Data analytics, etc. [4, 43]. Industry 4.0 gives the industry another point of view that enables it to work with innovations to gain the highest efficiency with the negligible utilization of assets in the manufacturing industry; however, it might expose the industry to some cyber threats as well [22].

Adoption of Industry 4.0 technologies in an existing manufacturing system is not very easy due to the presence of many challenges, but its adoption not only helps industrial managers to increase process safety, efficiency, and flexibility but also in making the processes more sustainable in economic, social, and environmental terms [7 & 42]. Man and Strandhagen define sustainable business models as those which instead of simply following a neoclassical approach also incorporate the social and environmental aspects [3]. According to Stock and Obenaus, sustainability has three different dimensions, which are social, environmental, and economical [16]. These are also known as the three pillars of sustainability.

The environmental aspect of it pertains to reducing the environmental impact of the technologies involved in the industry as much as possible. Organizations are focusing on reducing their carbon footprint, water consumption, waste created by packaging, especially the usage of plastics. These organizations, however, have found out that the implementation of some technologies in turn also leads to financial improvements, such as the reduction in packaging material not only benefits environmentally but also economically [36]. However, the fields that will always have great environmental impacts, such as the production of food, mining, curb this issue by imposing and setting benchmarks or standards which help monitor the factors that are required to maintain a healthy physical environment [37].

On the social front, what is important are answers to questions like whether the implementation of new technologies in the industry will lead to the huge layoff of the workforce, how is the product being made, whether any unethical means are being utilized in making of the product, such as child labor, or unfair/unpaid wages to the workers, hazardous/toxic working environment, and how much is the risk of cyber-crime. Employees should be satisfied with the work that is being done by the organization, should feel valued and approved of the business being conducted, and their pre-existing knowledge should complement the implementation and integration and not hinder it [40].

The economic front of a sustainable business is that which is profitable, has a competitive advantage and market orientation which is specific, while keeping in

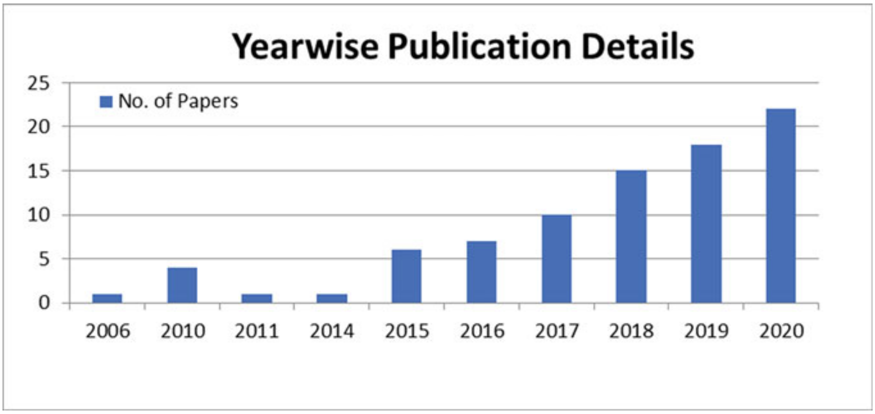


Fig. 1 Year-wise publication details

mind resource conservation and improved quality of life [16]. Economic viability in industrial terms also means that the project or the changes being implemented are economically feasible in the long run, and also affordable, or viable for SMEs, such as setting up of advanced facilities such as autonomous robots and cyber-physical systems, which requires a very high investment and also needs lots of capital to maintain and run [41, 55]. It is also the incorporation of the profits and the economic aspect such as reduced manufacturing cost that convinces organizations to agree with practicing and implementing sustainable strategies [2]. Figure 1 shows the year-wise publication details.

3 Methodology

In this paper, first, relevant sources of publications were searched and selected like science direct, emerald insight, Taylor and Frances. Research papers related to Industry 4.0, sustainability, ethical sustainability, and their applications were searched. The literature review was made by the method of systematically reviewing papers. The review methodology followed is shown graphically in Fig. 2.

This concept paper tries to find research which has been conducted in the past related to sustainability and industry 4.0, the keywords used during the search were

Fig. 2 Research methodology

"Industry 4.0", "Sustainability", "Sustainable Manufacturing", "Industry 4.0 Technologies", "ethical sustainability" and "Industry 4.0 and Sustainability". The searches were carried out on the following three websites: "Science Direct", "Emerald Insight", and "Taylor and Francis". Year-wise distribution of research papers has been shown in Fig. 1.

The authors focused on selecting the research papers or case studies relevant in the Indian scenario. Since the review was focused on the manufacturing sector, it was decided to select as many papers related to this field as possible, and eventually narrowed the papers finally studied down to 55.

4 Observations of Study

This paper discussed I4.0 technologies and issues related to ethical sustainability of these technologies. Key analysis of I4.0 technologies, keeping sustainability in background are summarized in Table 1.

5 Conclusion and Proposed Framework on Ethical Sustainable Manufacturing

Many researchers have studied the Industry 4.0 and ethical sustainability as separate issues. Very few studies have been conducted about I4.0 technologies and ethical sustainability aspects holistically considering Indian micro and small enterprises. There is a need to identify the technologies which are globally recognized and ethical sustainable too. Later, these technologies should be checked for their ethical sustainability, individually. Authors developed a framework connecting all the major enablers, which supports or enables the ethical sustainable manufacturing in I4.0. After critically analyzing the industry 4.0 technologies, on three aspects of sustainability, the authors have identified ten enablers for sustainable manufacturing in the digital era (as input enablers for framework). These ten enablers are "Increased customer awareness on Technology", "Top management support and planning", "Attracting local/Foreign Investment", "Infrastructure for new Technologies", "Availability of advanced software /Hardware", "Reduction in e-wastage and manufacturing cost", "Availability of trained workforce", "Development in E-economy", "Social responsibility and investor demands", "manufacture safe products safely" and "Awareness on government policies and support". These enablers help in making the manufacturing processes more ethical sustainable in the scenario of industry 4.0. As these are supporting factors, the arrows point inward toward the "ethical sustainable manufacturing in the digital era" bubble, showing that they are guiding input. For the future course of action/study, the framework suggested by the authors should be analyzed and examined in the practical scenarios of different developing economies.

Table 1 I4.0 technologies and ethical sustainability

I4.0 technologies	Sustainability issues			References
	Environmental	Social	Economical	
IoT	Many IoT devices are used; Increased use of non-renewable resources for making chipsets; Increases E-waste generation, abundance of data generated	Privacy and security issues; Increased vulnerability from hackers; Impacts the human willingness to work due to decreased human intervention	Highly competitive industry; Constant up-gradation is required; High initial cost required; Needs expensive supporting technology	[45, 48, 49]; Own contribution
Cloud computing	Big servers of cloud services companies consumes energy 24 × 7 × 365; Leaves high carbon footprint too	Security and trust issues; chances of data loss and leakage on public cloud spaces	Private cloud space are paid, Not affordable for many SMEs	[46, 47]; Own contribution
Flexible Manufacturing lines	Energy consumption will increase; Will create more e-waste, as there is no proper disposal plan	Have to Lay off unskilled workers; Lack of education and knowledge; Small businesses will shut down	High cost of R&D; Difficult design and installation; High maintenance cost; Difficult to fit in an existing facility	[9, 52]; Own contribution
Additive manufacturing	Can't recycle the support structure material used; Consumers more energy than conventional machining and molding processes	Copyright issues; Requires skilled labor; Cuts on labor employment	Very slow process, Expensive process implementation; Not suitable for mass manufacturing; Requires controlled environment for the functioning of expensive machines	[12, 23, 51]; Own contribution
Big Data and Analytics	High specification machines required; Consumes more energy; Leaves high carbon footprint	Requires high skilled manpower; job loss for semi-skilled and unskilled manpower;	Requires highly trained and hence high paid employees; Required software is expensive	[17, 34, 53, 54]; Own contribution

(continued)

Table 1 (continued)

I4.0 technologies	Sustainability issues			References
	Environmental	Social	Economical	
Augmented Reality	Will create a need for more electronic gadgets attached to every new manufacturing facility, leading to increased e-waste; Increased carbon footprint	Performance varies based on workers' experience; Training and skills of operators not utilized; Leads to the layoff of workers	The hardware required and the devices are costlier as compared to training existing manpower	[31–33]; Own contribution
Cyber-Physical Systems (CPS)	Reliability of real-time data; Availability of data in abundance; High energy consumption; High carbon footprint	Requires highly trained operators for running and maintenance of automated devices; Leads to the layoff of workers	Requires high initial investment; Expensive equipment; Difficult to procure; Difficult to incorporate with pre-existing systems	[1, 28–30, 39, 50]; Own contribution
Autonomous Robots	Has high energy consumption; The robots work autonomously with minimum interference	Large no of workforce layoff, due to automation of the procedures and tasks	Very expensive equipment; Requires high and expensive maintenance, not suitable for most of micro and small firms; Requires high paid & trained workforce	[25–27]; Own contribution

The two pillars of research, that is academia and industry should do empirical examination on all insights of outcomes and elements of the framework. Figure 3 shows the proposed framework on ethical sustainable Manufacturing in the Digital Era.

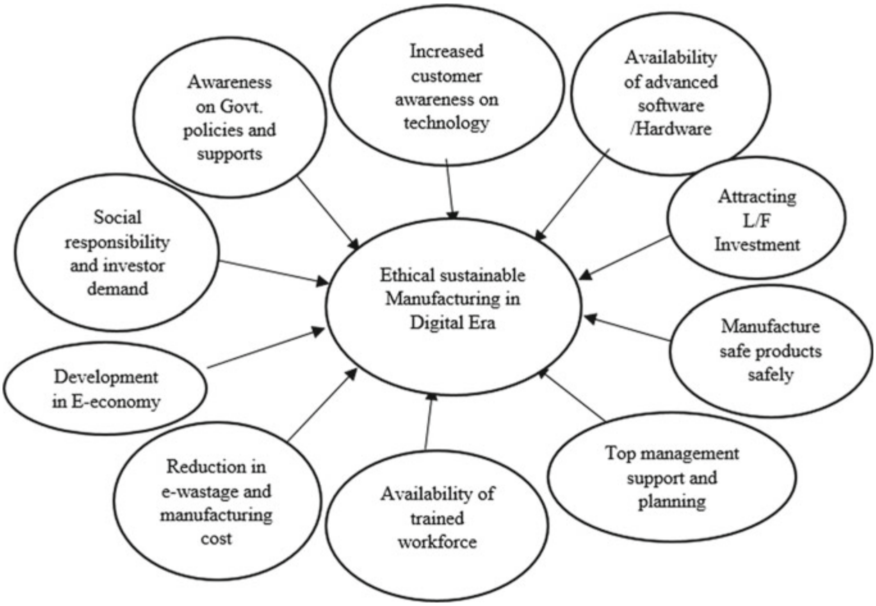


Fig. 3 Proposed framework on ethical sustainable Manufacturing in the Digital Era

References

1. Stock, T., & Seliger, G.: Opportunities for sustainable manufacturing in industry 4.0. Procedia Cirp. **40**, 536–541 (2016)
2. Kamble, S. S., Gunasekaran, A., & Gawankar, S. A.: Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives. Process Saf. Environ. Protect. **117**, 408–425 (2018)
3. Schuh, G., Anderl, R., Gausemeier, J., Ten Hompel, M., & Wahlster, W. (Eds.).: Industrie 4.0 Maturity Index: Managing the Digital Transformation of Companies. Utz, Herbert (2017)
4. Frank, A. G., Dalenogare, L. S., Ayala, N. F.: Industry 4.0 technologies: Implementation patterns in manufacturing companies. Int. J. Prod. Econ. **210**, 15–26 (2019)
5. Castagnoli, R., Büchi, G., & Cugno, M.: How Industry 4.0 Changes the Value Co-Creation Process. In: Customer Satisfaction and Sustainability Initiatives in the Fourth Industrial Revolution (pp. 21–36). IGI Global (2020)
6. Büchi, G., Cugno, M., & Castagnoli, R.: Smart factory performance and Industry 4.0. Technological Forecasting and Social Change, **150**, 119790 (2020)
7. Kumar, R.: Sustainable Supply Chain Management in the Era of Digitalization: Issues and Challenges. In: Editor, Efosa C. Idemudia, *Handbook of Research on Social and Organizational Dynamics in the Digital Era.* IGI Global, 2020. 446–460. Web. 1 Aug. 2019. doi:https://doi.org/10.4018/978-1-5225-8933-4.ch021. (Publisher & ISSN/ISBN No. 290319–062455). Arkansas Tech University, USA. (2020)
8. Iyer, A.: Moving from Industry 2.0 to Industry 4.0: A case study from India on leapfrogging in smart manufacturing. Procedia Manuf. **21**, 663–670 (2018)
9. Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G.: The expected contribution of Industry 4.0 technologies for industrial performance. Int. J. Prod. Econ. **204**, 383–394 (2018)

10. Chiarini, A., Belvedere, V., & Grando, A.: Industry 4.0 strategies and technological developments. An exploratory research from Italian manufacturing companies. Prod. Plann. Control, 1–14 (2020)
11. Kumar, A., Nayyar, A.: si 3-Industry: A Sustainable, Intelligent, Innovative, Internet-of-Things Industry. In: A Roadmap to Industry 4.0: Smart Production, Sharp Business and Sustainable Development (pp. 1–21). Springer, Cham (2020).
12. Javaid, M., Haleem, A.: Current status and challenges of Additive manufacturing in orthopaedics: an overview. J. Clin. Orthopaedics Trauma **10**(2), 380–386 (2019)
13. Matt, D. T., Rauch, E.: SME 4.0: The Role of Small-and Medium-Sized Enterprises in the Digital Transformation. In: Industry 4.0 for SMEs (pp. 3–36). Palgrave Macmillan, Cham (2020)
14. Henao-Hernández, I., Solano-Charris, E. L., Muñoz-Villamizar, A., Santos, J., Henríquez-Machado, R.: Control and monitoring for sustainable manufacturing in the Industry 4.0: A literature review. IFAC-PapersOnLine **52**(10), 195–200 (2019)
15. Caiado, R.G.G., Leal Filho, W., Quelhas, O.L.G., de Mattos Nascimento, D.L., Ávila, L.V.: A literature-based review on potentials and constraints in the implementation of the sustainable development goals. J. Clean. Prod. **198**, 1276–1288 (2018)
16. Stock, T., Obenaus, M., Kunz, S., & Kohl, H.: Industry 4.0 as enabler for a sustainable development: A qualitative assessment of its ecological and social potential. Process Safety Environ. Protect. **118**, 254–267 (2018)
17. Windolph, S.E.: Assessing corporate sustainability through ratings: Challenges and their causes. J. Environ. Sustain. **1**(1), 5 (2011)
18. Yadav, G., Luthra, S., Jakhar, S., Mangla, S. K., Rai, D. P.: A framework to overcome sustainable supply chain challenges through solution measures of industry 4.0 and circular economy: An automotive case. J. Clean. Prod. 120112 (2020).
19. Culot, G., Nassimbeni, G., Orzes, G., Sartor, M.: Behind the definition of industry 4.0: Analysis and open questions. Int. J. Prod. Econ. 107617 (2020)
20. Lass, S., Gronau, N.: A factory operating system for extending existing factories to Industry 4.0. Computers in Industry, **115**, 103128 (2020)
21. Corallo, A., Lazoi, M., & Lezzi, M.: Cybersecurity in the context of industry 4.0: A structured classification of critical assets and business impacts. Computers in Industry, **114**, 103165 (2020)
22. Ingaldi, M., Ulewicz, R.: Problems with the implementation of Industry 4.0 in Enterprises from the SME Sector. Sustainability, **12**(1), 217 (2020)
23. Ford, S., Despeisse, M.: Additive manufacturing and sustainability: an exploratory study of the advantages and challenges. J. Clean. Prod. **137**, 1573–1587 (2016)
24. Aquilani, B., Piccarozzi, M., Silvestri, C., & Gatti, C.: Achieving Environmental Sustainability Through Industry 4.0 Tools: The Case of the "Symbiosis" Digital Platform. In: Customer Satisfaction and Sustainability Initiatives in the Fourth Industrial Revolution (pp. 37–62). IGI Global (2020)
25. Tang, C. S., Veelenturf, L. P.: The Strategic Role of Logistics in the Industry 4.0 Era. Forthcoming in: Transportation Research Part E: Logistics and Transportation Review (2019)
26. Ball, D., Ross, P., English, A., Patten, T., Upcroft, B., Fitch, R., ..., Corke, P.: Robotics for sustainable broad-acre agriculture. In Field and Service Robotics (pp. 439–453). Springer, Cham (2015)
27. Bechtsis, D., Tsolakis, N., Vlachos, D., Iakovou, E.: Sustainable supply chain management in the digitalisation era: The impact of automated guided vehicles. J. Clean. Prod. **142**, 3970–3984 (2017)
28. Zhou, K., Liu, T., Zhou, L.: Industry 4.0: Towards future industrial opportunities and challenges. In: 2015 12th International conference on fuzzy systems and knowledge discovery (FSKD) (pp. 2147–2152). IEEE (2015, August)
29. Marilungo, E., Papetti, A., Germani, M., Peruzzini, M.: From PSS to CPS design: a real industrial use case toward Industry 4.0. Procedia Cirp. **64**, 357–362 (2017)
30. Wlodarczyk, T. W., Rong, C.: On the sustainability impacts of cloud-enabled cyber physical space. In: 2010 IEEE Second International Conference on Cloud Computing Technology and Science (pp. 597–602). IEEE (2010, November)

31. Mourtzis, D., Vlachou, E., Zogopoulos, V., Fotini, X.: Integrated production and maintenance scheduling through machine monitoring and augmented reality: An Industry 4.0 approach. In: IFIP International Conference on Advances in Production Management Systems (pp. 354–362). Springer, Cham (2017, September)
32. Ibarra, D., Ganzarain, J., Igartua, J. I.: Business model innovation through Industry 4.0: a review. Procedia Manuf. **22**, 4–10 (2018)
33. Strandhagen, J. O., Vallandingham, L. R., Fragapane, G., Strandhagen, J. W., Stangeland, A. B. H., Sharma, N.: Logistics 4.0 and emerging sustainable business models. Adv. Manuf. **5**(4), 359–369 (2017)
34. Lee, J., Kao, H. A., & Yang, S.: Service innovation and smart analytics for industry 4.0 and big data environment. Procedia Cirp, **16**, 3–8 (2014)
35. Sreenivasan, R., Goel, A., Bourell, D.L.: Sustainability issues in laser-based additive manufacturing. Physics Procedia **5**, 81–90 (2010)
36. Kumar, R.: Espousal of industry 4.0 in Indian manufacturing organizations: Analysis of enablers. In: Editor, Gaur, L. & Others, Handbook of Research on Engineering Innovations and Technology Management in Organizations, IGI Global, ISBN13: 9781799827726|ISBN10: 1799827720|EISBN13: 9781799827733. https://doi.org/10.4018/978-1-7998-2772-6 (2020)
37. Bhanot, N., Rao, P.V., Deshmukh, S.G.: Enablers and barriers of sustainable manufacturing: results from a survey of researchers and industry professionals. Procedia CIRP **29**, 562–567 (2015)
38. Çankaya, S. Y., Sezen, B.: Industry 4.0 and Sustainability. In: Handbook of Research on Creating Sustainable Value in the Global Economy (pp. 67–84). IGI Global (2020)
39. Botlíková, M., Botlík, J.: Local extremes of selected industry 4.0 indicators in the European space—structure for autonomous systems. J. Risk Financial Manage. **13**(1), 13 (2020)
40. Vaidya, S., Ambad, P., & Bhosle, S.: Industry 4.0–a glimpse.Procedia Manuf. **20**, 233–238 (2018)
41. Paravizo, E., Chaim, O. C., Braatz, D., Muschard, B., Rozenfeld, H.: Exploring gamification to support manufacturing education on industry 4.0 as an enabler for innovation and sustainability. Procedia Manuf. **21**, 438–445 (2018)
42. de Amorim, W. S., Deggau, A. B., do Livramento Gonçalves, G., da Silva Neiva, S., Prasath, A. R., & de Andrade, J. B. S. O.: Urban challenges and opportunities to promote sustainable food security through smart cities and the 4th industrial revolution. Land Use Policy, **87**, 104065 (2019)
43. Cohen, B.: Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability. Technol. Soc. **28**(1–2), 63–80 (2006)
44. Sukkasi, S., Chollacoop, N., Ellis, W., Grimley, S., Jai-In, S.: Challenges and considerations for planning toward sustainable biodiesel development in developing countries: Lessons from the greater Mekong subregion. Renew. Sustain. Energy Rev. **14**(9), 3100–3107 (2010)
45. Ghobakhloo, M.: Industry 4.0, digitization, and opportunities for sustainability. J. Clean. Prod. 119869 (2019)
46. Singh, S., Jeong, Y.S., Park, J.H.: A survey on cloud computing security: Issues, threats, and solutions. J. Netw. Comput. Appl. **75**, 200–222 (2016)
47. Thakur, S., & Chaurasia, A.: Towards Green Cloud Computing: Impact of carbon footprint on environment. In: 2016 6th International Conference-Cloud System and Big Data Engineering (Confluence) (pp. 209–213). IEEE (2016, January)
48. Čolaković, A., Hadžialić, M.: Internet of Things (IoT): A review of enabling technologies, challenges, and open research issues. Comput. Netw. **144**, 17–39 (2018)
49. Bibri, S.E.: The IoT for smart sustainable cities of the future: An analytical framework for sensor-based big data applications for environmental sustainability. Sustainable Cities and Society **38**, 230–253 (2018)
50. Alcácer, V., Cruz-Machado, V.: Scanning the industry 4.0: A literature review on technologies for manufacturing systems. Eng. Sci. Technol. Int. J. (2019)
51. Kellens, K., Mertens, R., Paraskevas, D., Dewulf, W., Duflou, J.R.: Environmental impact of additive manufacturing processes: Does AM contribute to a more sustainable way of part manufacturing? Procedia CIRP **61**, 582–587 (2017)

52. Bag, S.: Flexible procurement systems is key to supply chain sustainability. J. Transp. Supply Chain Manage. **10**(1), 1–9 (2016)
53. Wang, L., & Wang, G.: Big data in cyber-physical systems, digital manufacturing and industry 4.0. Int. J. Eng. Manuf. (IJEM), **6**(4), 1–8 (2016)
54. Witkowski, K.: Internet of Things, Big Data, industry 4.0–innovative solutions in logistics and supply chains management. Procedia Eng. **182**, 763–769 (2017)
55. Dutta, G., Kumar, R., Sindhwani, R. and Singh, R.: Digital transformation priorities of India's discrete manufacturing SMEs—a conceptual study in perspective of Industry 4.0. Compet. Rev. Int. Bus. J. (Forthcoming). https://doi.org/10.1108/CR-03-2019-0031 (2020)

Computer-Aided Diagnostic System for Classification and Segmentation of Brain Tumors Using Image Feature Processing, Deep Learning, and Convolutional Neural Network

Shivanshu Rastogi, Mohammad Akbar, and Dhruv Mittal

Abstract This research aims at the detection of the tumor clusters, found in the brain and classifying the type of tumor using Convolutional Neural Network (CNN) using MR Images of the patient. The proposed technique/mechanism consists of several phases, namely, Acquisition, Refining, Segmentation, and finally the Classification. The image refining process includes several sub-processes such as Noise Removal and Edge Detection. Further, based upon the input of the end-user, the class variance value gets calculated from the extracted features for segmentation and gets stored in a matrix called the convolutional pattern. The developed system classifies the type of tumor that either it is malignant or benign using Neural Network and Deep Learning Algorithms. The Idea of this project is to understand how we can develop industry grade, doctor acceptable, and diagnosable correct; an engineered mechanism for evaluating tumor presence in the subject so that faster and better measures can be taken to provide a good cure to the patient at the early stage.

Keywords Convolutional neural network · MR images · Convolutional matrix · Class variance

1 Introduction

Significance and essential need of medical image processing comes out from the two basic principal application areas, one of them is the enhancement of illustrated details for human-being elucidation and obviously, the other one is to process the site data that can be used by a self-governed machine apprehension.

Medical Image Processing (MIP) has an immense diversity of application areas like as in various kinds of tumors detections, object detection inside the human body through ultrasonic scanning, magnetic resonance imaging, processing of X-Rays, electron micrographs,

S. Rastogi · M. Akbar (✉) · D. Mittal
Moradabad Institute of Technology, Moradabad, UP, India
e-mail: akbar_mit@outlook.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_18

Nuclear Magnetic Resonance Imaging (NMRI) works with the summation of the applications disclose earlier. Moreover, DIP—Digital Image Processing is widely used to solve the wide diversity of problems. Without any single doubt that these blocks require some methods which are capable of analysis of the problems along with the magnifying information for the better visual interpretation for humans. So, by using the methods and technique of DIP combined with state-of-the-art deep learning technology, the described method is mentioned which is capable of identifying tumors in the human brain.

The procedure of image processing [1] such as enhancement, restoration is used for the rectification of the low quality degraded or blurred images. There are some applications of image processing which are even successful and most of the officials are using it in respected different departments such as Astronomy—The study of celestial objects, Defense—To study and monitor the neighboring countries to prepare for the resisting attack, In Biology—Different Medical applications and other regular industrial applications [2].

As per the concern of medical imaging, the images could be finely used in the screening of tumors as well as in the detection of it. To achieve adequate results through this approach, the primary area of application requires the use of some DIP (commonly termed as Digital Image Processing) techniques.

As we all know that "Not Every Tumor is Cancerous, but every cancer was definitely started from a tumor first" and they are usually divided into two categories "Benign" and "Malignant" in which benign is non-cancerous and doesn't usually result in the human death but it does cause some pain and gets dissolved by their own while the malignant ones are cancerous tumors and develop more rapidly, and with this proposed techniques and mechanism the tumors could be segmented and classified to improve the patient's disease transparency.

Thus, with the overall mechanism, we want to give the user the simulation that he/she is suffering from the original tumor (Malignant—the cancerous one) or not with minimal steps involved.

(1) The user will provide the MRI Image to the mechanism (by clicking it or by providing the directory).
(2) The user will get the output result in form of the visualization over the segmented area along with the actual classification that either the MRI image consist of any cancerous tumor or not.

2 Diagnostic System

There are numerous approaches to determine brain cancer, such as Chest-Radiograph (CR), whereas techniques like Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and Sputum Cytology (SC) are some of the other approaches to detect the problem.

The techniques of Image processing provide a very powerful and adequate tool for improving the standard of analysis of tumors. The operation of image processing expertise can amplify the analysis of the radiologists as well as for the doctors in diagnosing diseases and to offer swift or speedy access to medical statistics gained significance in a short time. In this paper, OTSU's algorithm along with Convolutional Neural Network (CNN) has been used as per the processes.

The general illustration of brain cancer-nodule(s) segmentation and classification system consists of five necessary steps, refer Fig. 1. The initial step starts with taking a convocation of MR images from the accessible report by clicking the snaps or arranging the soft copy, if possible. The next step is to go through the image refining procedures, to get the best grade of the clearness and the quality. The third step is Image Segmentation [3, 4] which covers an active role in Image Processing, then here comes the Feature Extraction to generate the values for matching it with the consort proposed matrix, and the fifth step contains classification [5] which will give the diagnosis result after matching the extracted values with the already proposed model.

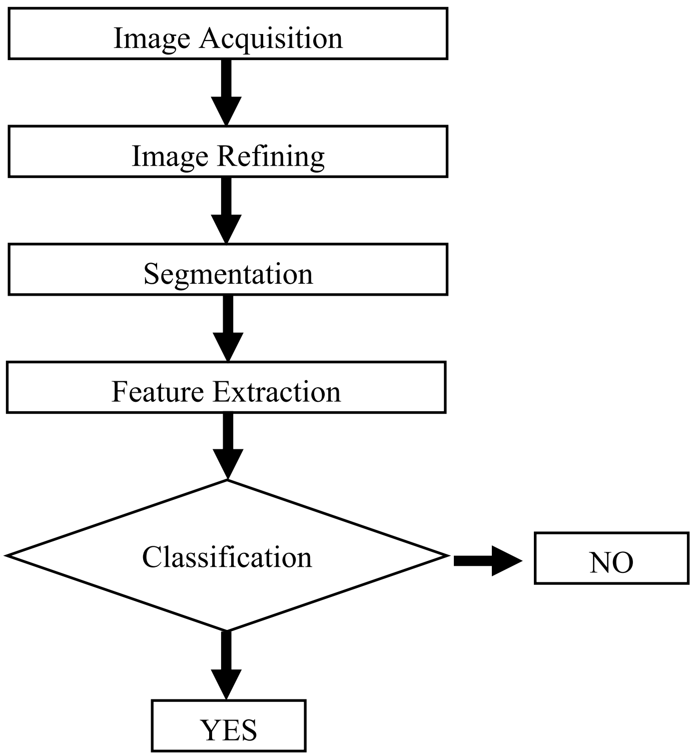


Fig. 1 Flowchart of the proposed mechanism

2.1 Image Acquisition

The initial step in the field of Medical Image Processing (MIP) is Image Acquisition or attainment. The patient's MR image(s) will get collected from the local device memory, or the end-user can click it in the real time from the combined MR report itself. The medical figures or data is usually in DICOM format, but the mechanism allows the own conversion to match the required image with the proposed model. The Magnetic Resonance Images [6] are preferred for the brain diagnosis because they provide more detailed information about the inner organs (soft tissues) and through this means we can visualize the Images in 2D as well as in 3 dimensional images. Therefore, the soft copy of the MR image(s) is given (350px x 350px atleast) in size. Further, the input of MR image(s) contains several noises such as noises like Speckle-Noise, Poisson-Noise, Salt and Pepper Noise, Gaussian-Noise. Therefore, the image refining [7] stage is needed to reduce or to eliminate noises for proper computation.

2.2 Image Refining

Image refining is certainly one of the major categorizations of image processing, which attempts to mold diagnosis further discernible. Image refining is the procedure to escalate the overall standard or the quality of the image, to make the momentous image superior to the original captured or taken image. See Fig. 2.

In this mechanism [8], the additional noise(s) presented in the image is removed, the non-local means algorithm is used for this method. Let us consider '*W*' as the region of the image. Whereas *x* and *y* are two points located inside the region of the image. Then, the algorithm is

$$u(x) = \frac{1}{C(x)} \int_{\Omega} v(y) f(x, y) \mathrm{d}y$$

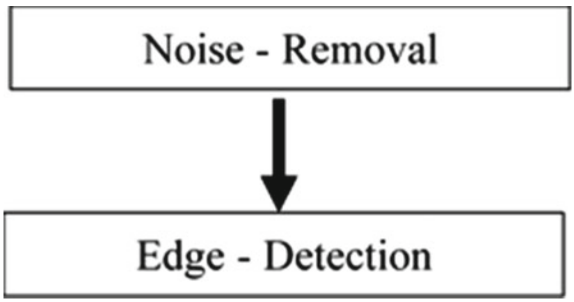


Fig. 2 Modules of image refining phase

where *u(x)* is the sieve value of the image at point *x, v(y)* is the befoul value of the image at-point *y, f(x, y)* is the stack function, and the elemental assess over ∀y ∈ Ω. *C(x)* is a normalizing factor, given by

$$C(x) = \int_{\Omega} f(x, y)\mathrm{d}y$$

After this process, the edges from the input image(s) get extracted and given as input for segmentation. Sobel-Kernel is used in both straight and the sheer management to get the initial derivate in flush (the horizontal) direction (Gx) and plumb (the vertical) direction (Gy). See Fig. 3.

With reference to both bipartite images, we will calculate edge-gradient and the direction for every pixel by using following equations. See Fig. 4 for results.

$$\text{Edge (Fringe) Gradient } (G) = \sqrt{\left(G_a^2 + G_b^2\right)}$$

$$\text{The Angle } (\theta) = \tan^{(-1)} \frac{Gy}{Gx}$$

This method is popularly known as the Canny Edge Detection Algorithm, and in this, the incline (slope) direction is always straight-up to edges. It is now bowed to

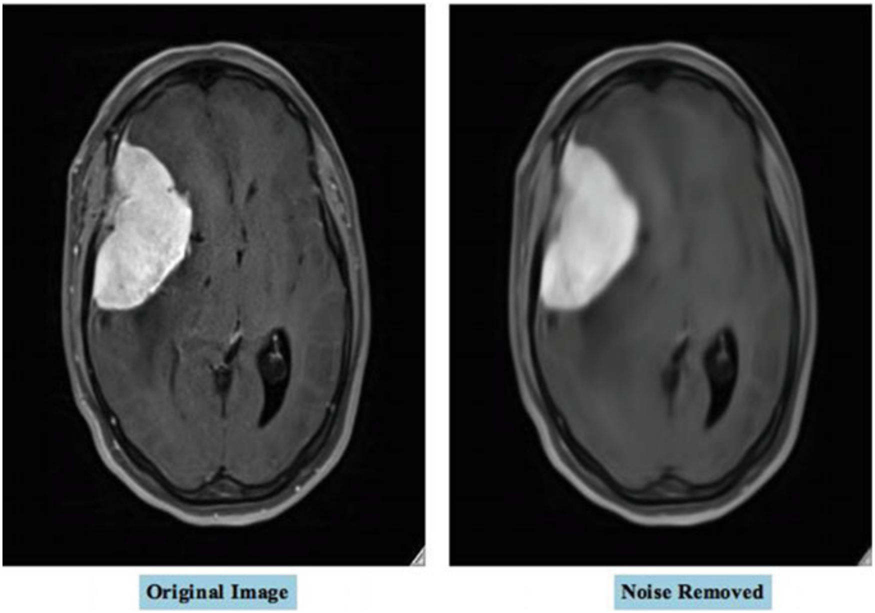


Fig. 3 MR images after noise removal

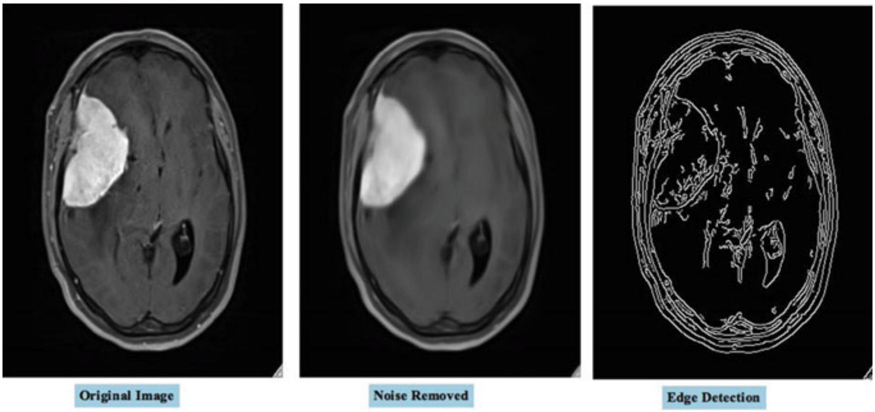


Fig. 4 Images after noise removal and edge detection

one based on four flares representing Plumb (the vertical), Flush (the horizontal), and two Crossways (the diagonal) directions.

2.3 Segmentation

Segmentation is a vital channel for most of the image analysis of subsequent tasks. It splits an image into its compromise regions, areas, and objects. This phase intends to make images smooth or change the depiction of the image into something more consequential and cinch to inspect. The schematic represents the componential processing of the segmentation phase, refer Fig. 5.

3 Experimental Results and Analysis

In this approach [9], we are using *'median filter'*, and as per the collective outputs of the divisionary (Image segmentation) step, attribute—the controlled Watershed's algorithm approach for segmentation has superior authority and better quality than the inception approach. After the segmentation of the tumor from the input MR image, morphological operations are performed to get the segmented part of brain and to disqualify the inessential parts further, by performing some important morphological operations, and it will be used in apparent the brain nodule as well to obtain individual results. In the feature extraction phase, the features extracted from the image is used for the decisive calculation and stratifying the wary area of the brain nodule.

The values from the respected functions get explicitly stored in the Convolutional Matrix, and then the pattern matching is done using neural network (Keras

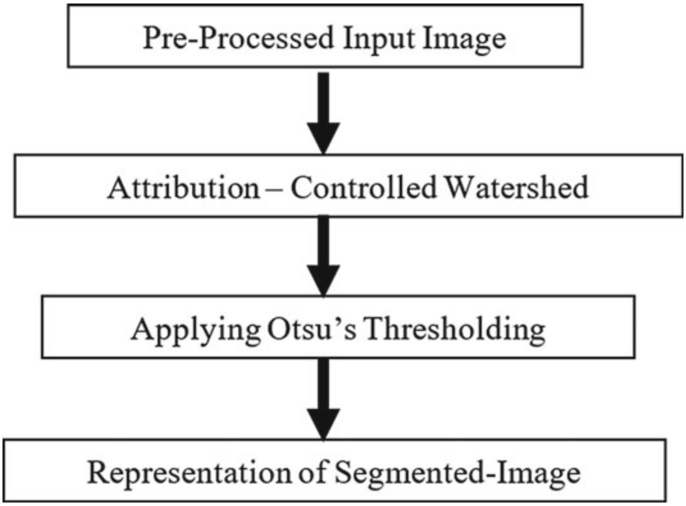


Fig. 5 Classification of segmentation process

for Implementation) and through this way it can help the doctors to finally take the correct resolution by profoundly analyzing the nodule. The valuable execution of the system assess is based on three factors: accuracy, responsiveness, and precision for the appropriate image processing techniques [8, 9].

This system offers reactivity of 100%, attentiveness of 81.23%, and accuracy of 89.78%. The result from this mechanism and the scrutiny of doctors together increase the efficiency of detecting malevolent and benign brain nodules so that the better treatment can be given on time. Moreover, if the cancerous nodule is caught in its earlier or initial stage, then the fortuity of outliving/surviving of the patient escalates. For results, refer Fig. 6.

4 Conclusion

The corporality rate of the dangerous brain cancer is excessive among all of the other kinds of cancers present; it can only be perceived early by detecting the lumps of the brain, and in this study, procedure of image segmentation and further classification are implemented to obtain the early result that can be used for diagnosis of tumor.

By using the steps, both types of nodules could be extracted from the input MR image and get processes in the classification phase with the help of the construction of the convolutional matrix from feature extraction. This ability can help the radiologists and the doctors by providing them the closer detail of the detected nodules without any glitch which is not possible by humans at an earlier stage. This procedure is not so much costly, not time consuming, and easy to use and execute as it is helping

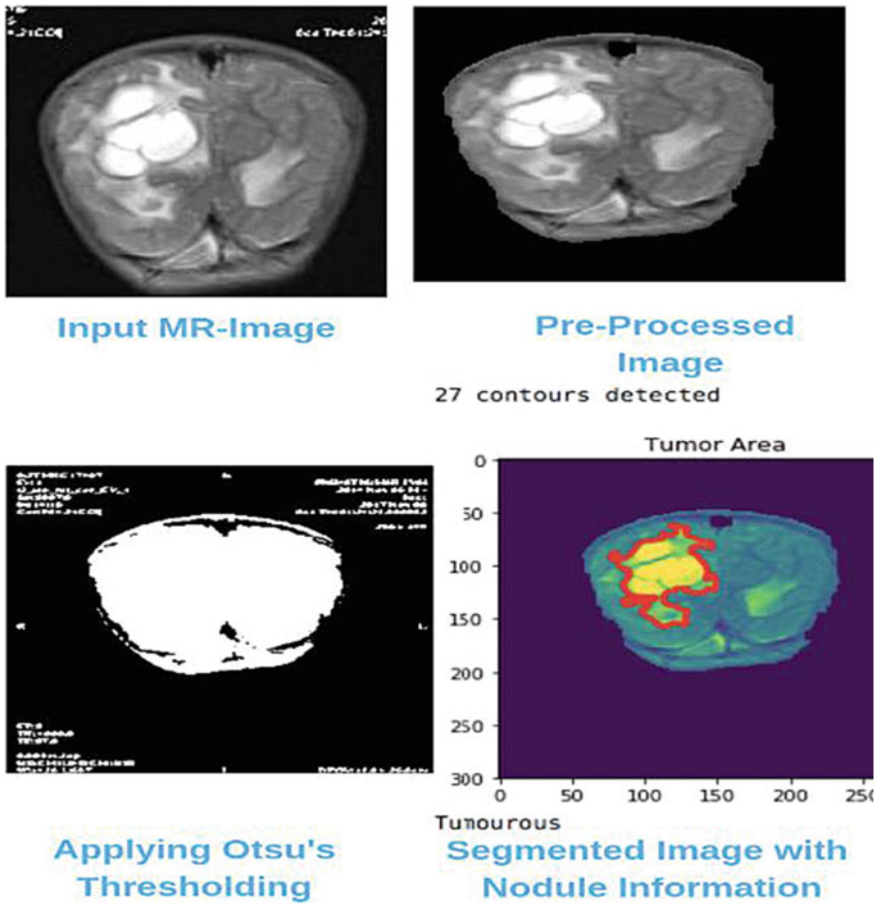


Fig. 6 Results of segmentation process

the right person to take the correct decision in a short time and at a higher rate of accuracy.

References

1. Aborisade, D.O.: A novel fuzzy logic based impulse noise filtering technique. Int. J. Adv. Sci. Technol. **32** (2011)
2. Ahmed: A modified fuzzy c-means algorithm for bias field estimation and segmentation of MRI data. IEEE Trans. Med. Imaging **21**(3) (2002)
3. Chen, C.W., Luo, J., Parker, K.J.: Image segmentation via adaptive K-mean clustering and knowledge-based morphological operations with biomedical applications. IEEE Trans. Med. Imag. 7 (1998)

4. Demirhan, M.T., Guler, I.: Segmentation of tumor and edema along with healthy tissues of brain using wavelets and neural networks. IEEE J. Biomed. Health Inf. **19**(4) (2015)
5. Beckmann, E.C.: CT scan early days. In: Ben George, E., Karnan, M. (eds.) International Journal of Radiology Radiation Oncology All Related Sciences, MRI Brain Image (2014)
6. Enhancement using filtering techniques. Int. J. Comput. Sci. Eng. Technol. IJCSET (2012)
7. Guillemaud, Brady: Automated model-based bias field correction of MR images of the brain. IEEE Trans. Med. Imag. **18**(10) (1999)
8. Jacene, H.A., Goetze, S., Patel, H., Wahl, R.L., Ziessman, H.A.: Advantages of hybrid SPECT/CT versus SPECT alone. Open Med. Imag. J. **2** (2008)
9. Rivaz, H., Boctor, E.M., Choti, M.A., Hager, G.D.: Ultrasound elastography using multiple images. Med. Image Anal. **18**(2) (2014)

Modeling Interrelationships of Sustainable Manufacturing Barriers by Using Interpretive Structural Modeling

Deepak Sharma, Pravin Kumar, and Rajesh Kumar Singh

Abstract The growing demand in the manufacturing sector has yielded serious negative impact on 3Ps (people, planet, and profit), and it requires the most change among the businesses with sustainability goals. Therefore, it becomes very crucial to identify and diminish the outcomes of critical barriers of sustainable manufacturing (SM). This paper analyzes eight vital barriers selected with the opinion of various researchers and industry experts on the basis of their importance; they are then analyzed and prioritize by using interpretive structural modeling (ISM). This technique is used to develop an anatomy model and its findings give a vital insight to managers regarding factors pushing them back for not incorporating SM practices.

Keywords Sustainable manufacturing · Critical barriers · Interpretive structural modeling · Driving and dependence power · MICMAC analysis

1 Introduction

U.S. Department of Commerce (International Trade Administration 2007) explained sustainable manufacturing (SM) as an environmental initiative, "the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound." Sustainability is a gradually vital human activity requirement making sustainable development a prime goal of human development. Sustainable development at its heart is the belief that the development process will tackle social, cultural, and environmental concerns simultaneously and holistically.

D. Sharma (✉)
GLA University, Mathura, India
e-mail: deepak.sharma@gla.ac.in

D. Sharma · P. Kumar
Delhi Technological University, Delhi, India

R. K. Singh
Management Development Institute (MDI), Gurgaon, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_19

In developing countries, the rate of manufacturing industries is vital for economic growth. India is on top among the other countries for having biggest economies and this will continue for the coming two decades also. Growing is always appreciated if it is done from a sustainable point of view, but the fact is that consumption of nonrenewable resources increases rapidly which gives rise to more pollution and waste. It has thus become the need of time for manufacturing companies to undertake practices that reduce environmental smash by keeping socio-financial benefits [6].

It can be noted that the introduction of sustainable practices will address or minimize the ecological, sociofinancial hurdle to a greater extent [3]. In order to incorporate SM practices at a rapid rate, it becomes mandatory to do detailed emphasis on its obstacles. It is only possible when both researchers and industry experts joined hands for identification of vital barriers being mitigated. In the past studies, the authors analyzed and assessed barriers of SM but most of them have not done it from their important point of view. The vital barriers are depicted from literature review coupled with industrial experts' opinions, then driving and dependence of barriers with its analysis was done by using ISM and MICMAC. The intent of this work is to analyze the crucial bottlenecks or obstacles, priotize them with a justified cause-effect relationship. This work definitely guides academics, government regulators, and practitioners in making these practices fortunate in manufacturing sector.

2 Literature Review

Garetti and Taisch [4] defined sustainable manufacturing as the capability of using natural resources intelligently in manufacturing for the fulfillment of economic, environment, and social aspects and hence preserve the environment and to upgrade quality of life. Sustainability is a term that has been interpreted in many ways to different people and has different meanings. The Brundtland Commission implemented sustainable development in a widespread manner, describing it as "growth that meets the needs of the present without undermining future generations' ability to meet their own needs" [13].

Awan et al. [16] in his study depicted key factors affecting successful implementation of social sustainability in manufacturing organizations by using interpretive structural modeling (ISM). In one of his studies, Malek and Desai [7] prioritizes sustainable manufacturing barriers by calculating their weights by applying Best Worst Method in one of India's manufacturing organizations. Thirupathi and Vinodh [15] in his study developed a model of SM enablers by using ISM, and then validated it by using structural equation modeling (SEM). Dubey et al. [2] developed a theory for SM by using total interpretive structural modeling. In his study, he developed a unique framework for SM, which suggests that how theory of human agency and theory of institutional can contribute to theory of ecological modernization. Table 1 shows the selected list of critical barriers with their description and references.

Table 1 Sustainable manufacturing barriers with its description

S.No	Critical barriers	Description	References
CB1	Lack of understanding about the concepts of sustainability	Insufficient literature available on sustainability data	Mittal et al. [12], Kulatunga et al. [10], Koho et al. [9], Mathiyazhagan et al. [11], Amrina and Yusof [1]
CB2	Insufficient efforts in imparting knowledge	Inadequate co-relative data on sustainability	Kulatunga et al. [10], Mathiyazhagan et al. [11], Koho et al. [9]
CB3	Poor knowledge of customers for green products and processes	Lack of reach of awareness about green products	Mittal et al. [12], Kulatunga et al. [10], Koho et al. [9], Mathiyazhagan et al. [11]
CB4	Negative attitudes toward the concept of sustainability	Lack of knowledge of the concepts of sustainability	Kulatunga et al. [10], Amrina and Yusof [1]
CB5	Insufficient funds for green projects	Mismanagement in judicious funds distribution	Xia et al. [17], Mathiyazhagan et al. [11], Kulatunga et al. [10]
CB6	Performance benchmarks and Lack of standardized metrics	Absence of practicable guidelines and parameters	Amrina and Yusof [1], Koho et al. [9]
CB7	Insufficient support from Pro's of the field	Total negligence by concerned top brass	Mathiyazhagan et al. [11]; Mittal et al. [12], Koho et al. [9], Amrina and Yusof [1]
CB8	High cost	Primary cost for investing sustainable technology is high	Mittal et al. [12], Amrina and Yusof [1], Mathiyazhagan et al. [11]

3 Methodology and Origination of Model

3.1 ISM Modeling

ISM was initially proposed [8] by enabling groups or individuals to create a map of complex relationships based on user awareness and practical experience to establish a hierarchy level between varying levels. This approach signifies a contextual relationship or categorizes factors in between dependent and independent (driving). This may not give you a transparent decision but can motivate organizations to understand factors pushing them back for not incorporating SM practices. Such decision-making strategies rely heavily on human decisions, involving relationships between and within attributes. ISM methodology comprises the following steps [5].

(1) Firstly, barriers according to our problem are depicted (going through literature and experts view) and recruited through group problem technique and literature survey.
(2) Identified a contextual formulation between the variables.

(3) For essential barriers, a structured self-interaction matrix (SSIM) is built on behalf of contextual relationship. This matrix shows the pair-wise relationship between these device measures.
(4) From SSIM a reachability matrix (RM) is formed and then it is checked for transitivity.
(5) Partition of RM into different levels.
(6) The RM is transformed into its conical form.
(7) A directed graph (digraph) is drawn on the basis of the above analysis, and transitivity ties are eliminated, and digraph is transformed into an ISM model by replacing measure nodes with statements.

The outcomes of ISM technique are shown in Tables 2, 3, 4 and 5. ISM modeling as shown in Fig. 1.

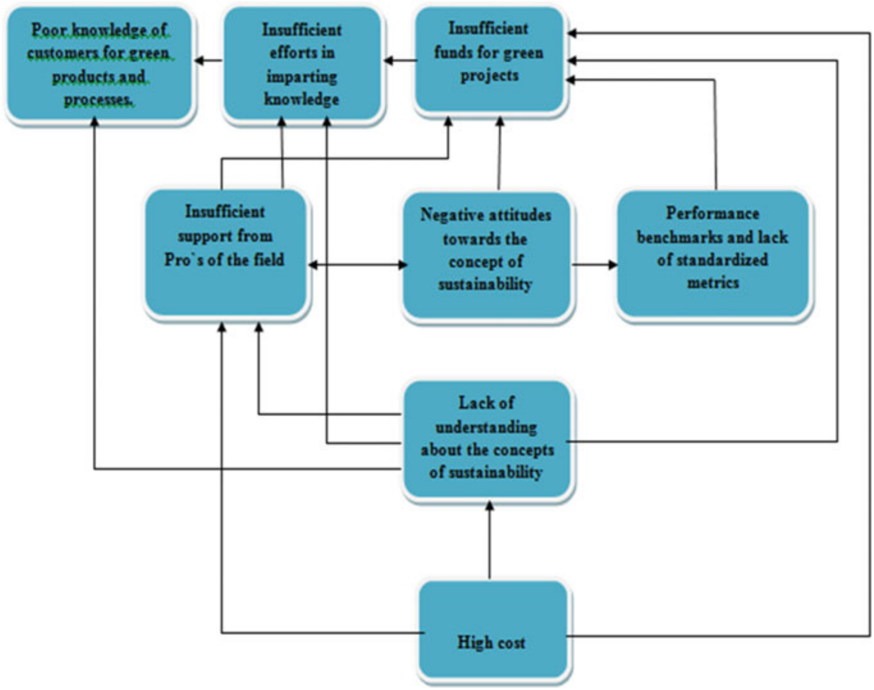


Fig. 1 ISM-based model for barriers

Table 2 Structured self-interaction matrix

Critical barriers	8	7	6	5	4	3	2
CB1	A	V	O	V	O	V	V
CB2	O	A	O	O	O	O	
CB3	O	O	O	O	O		
CB4	O	O	O	V			
CB5	A	A	A				
CB6	O	O					
CB7	A						

Table 3 Final reachability matrix

Critical barrier	1	2	3	4	5	6	7	8
CB1	1	1	1	0	1	0	1	0
CB2	0	1	0	0	0	0	0	0
CB3	0	0	1	0	0	0	0	0
CB4	0	0	0	1	1	0	0	0
CB5	0	0	0	0	1	0	0	0
CB6	0	0	0	0	1	1	0	0
CB7	0	1	0	0	1	0	1	0
CB8	1	1	1	0	1	0	1	1

Table 4 Final conical matrix

Critical barriers	2	3	5	4	6	7	1	8	Drive power
2	1	0	0	0	0	0	0	0	1
3	0	1	0	0	0	0	0	0	1
5	0	0	1	0	0	0	0	0	1
4	0	0	1	1	0	0	0	0	2
6	0	0	1	0	1	0	0	0	2
7	0	0	1	0	0	1	0	0	2
1	1	1	1	0	0	1	1	0	5
8	1	1	1	0	0	1	1	1	6
Dependence power	3	3	6	1	1	3	2	1	20

3.2 ISM Organization of Barriers on the Basis of MICMAC Analysis

This section shows grouping of barriers into four clumps. MICMAC principle is based on multiplication properties of matrices [14]. Matrice d' Impacts croises-

Table 5 Level separation table

Critical barrier	Reachability set	Antecedent set	Intersection set	Levels
CB1	1, 2, 3,5,7	1,8	1	3
CB2	2	1,2,7, 8	2	1
CB3	3	1,3,8	3	1
CB4	4,5	4	4	2
CB5	5	1,4,5,6,7,8	5	1
CB6	5,6	6	6	2
CB7	2,5,7	1,7,8	7	2
CB8	1, 2, 3,5,7, 8	8	8	4

multiplication appliqué an classment (cross-impact matrix multiplication applied to classification). This analysis is done to figure out the driving and bearing/dependence powers of parameters shown in Fig. 2. The first clump shows "autonomous parameters that is having weak driving and dependence powers." The second clump comprises "dependent parameters" showing strong dependence but weak driving. Third clump comprises parameters having strong correlation of driving and bearing/dependence, and are unstable and in the last fourth clump shows "independent ones" having strong driving but less effective bearing/ dependence power.

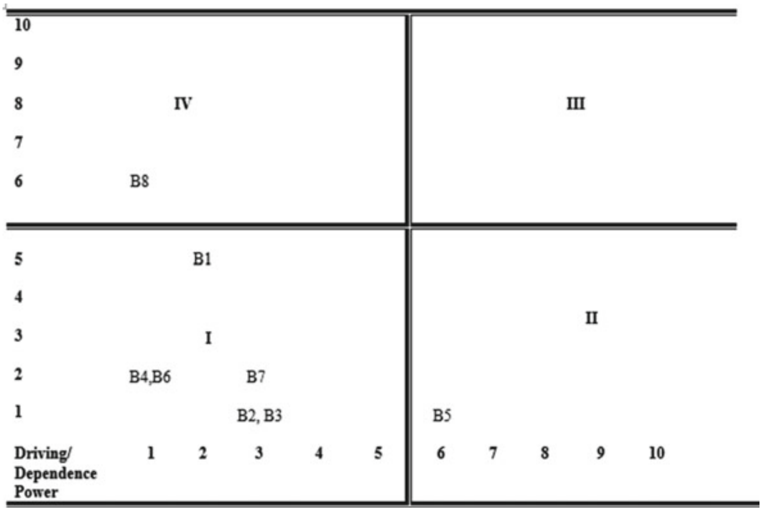


Fig. 2 MICMAC analysis

4 Results and Discussions

Eight critical barriers are depicted and evaluated which pulls back manufacturing organizations for not incorporating SM practices. These obstacles are organized in a defined hierarchy with the help of ISM modeling as shown in Fig. 1. High cost (CB8) and lack of understanding about the concepts of sustainability (CB1) turn out to be most driving barriers as these occupies the bottom level of ISM model. Insufficient funds for green projects (CB5) are the most dependent variables which are clearly shown in ISM model (Fig. 1) as well as through MICMAC analysis (Fig. 2). Performance benchmarks and insufficient structured formation (CB6) has a noticeable effect on CB5, i.e., insufficient funds for green projects.

5 Conclusion

This research article provides probable outcomes, increasing the production units' sustainability aspects. During evaluation, high cost and lack of awareness turns out to be the strongest driving barriers which are vital obstacle from industrial professionals' point of view.

Due to competitive production cost enhancement, industry people find it challenging to sustain and improve products at viable cost. Industry professionals are required to be updated urgently on SM practice benefits. They must be trained in the use of SM techniques and its specific framework so that it helps in their proactive participation and support toward SM techniques. The deterrent cost of using SM technology can be addressed positively with the help of government, i.e., financing at lower interest rate with better credit terms. The design focus of this study is to improve viability, sustainability, and quality in manufacturing.

References

1. Amrina, E., Yusof, S.M.: Drivers and barriers to sustainable manufacturing initiatives in Malaysian automotive companies. In: Proceedings of the Asia Pacific Industrial Engineering and Management Systems Conference, pp. 629–634 (2012)
2. Dubey, R., Gunasekaran, A., Singh, T.: Building theory of sustainable manufacturing using total interpretive structural modelling. Int. J. Syst. Sci. Oper. Logistics **2**(4), 231–247 (2015)
3. Gardas, B.B., Raut, R.D., Narkhede, B.E., Mahajan, V.B.: Implementation of sustainable practices in Indian oil and gas industries. Indus. Eng. J. **8**(9), 13–18 (2015)
4. Garetti, M., Taisch, M.: Sustainable manufacturing: trends and research challenges. Prod. Plann. Control **23**(2–3), 83–104 (2012)
5. Kannan, G., Pokharel, S., Kumar, P.S.: Resour. Conserv. Recycl. **54**, 28–36 (2009)
6. Joung, C.B., Carrell, J., Sarkar, P., Feng, S.C.: Categorization of indicators for sustainable manufacturing. Ecol. Ind. **24**, 148–157 (2013)
7. Malek, J., Desai, T.N.: J. Clean. Prod. **226**, 589–600 (2019)
8. Warfield, J.N.: IEEE Trans Syst Man Cybern 74–80 (1974)

9. Koho, M., Torvinen, S., Romiguer, A.T.: Objectives, enablers and challenges of sustainable development and sustainable manufacturing: Views and opinions of Spanish companies. IEEE Int. Symp. Assemb. Manuf. (ISAM) (2011)
10. Kulatunga, A., Jayatilaka, P.R., Jayawickrama, M.: Drivers and barriers to implement sustainable manufacturing concepts in sri lankan manufacturing sector. In: Proceedings of 11th Global Conference on Sustainable Manufacturing, Berlin, Germany. pp. 171–176 (2013)
11. Mathiyazhagan, K., Govindan, K., NoorulHaq, A., Geng, Y.: An fISMg approach for the barrier analysis in implementing green supply chain management. J. Clean. Prod. **47**, 283–297 (2013)
12. Mittal, V., Egede, P., Herrmann, C., Sangwan, K.: Comparison of drivers and barriers to green manufacturing: A case of India and Germany. Re-engineering Manufacturing for Sustainability, Springer Singapore. pp. 723–728 (2013)
13. Pezzoli, K.: Sustainable development: a transdisciplinary overview of the literature. J. Environ. Plann. Manage. **40**(5), 549–574 (1997)
14. Sharma, H.D., Gupta, A.D., Sushil.: The objective of waste management in India: A futures enquiry, Technol. Forecasting Soc. Change **48**(3), 285–309 (1995)
15. Thirupathi, R.M., Vinodh, S.: Application of interpretive structural modelling and structural equation modelling for analysis of sustainable manufacturing factors in Indian automotive component sector. Int. J. Prod. Res. **54**(22), 6661–6682 (2016)
16. Awan, U., et al.: Understanding influential factors on implementing social sustainability practices in manufacturing firms: An ISM analysis. In: 28th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2018), vol. 17 pp. 1039–1048. Procedia Manufacturing, Columbus, OH, USA (2018)
17. Xia, X., Govindan, K., Zhu, Q.: Analyzing internal barriers for automotive parts remanufacturers in china using grey-dematel approach. J. Clean. Prod. **87**, 811–825 (2015)

Energy-Economic Study of Smart Lighting Infrastructure for Low-Carbon Economy

Shivendra Nandan, Rishikesh Trivedi, Gunjan Aggarwal, and Kaushalendra Kumar Dubey

Abstract Fossil fuel-based energy generation and day-by-day increasing load on power are prominent issues which are globally discussed. Electricity is an essential need for any nation's development. 67% of electricity production is generated from the thermal power sector in India at present and 30% of carbon emission globally accounted from coal-fired thermal power plant. This paper is focused on the energy-economic analysis of all categories of lighting systems for the implementation of energy-efficient infrastructure in urban and rural areas of Indian states to achieve economic and environmental goals while reducing greenhouse gas emissions and escalating resilience to climate change impacts. The employment of solar photovoltaic (SPV)-based lighting system is anappropriate solution for eminence light for households with least consumption of energy and able to map the decarbonized economy. The major comparative study of all the mentioned lighting system has been investigated. The single unit of 11 W (equivalent to 60 W, 13 W of conventional bulb and CFL respectively) LED-based lighting system is able to save yearly 40–41 unit of energy consumption, and it can reduce 82% of carbon emission also as compared to equivalent lighting systems.

Keywords Solar photovoltaic lighting · Low-carbon economy · Energy saving · Global warming

Abbreviations

SPV	Solar Photovoltaic
LED	Light Emitting Diode
MNRE	Ministry of New and Renewable Energy

S. Nandan · R. Trivedi · K. K. Dubey (✉)
School of Mechanical Engineering, Galgotias University, Gautam Budha Nagar, Noida, UP, India
e-mail: kaushalendra.dubey@galgotiasuniversity.edu.in

G. Aggarwal
Department of Physics, Sharda University, Gautam-Budha Nagar, Noida, UP, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_20

SLS	Solar lighting systems
CCT	Correlated color Temperature
STC	Standard Test Conditions
CFL	Compact Fluorescent Light
W	Watt
W.LED	White LED
CO_2	Carbon Dioxide
MW	Mega Watt
USD	United States Dollar

1 Introduction

Four hundred million Indians have no access to electricity, 63% of all rural households in India use kerosene and animal dung or biodegradable waste for lighting and cooking and suffer with minimal lighting services in their houses. It increases human diseases like Chronic Obstructive Pulmonary Disease (Chest infection, Asthma, Emphysema), Glaucoma, etc. Solar-powered LED-based lighting system can give solution for rural electrification or off-grid areas in an energy-efficient manner [2, 6, 10–12]. India has rich solar energy resource potential. The solar radiation intensity received in a geographical area of 3.2 million Km^2 with 20 MW/Km^2 usually in India. Installed capacity of solar lighting system in India phase-1, phase-2, and phase-3 is 5 million, 10 million, 20 million in the year of 2010–13, 2013–17, and 2017–22, respectively [1, 8]. By 2012, a total of 4,600,000 solar lanterns and 861,654 solar-powered home lights were installed. The Ministry of New and Renewable Energy is offering a 30–40% financial support of the 210 wattage capacity of lanterns, home lights, and small systems (up to 210 W_p) [1]. The different capacities of coal-fired power plant of India have been investigated by using VRS analysis with the considerable performance parameters like unified, environmental, and operational efficiency. The Koradi power plant has the worst performance in all aspects of efficiencies [13]. The authors have developed the economic model for the house electricity system with solar photo-voltaic integration. This system is able to reduce electricity tariff, carbon emission, and employability of sustainable energy-efficient standalone power generation unit [14]. The present topic of research mainly deals with the energy-economic study of conventional and smart lighting systems, and its carbon economy analysis gives the scope for energy-efficient lighting infrastructure which can help for low-cost lighting systems for rural areas and make the local economy infrastructure.

Table 1 Solar lighting system specifications as per MNRE [7]

MNRE parameters →	Light source	PV module	Battery	Efficiency	Average duty Cycle	Autonomy
Solar Home Lighting System	Cool White Light Emitting Diode (W-LED)	8 Wp	Sealed maintenance free, 12 V—7 AH	Min. 85% Total Efficiency	5 h a day	Min. 3 days
Solar Street Lighting System	White Light Emitting Diode (W-LED)	40 Wp	Tubular Lead acid Flooded or Tubular GEL, 12 V—40 AH	Min. 85% Total Efficiency	Dusk to Dawn	Min. 3 days
Solar Lantern	Cool White Light Emitting Diode (W-LED)	3–5 Wp	Sealed maintenance free Lead acid, 12 V—7 AH	Min. 85% Total Efficiency	4 h a day	Min. 3 days

2 Energy-Efficient Solar Lighting Systems for Urban and Rural Area

The electricity consumption in urban areas is more than rural areas. LED-based smart and efficient lighting system is suitable for urban areas due to least energy consumption and solar photovoltaic power operated LED lighting system is important for rural, basically, un-electrified villages. The Ministry of New and Renewable Energy (MNRE) of Govt. of India has planned a detailed trajectory to meet the target of installation of solar lighting systems (SLS) in terms of solar street light, home light, lantern, etc., for remote areas and as well as for urban sector. Table 1 explained the design standards of SLS as per MNRE guidelines to manufactures.

3 Equivalent Lighting System with Energy Consumption and Losses

The comparison between conventional, CFL, and LED bulb is available in Table 2 as per the manufacturer standards. The lumen (lm) value is opted as 830 lm for perfect lighting effect for all category of lighting system for household application.

Table 2 Lighting specifications [9]

Lighting and energy parameters	Equivalent lighting System		
	incandescent bulb	CFL bulb	LED bulb
Wattage capacity for 830 lm	60 W	13 W	11 W
Average Life span (month and years) for 10 h daily usage	3 months (1000 h)	2.9 years (10,000 h)	6.10 years (25,000 h)
Energy loss (%)	90	30	15

4 Energy and Carbon Emission Analysis

The energy consumption by appliances is an important input for electricity tariff, investment on system installation, etc. Whereas energy losses with cost estimation contribute to the complete expenditure.

The following equations give energy consumption, energy losses, and cost of system.

Energy consumption by appliances in unit (KWh)- wattage (W) × working hours(H) × no. of appliances(N)
Energy loss by appliances in unit (KWh)- Energy loss in Wattage (E_L) × working hours(H) × no. of appliances(N)
Lost energy cost-energy tariff in Rs per unit × Energy loss in KWh
Carbon emission and its ton of CO_2 (TCO_2) cost have significant participation for system employability and its economic aspect.

As per EPA, the CO_2 emission from coal-fired thermal power plant for one unit (1KWh) of power is about 707 g of CO_2. [7.07×10^{-4}metric tons CO_2/unit, source https://www.epa.gov/energy [4]
(Only CO_2 emission is considered, no other greenhouse gas emissions).

Carbon emission by appliances = 707 g of CO_2/unit × Energy consumption by appliances in unit (KWh).
The possible Cost of TCO_2 globally is about 20 USD/TCO_2 as per World Bank data.
Total cost of system = System manufacturer price (C1) + Lost energy cost (C2) + Carbon tariff (C3).

5 Energy Consumptions, Energy Losses, and Carbon Economy Balance Sheet

The tabular form of calculation is based on the single unit of incandescent, CFL, and LED bulb of same Lumen value of 830 lm and working hrs. of 10hrs daily.

Energy losses of lighting system with average life span is available in Table 3. The comprehensive analysis of the proposed title is designed in Table 3.

Table 3 Energy and carbon economy analysis

Energy consumption estimation (energy consumption in KWh) Energy consumption = Watt power of appliances (Wp) x No. of Appliances (N) x Working Hours (H)……………….(1)		
Incandescent Bulb (60 W)	**CFL (13 W)**	**LED (11 W)**
60 × 10hrs = 600 WHr = 0.6 KWh	13 × 10 = 130 WHr = 0.13 KWh	11 × 10 = 110 WHr = 0.11 KWh
For one year		
0.6 KWh × 365 = 219 KWH/yr	0.13 × 365 = 47.45 KWh/yr	0.11 KWh × 365 = 40.15 KWh/yr
Carbon Emission Estimation [As per EPA—707 g of CO_2 per unit] Carbon_emission = Energy consumption x gram CO_2 emission per unit of energy consumption ……………………(2)		
219 KWh/yr x 707 g of CO_2/unit = **155 Kg of CO_2/yr**	47.45KWh/yr x 707 g of CO_2/KWh = **33.5Kg of CO_2/yr**	40.15KWh/yr x 707 g of CO_2/KWh = **28.3Kg of CO_2/yr**
% saving of CO_2 Emission		
	155–33.5 / 155 = 78.33%	155–28.3.5 / 155 = 82%
Energy Loss Estimation (Energy_loss)		
Incandescent Bulb (60 W)	CFL (13 W)	LED (11 W)
90% = 54 W	30% = 3.9 or 4 W	15% = 1.65 or 2 W
Energy Loss For 10 h& 1 Year (Energy_lost per year) Energy_lost per year = Energy_loss x working hours (H) x no of days in year…………………….(3)		
54 W x 10 hr × 365 = 197 KWh/yr	4 W x 10 hr × 365 = 14.6 KWh/yr	2 W x 10 hr × 365 = 7.3 KWh/yr
Lost Energy Cost Estimation-C2 Tariff/unit of energy@5/-Rs [3] Lost energy cost = Energy_lost per year x tariff of energy……………………………(4)		
197 × 5 = 985 Rs/yr (for 5 years-4925 Rs)	14.6 × 5 = 73 Rs/yr (for 5 years-365 Rs)	7.3 × 5 = 36.5Rs /yr (for 5 years-162.5 Rs)
Lighting system replacement cost in 5 years for 10 h working daily-C1 Replacement Cost = cost of lighting system x no.of replacement in 5 years as per average life of light………………………….(5)		
20 times replacement (3 months average life)	02 times replacement (33 months average life)	01 time installation (82 months average life)
10 Rs/bulb	200 Rs/bulb	200 Rs/bulb [5]
Total replacement cost (C1)-200 Rs	400 Rs	200 Rs
Carbon economy estimation of lighting system in 5 years-C3 Carbon economy cost = Kg of CO_2/yr × 5yrs × 20USD…………………..(6)		
155Kg of CO_2/yr × 5 = 775Kg of CO_2	33.5Kg of CO_2/yr × 5 = 167 kg of CO_2	28.3Kg of CO_2/yr × 5 = 141.5 kg of CO_2
0.775 × 20 USD = 1116 Rs (1 USD-72 INR)	0.167 × 20 USD = 241 Rs	0.142 × 20 USD = 204 Rs
Total Cost during 5 years © = C1 + C2 + C3…………………………(7)		
C = 6241 Rs	C = 1106 Rs	C = 587 Rs

Table 4 Energy loss, carbon emission by lighting units, and its economy

Energy and economic parameters	Incandescent Bulb (60 W)	CFL (13 W)	LED (11 W)
Yearly energy consumption (unit)	219	47.45	40.15
Yearly energy loss (unit)	197	14.6	7.3
Yearly cost of lost energy in Rs	985	73	36.5
Yearly carbon emission (Kg CO_2)	155	33.5	28.3
% saving of carbon with respect to incandescent bulb		78.33%	82%
Yearly carbon tariff (TCO_2) in INR	223.2	48.2	40.7

6 Result and Discussion

The major output of energy and economic study of conventional and smart lighting system is available in Table 4, which clearly explains the energy loss, carbon emission by lighting units, and its economy. Figure 1 shows the decarbonized assessment of new trends of lighting system with least energy consumption.

7 Conclusions

The power generation in India is almost dependent on coal-fired thermal power plant, which leads the considerable amount of CO_2 discharge and environmental toxicity. The lighting infrastructure is a key infrastructure for domestic and rural population. The lighting load is more in urban areas as compared to rural and remote areas. The smart lightning systems in terms of LED lights are revolutionary technologies that harness solar energy through solar photovoltaic system, and it becomes the preferred light source in the near future. In the perspective of climate change and environment safety, solar energy is established as a significant alternative source of energy for renewable and sustainable technology. This comprehensive study assesses the conventional and new trends of lighting systems which have 70–80% of low-carbon emission and valuable earning of carbon credit with least energy consumption. This smart and energy-efficient light infrastructure is an eminent solution for urban and rural sectors.

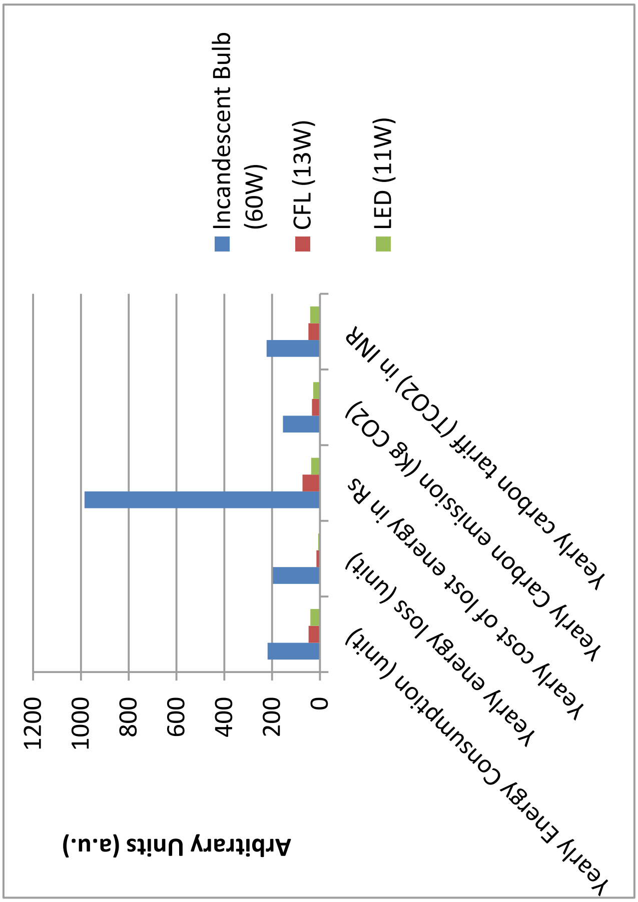


Fig. 1 Energy and carbon economic parameters

References

1. Physical Progress (Achievements). Ministry of New & Renewable Energy. Retriesved 18 July 2019
2. Aggarwal, G., Dubey, K. K., Hasan, M.M.: Enersgy efficient solar street lighting system for rural areas. SOLARIS 2012,IIT- BHU. India.ISBN 978-93-82332-03-9,pp. 203–208, 7–9 Feb 2012
3. Available at: https://www.bsesdelhi.com-web-brpl-know-your-tariff. Accessed on 20 Mar 2020
4. EPA.: AVERT, US national weighted average CO_2 marginal emission rate, year 2017 data,EPA, Washington, DC. Available at: https://www.epa.gov/energy (2018). Accessed on 20 Mar 2020
5. Available at: https://www.lighting.philips.co.in/prof/lighting-electronics#pfpath=0-GE01_GR. Accessed on 20 Mar 2020
6. Available at: https://www.engineeringtoolbox.com/co2-emission-fuels-d_1085.html. Accessed on 20 Mar 2020
7. Available at: https://mnre.gov.in/systems-specifications. Accessed on 20 Mar 2020
8. Available at: https://www.energy.gov/energysaver/save-electricity-and-fuel/lighting-choices-save-you-money/led-lighting. Accessed on 20 Mar 2020
9. Available at: https://www.sust-it.net/lighting-energy-calculator.php. Accessed on 20 Mar 2020
10. Prakash, O., Chel, A., Tiwari, G. N.: Performance evaluation and economic analysis of PV integrated mud house for composite climate. In: 3rd International Conference on Solar Radiation and Day Lighting (SOLARIS 2007) New Delhi, India (2007)
11. Available at: https://www.eea.europa.eu/soer-2015/countries-comparison/climate-change-mitigation. Accessed on 20 Mar 2020
12. Asumadu-Sarkodie, S., Owusu, P. A.: Carbon dioxide emissions, GDP, energy use and population growth: A multivariate and causality analysis for Ghana, 1971–2013. Environ. Sci. Poll. Res. Int. https://doi.org/10.1007/s11356-016-6511-x (2016)
13. Bajpai, V.K., Singh, S.K.: Measurement of operational and environmental performance of the coal-fired power plants in india by using data envelopment analysis. Int. J. Soc. Behav. Educ. Econ. Bus. Indus. Eng. 8(12) (2014) (World Academy of Science, Engineering and Technology)
14. Bagalini, V.,Zhao, B.Y., Wang, R.Z.,Desider, U.: Solar PV-battery-electric grid-based energy system for residential applications: system configuration and viability, AAAS Research, vol. 2019, Article ID 3838603, pp. 17. https://doi.org/10.34133/2019/3838603

Analysis of Lean Six Sigma Implementation Indicators in Health Care sector—A Customer Perspective

M. Shilpa, M. R. Shivakumar, S. Hamritha, V. G. Ajay Kumar, and S. Shreyansh

Abstract This paper presents a combinatorial approach which helps the customer / patient choose from the multiple alternatives of hospitals which have implemented Lean Six Sigma (LSS) in their business. The methodology adopted was to recognize the key indicators or attributes of LSS implementation in five hospitals at Bangalore city, which relate to the benefits a customer can gain. A technique for Order Preference by Similarity to Ideal Solution (TOPSIS) along with Analytical Hierarchical Process (AHP) has been applied to analyze the survey responses that are collected from the customers visiting these hospitals for varied reasons and arrive at ranks for these hospitals. This work presents in-sights into the LSS implementation benefits to customers and helps to choose the hospital depending upon the customer preference. In the current work, five hospitals and eight LSS implementation indicators are analyzed; this can be extended to other hospitals and a greater number of indicators from different processes can be studied.

Keywords Lean six sigma · Implementation indicators · Health care · Hospital ranking

1 Introduction

The current epoch demands that all the processes are simplified to the fullest extent so as to gain colossal competitive edge in the market. Process simplification eliminates waste and repetitive activities in the system. Lean manufacturing is a technique that eliminates waste in all possible processes of an organization. Six Sigma methodology is a tool that helps identify the performance of the product in terms of quality [1]. Six Sigma and lean jointly define the methodology for the organizations to achieve the desired quality and adopt cost-effective methods that reduce and eliminate various

M. Shilpa (✉) · M. R. Shivakumar · S. Hamritha · V. G. Ajay Kumar
M S Ramaiah Institute of Technology, Bangalore, Karnataka 560054, India
e-mail: mallikashilpa@gmail.com

S. Shreyansh
Annamacharya Institute of Technology and Sciences, Rajampet, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_21

types of wastes in the process. LSS carries out both the activities, i.e., process simplification and waste elimination [2]. This helps the organizations to overcome the losses that generally incur during the production and sustain global competitiveness. By and large, the benefit of LSS is that it builds up system capabilities and graduates toward continual improvement [3]. Application of LSS is not limited to one stream. It has found its benefits in various fields like manufacturing, services, and health sector.

Some of the benefits of LSS include cycle time reduction, reduced lead time, lesser number of machines, improved flow in process, uniform process output, reduced number of defects, and structured problem-solving [4, 5]. Apart from these benefits, it provides the advantage of cost reduction in the process. By understanding the strength and the need for the application of this tool, defect-free products can be delivered faster and customers can be served better. A successful implementation of LSS requires incorporating some of the techniques such as analysis of product and process quality using mathematical tools, focus on reducing variation and in-depth understanding of the importance of visual workplace and clean environment [6]. It also necessitates creation of a centralized focal point in the organization which firmly establishes the vision and mission of this program. A coherent relationship has to be enhanced among the team members and a training program has to be planned which should contain the application of LSS [7, 8]. Process improvement using LSS is a data-driven approach and hence it is possible to achieve the earlier predicted results. This tool brings in a new culture of continuous improvement in the organization which will drive the system toward development [9], and thus it is a widely accepted tool to develop new business strategies and improve business profitability leading to organizational excellence [10].

2 Review of Literature

Lean Six Sigma is a robust management tool, which has been widely adopted by many organizations to excel both at operations and strategic level. An extensive review of literature has been carried out on Lean Six Sigma by referring to renowned books and journal papers and the review is collated here.

LSS has wide applications for process improvement in manufacturing and service sectors. In manufacturing organizations, LSS framework had been applied to automotive component production so as to enhance the product quality and minimize the waste [11]. This was helpful in areas where continuous improvement was necessary, and literature also highlights that the application of this tool needs immense knowledge, lot of practice, and the organization has to provide suitable training for the practitioners for its successful implementation. There is evidence of successful implementation of this tool adopted in the manufacturing industry to improve operations' safety practices [12]. This had called for the applications of tools life Failure Mode Effect Analysis, Supplier Input Process Output Customer (SIPOC), and PDCA (Plan Do Check Act) approaches which helped improve the sigma level of the process. Application of Lean Six Sigma to improve operations' safety was successful as the operational hazards and controllable risks were identified and eliminated, which reduced the financial loss [13]. More literature was available on the application of this tool to improve productivity in the manufacturing industry, wherein the researchers have often used the combinatorial approach of DMAIC (Define, Measure, Analyze, Improve, and Control) [14] and Design of Experiments to optimize the material removal rate and have achieved less tool wear. LSS had also been widely applied for system integration, product and process innovation, quality improvement research and development [15]. Application of LSS to investigate failure causes was also present in the literature [16]. Relevance of application of LSS to ERP, data mining, risk management, and project management had also been explored in the literature [17].

In the literature, LSS had been most widely applied to health care sector when compared to others. In health care sector, LSS had been used for process improvement, process innovation, continuous improvement, quality improvement, research and development, and system integration. Researchers have explored the applicability of this tool in this sector for some of their functions like radiology and emergency departments to reduce the patient's travel time; simplification of some of the operations had led to significant improvement in the system functioning and eventually reduced the patient wait time [18]. With the application of DMAIC methodology, LSS had also seen its applications to enhance the system performance of the hospitals by identifying the customer needs.

In the literature, there was evidence of application of LSS to military services, small and medium enterprises, financial services, information technology, outsourcing, and printing services [19]. There was very little work carried out in the application of this tool in tire manufacturing, consultancy, call center services, education and food services. In military, finance, outsourcing, call center, education, food, printing / publishing, and consultancy services, LSS had been applied for process improvement [20]. In information technology, LSS had been applied for electronic transition, web technology, and product life cycle; in tire manufacturing, it had been applied for tool life enhancement; and in wood products, it had been applied for quality improvement.

3 Need for This Study

Hospitals, on the other hand, can be viewed as systems. Hospital systems operate in a completely different manner than that of manufacturing and business systems. The patient's expectations from such systems are very high, which is justified. The working of hospital systems and their structures lead to producing results that are expected to be consistent. For this purpose, hospitals should completely understand the customer or patient requirements, for which the hospitals should be open to changes in their fundamental structures [21]. Also, they should understand the dynamic community attitude that is prevalent. Some of the hospitals who have carried out fundamental changes in their structures and operations are able to see the visible results from patient viewpoint. The patients' expectations are very high off-late w.r.t cleanliness, performance, reliable laboratory results, charges, and medication.

During this pandemic, the patients give a second thought and evaluate if it is absolutely necessary to physically reach the hospital for obtaining services. Most of the practicing doctors have changed their preferences from physical appointment at the hospital to audio–video consultation. The hospitals along with the practitioners should now adapt to the new changes happening in the society and expectations from the patients which are shifting toward virtual reality [22]. There is an urgent need for the practitioners to be sufficiently trained upon with the latest electronic tools and media and use the virtue of their experience to provide the right medical advice to the patients who not only arrive at the hospital but also to those who prefer electronically enabled appointments.

With the adaptation of technologies for consultation and radiology requirements, not only hospitals but also health consultants should take extra efforts in making this entire process defect-free. They should continuously strive hard toward error reduction. It is not unusual to see many hospitals working toward this new paradigm shift, although quite often patients have one or many issues related to the facilities that are provided for them. Change management is not only a challenge for the hospital staff but also for its customers or patients, some of whom are not technologically oriented. This is true to a larger extent in a country like India, where the use of mobile phone technology or Internet technology is just gearing up its speed. This creates another issue of orienting the patients to use the hospital's media platform to conduct an effective audio–video consultation.

From the patients' viewpoint, any patient would greatly prefer to visit the same hospital which he would have visited earlier, more so he would want to see the same consultant. Although it appears very easy for any hospital to retain its patients, small and simple deviations in performance can bring about a serious loss to the hospital in terms of its potential customers and reputation is concerned. Quality improvement should be a continuous process in such systems, where the customer feedback should be rightly considered to overcome the shortcomings, and this should happen at a faster speed compared to other systems. Aiming to make such systems defect-free and to reduce the lead time between the identification of a performance deviation and correction, call for the use of quality improvement concepts like Six Sigma coupled with lean management concepts whose key objective is to reduce waste. There is sufficient evidence in the literature to state that hospitals are fast adopting the concept of LSS, which is a combination of lean management and Six Sigma methodology, to continuously improve their service toward the patients [23]. The literature stresses largely on the application, implementation barriers, and benefits of LSS to hospital systems, whereas very little work is present in the literature which addresses the post-hospitalization / treatment satisfaction of the patients after the implementation of LSS.

The literature had presented abundant work on the analysis of barriers to implementation of LSS in health care services, wherein the researchers had found that implementation was very slow in service sector when compared to that of manufacturing. Organizations are able to successfully implement LSS in barely any of their processes, although put in time and effort to overcome these barriers [24]. In such situations, it becomes essential to opt for such processes which have direct or indirect connect with the customer. In health care organizations, most of the business processes have a direct connect with the customer, and hence, it becomes difficult or rather slow to employ this tool to all such processes. Much of the literature dealt with the application of LSS for health care sector and very little work was carried out to analyze the extent to which the customer or the patient is benefitted and what the key indicators were. In this paper, the implementation benefits of LSS in health care sector are analyzed from the customer perspective.

4 Methodology

This paper attempts to analyze the benefits a customer avails after the implementation of LSS in the health care sector. For this purpose, five hospitals in Bangalore city, A, B, C, D, and E, which had implemented LSS in most of their processes, have been selected for the study. Depending on the processes in which these hospitals had implemented LSS, common indicators of successful LSS implementation have been identified through review of literature. The eight identified key indicators are Emergency Room Services (ERS), Diagnostics Lab Services (DLS), Consultant Availability (CA), policy related to patients (PF), Patient Record Maintenance (PRM), infrastructure (HI), culture (HC), and staff motivation to address the patients' peripheral issues (HSM). Interactive discussions with professionals from the hospitals and LSS practitioners have been conducted and validation of these key indicators is carried out [25].

TOPSIS has been applied to arrive at a choice among the five hospitals depending on the customer preferences. TOPSIS uses the specific Euclidean distance from the positive and negative ideal solutions to arrive at the finest choice. This method involves collecting the data required for alternatives, evaluating the normalized decision matrix, using weights to obtain positive and negative ideal solutions, enumeration of separation measures, relative value for positive and negative ideal solutions, and hierarchical grading of the choices based on customer preferences. The weights for the key indicators of successful LSS implementation in the hospitals have been estimated using AHP. AHP was developed by Thomas Saaty [26] to select and rank the multiple attributes or alternatives, by calculating the weights, so as to help in decision-making. It is a powerful tool to aid multi-criteria decision-making, which blends the outcomes of pairwise comparison matrices to arrive at the ranks. The steps in AHP involve establishing the hierarchical structure, building up of pairwise comparison matrix, and then assessing the consistency using consistency index and consistency ratio [27]. The pairwise comparison matrix, which has been constructed by referring to the literature and by conducting comprehensive discussion with practicing professionals from both academia and hospitals, is shown in Table 1.

Table 1 Pairwise comparison matrix of LSS implementation indicators

Indicators	ERS	DLS	CA	PF	PRM	HI	HC	HSM
ERS	1	2	2	3	7	2	3	2
DLS	½	1	3	7	4	8	2	3
CA	1/2	1/3	1	4	6	6	5	2
PF	1/3	1/7	¼	1	1/2	1/3	1/4	1/4
PRM	1/7	1/4	1/6	2	1	1/2	1/2	1/4
HI	½	1/8	1/6	3	2	1	1/2	1/2
HC	1/3	1/2	1/5	4	2	2	1	2
HSM	1/2	1/3	½	4	4	2	1/2	1

From the above matrix, consistency ratio is calculated, which provides a measure of consistency of judgments relative to large samples of purely random judgments. This ratio should be less than 0.1 to justify reliable judgments. The consistency ratio obtained is 0.08740 which is less than 0.1; hence it can be inferred that the pairwise matrix is consistent and is acceptable for further analysis. Using AHP, the weights for the eight indicators are estimated and are as follows: ERS = 0.23009, DLS = 0.25092, CA = 0.19229, PF = 0.03148, PRM = 0.03939, HI = 0.05764, HC = 0.09771, and HSM = 0.10048.

A survey has been conducted to study the extent to which customers visiting the five identified hospitals actually experienced the benefits of LSS implementation. The survey questionnaire was prepared with questions related to the eight indicators of LSS implementation. The questionnaire has 16 questions (two questions on each key indicator) following Likert scale from 1 to 5; 1 is least and 5 is highest, and responses from the customers were analyzed. The customer satisfaction data has been collected, collated, and analyzed for each of the five hospitals with respect to the key indicators, through the questionnaire. It is evident that though the hospitals had implemented LSS, not all of them obtained the same or similar response from their customers.

Each indicator has its own scale of measurement and hence it is necessary to bring all the attributes on a common scale (0–1) for further analysis. This is done by normalizing the survey response data using TOPSIS and the normalized decision matrix is obtained. This normalized decision matrix is converted to weighted normalized matrix [28] by multiplying the values with their respective weights.

Among the eight key LSS implementation indicators, ERS, DLS, and CA are the beneficial attributes whereas PF, PRM, HI, HC, and HSM are non-beneficial attributes. The positive (P^+) and negative (P^-) ideal solutions [29] are obtained using Eq. (1) and the solutions are shown in Eq. (2).

$$\begin{aligned} P^+ &= \{V_{ij}^+ 1, \ldots\ldots. V_n^+\} = \{(\max V_{ij} \mid i \in I^{'}), (\min V_{ij} \mid i \in I^{''})^{'}\}^{'} \\ P^- &= \{V_{ij}^- 1, \ldots\ldots. V_n^-\} = \{(\max V_{ij} \mid i \in I^{'}), (\min V_{ij} \mid i \in I^{''})^{'}\}^{'} \end{aligned} \quad (1)$$

Table 2 S_i^+ , S_i^- and C_i^* their corresponding ranks

Hospitals	S_i^+	S_i^-	C_i^*	Rank
A	0.0090	0.0168	0.6507	1
B	0.0107	0.0137	0.5628	2
C	0.0186	0.0079	0.2980	5
D	0.0141	0.0138	0.4945	4
E	0.0115	0.0125	0.5200	3

$$\begin{aligned} P^+ &= \{0.1097\ 0.1169\ 0.0899\ 0.0108\ 0.0155\ 0.243\ 0.0402\ 0.0423\} \\ P^- &= \{0.0969\ 0.1063\ 0.0802\ 0.0161\ 0.0189\ 0.0278\ 0.0459\ 0.0467\} \end{aligned} \quad (2)$$

The separation measures are obtained using Eq. (3) and (4); relative closeness values are obtained using Eq. (5). The hospitals are now hierarchically graded based on the C* values, which are arranged in descending order [30]. The separation measures, relative closeness values, and hospital ranks are summarized in Table 2.

$$S_j^+ = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_j^+\right)^2} \quad (3)$$

$$S_j^- = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_j^-\right)^2} \quad (4)$$

$$C_i^* = \frac{S_j^-}{S_j^+ + S_j^-} \quad (5)$$

where

V_{ij} is weighted normalized matrix.

V_{ij} + is maximum value and Vij- is minimum value.

S_j + and S_j- are separation matrix for ideal positive and negative, respectively.

Hospital A has the first rank, pointing out that it is the best choice for the customer taking into account the eight LSS implementation indicators that are identified in this work. This analysis helps customer to choose from the multiple hospital options if their preference is one among the eight indicators identified in this paper. For example, if a customer gives added preference to diagnostics lab services, and he can refer to the survey responses to make the best choice. If tie exists in the survey response, he can look into the ranking of hospitals which would help him make optimal choice. This is for the reason that a higher ranking hospital has better customer evaluation with respect to other parameters too.

5 Conclusions

In the literature, sufficient work was carried out in exploring the barriers to LSS implementation. Very little work had been conducted to overcome those barriers by formulating various strategies, and to analyze the benefits of LSS implementation. This paper has explored the reach and feel of LSS implementation benefits to the customers / patients visiting the hospitals for various causes. TOPSIS in combination with AHP has been applied in identifying the successful LSS implementation indicators of five hospitals, constructing pairwise comparison matrix, checking the consistency, normalizing the survey data, and ranking these hospitals based on the key indicators. This helps the customer make an informed decision while he is choosing among the hospitals with his preference matching with one of the indicators identified in this paper. This paper has identified eight key indicators; work could be extended for more number of attributes. Here, five hospitals which have implemented LSS are selected for comparison; this could be expanded for other hospitals too. Additional key indicators could also be explored for further studies, depending on the hospitals and services that are provided.

References

1. Shokri.: A quantitative analysis of six sigma, lean and lean six sigma re-search publications in the last two decades. Int. J. Qual. Reliab. Manage. **34**(5), 598–625 (2017)
2. Cherrafi, A., Elfezazi, S., Chiarini, A., Mokhlis, A., Benhida, K.: The integration of lean manufacturing, six sigma and sustainability: a literature review and future research directions for developing a specific model. J. Clean. Prod. **139**, 828–846 (2016)
3. Albliwi, S.A., Antony, J., Lim, S.A.H.: A systematic review of lean six sigma for the manufacturing industry. Business Proc. Manag. J. **21**(3), 665–691 (2015)
4. Albliwi, S., Antony, J., Lim, S.A., Wiele T.V.D.H.: Critical failure factors of lean six sigma: a systematic literature review. Int. J. Qual. Reliab. Manage. **31**(9), 1012–1030 (2014)
5. Aleu, F.G., Van Aken, E.M.: Systematic literature review of critical success factors for continuous improvement projects. Int. J. Lean Six SigMa. **7**(3), 214–232 (2016)
6. Aleu, F.G., Van Aken, E.M.: Continuous improvement projects: An author- ship bibliometric analysis. Int. J. Health Care Quality Assurance **30**(5), 467–476 (2017)
7. Maneesh, K.:Critical success factors and hurdles to six sigma implementation, the case of UK manufacturing SME. Int. J. Six Sigma Competitive Adv. **3**(4), 333–351 (2007)
8. Sreedharan, V.R., Raju, R.: A systematic literature review of lean six sigma in different industries. Int. J. Lean Six Sigma **7**(4), 430–466 (2016)
9. Vashishth, A., Chakraborty, A., Antony, J.: Lean six sigma in financial ser- vices industry: a systematic review and agenda for future research. J. Total Quality Manage. Business Excellence. **30**(4–5), 1–19 (2017)
10. Yadav, G., Desai, T.N.: Lean six sigma: a categorized review of the literature. Int, J, Lean Six Sigma **7**(1), 2–24 (2016)
11. Raveen, R., Shalini, S.: A Lean Six Sigma framework to enhance the competitiveness in selected automotive component manufacturing organizations, South African. J. Econ. Manage. Sci. **21**(1), 1–13 (2018)
12. Gajbhiye, P.R., Waghmare, A.C., Parikh, R.H..: Safety management in manufacturing industry: a lean six sigma approach. In: 5th International and 26th All India Manufacturing Technology, Design and Research Conference, pp. 646–1:646–6 (2014)

13. Shanmugaraja, T.T.: Lean six sigma study to improve productivity in a manufacturing industry. Int. J. Eng. Res. Appl. **7**(9), 38–46 (2017)
14. Antony, J., Antony, F.J., Kumar, M., Cho, B.R.: Six sigma in service organizations. benefits, challenges and difficulties, common myths, empirical observations and success factors. Int. J, Qual. Reliab. Manage. **24**(3), 294–311 (2006)
15. Amol, T., Prakash, V., Nitin, S.: A conceptual frame work for application of six sigma improvement methodology in non—formal service sector. Int. J. Six Sigma Competitive Adv. **6**(4), 321–338, 7(2/3/4), 209–242 (2011)
16. Muthuswamy Shanmugaraj, M., Nataraj, N.:Total performance excellence—a model to implement six sigma in service organizations. Int. J. Six Sigma Competitive Adv. **6**(3), 297–328 (2012)
17. Harjaca, S.J., Atrensa, A., Moss, C.J.: Six sigma review of root causes of corrosion incidents in hot potassium carbonate acid gas removal plant. Engi. Failure Anal. **15**(5), 480–496 (2008)
18. Alessandro, L.: Lean six sigma in service industry. In: Advanced Topics in Advanced Operations Management, pp. 1–14 (2012)
19. Roughton, J.E., Crutchfield, N.: Six sigma as a management system 2008—a tool for effectively managing a JHA process. Job Hazard Anal. 407–440 (2008)
20. Shah, R., Chandrasekaran, A., Linderman, K.:In pursuit of implementation patterns: the context of Lean and Six Sigma. Int. J.Prod. Res. **46**(23), 6679–6699 (2008)
21. Jowwad, M.S., Gangha, G., Indhu, B.: Lean six sigma methodology for the improvement of the road construction projects. Int. J. Civil Eng. Technol. **8**(5), 248–259 (2017)
22. Albliwi, S., Antony, J., Lim, S.A.H., van der Wiele, T.: Critical failure factors of Lean Six Sigma: A systematic literature review. Int. J. Qual. Reliab. Manage. **31**(9), 1012–1030 (2014)
23. Rajesh, A.: Interpretive structural modelling.: a comprehensive literature review on applications. Int. J. Six Sigma Competitive Adv. **10**(3/4), 258–331 (2017)
24. Chang, S.I., Douglas–Mankin, K.D., Chang, M.J., Ang–Carabuena, L.A., Tavakkol, B.: Identifying data – driven healthcare facilities: a case study in VHA Hospitals. Int. J.Six Sigma Competitive Adv. **10**(2), 98–111 (2016)
25. Ahmed, S., Manaf, N.H., Islam, R.: Effects of Lean Six Sigma application in healthcare services: a literature review. Rev Environ Health. **28**(4), 189–194 (2013)
26. Saaty, R.W.: The analytic hierarchy process—what it is and how it is used. Math. Model. **9**(3–5), 161–176 (1987)
27. Do, J.Y., Kim, D.K.: AHP-based evaluation model for optimal selection process of patching materials for concrete repair: focused on quantitative requirements. Int. J. Concrete Structures Mater. **6**(2), 87–100 (2012)
28. Yoon, K. P., Hwang, C. L.: Multiple attribute decision making: An introduction (Vol. 104). Sage publications (1995)
29. Shilpa, M., Naidu, N.V.R.: Quantitative evaluation of quality loss for fraction defective case using Taguchi's Quality loss function. Int. J. Logistics Syst. Manage. (IJLSM), special Issue on: "Modeling Supply Chain Planning Problems by Integrating Data Analysis and Optimization Techniques",**18**(1), 126–138 (2014)
30. Shivakumar, M.R., Ashwini, N.: Optimization of CNC turning operation parameters of Aluminum Alloy 6061 with multiple performance characteristics using Taguchi method and grey relational analysis. Int. J. Mech. Dyn. Anal. **5**(1), 1–4 (2019)

Supplier Selection for Sustainable Supply Chain Using an Integrated GRA-VIKOR Approach in an SME

Sanatan Ratna and B. Kumar

Abstract The traditional supply chain management has evolved over the years due to the changing government regulations which intend to save the environment. The focus has shifted on sustainability which means that the needs of the present generation are fulfilled without making any significant impact on the resources which would be required by the future generations. As a result, it has become quite obvious that supplier selection in any sector needs to consider factors which affect the environment. In the current research work, six criteria for supplier selection in GSCM (green supply chain management) are considered initially, out of which the four major ones are shortlisted using GRA (grey relation analysis). The shortlisted criteria are used for supplier selection in the bicycle parts manufacturing industry. This selection of supplier using the shortlisted GSCM criteria is done using VIKOR which is based on finding the utility measure as well as regret measure of each alternative.

Keywords Green supply chain management (GSCM) · Grey relation analysis (GRA) · VIKOR · Utility measure · Regret measure

1 Introduction

The rapid pace at which industrialization has taken place has led researchers across the globe look for sustainable development. Sustainable development [1] refers to meeting the needs of the people living currently without significantly affecting the resources needed for people living in the future. In order to achieve this, there is need to implement green supply chain management (GSCM) in place of traditional SCM. For this purpose, number of factors affecting GSCM in the bicycle manufacturing sector are considered using literature review. In the next step, the important criteria are shortlisted using GRA. The supplier selection based on the four shortlisted criteria is

S. Ratna (✉)
Amity University Uttar Pradesh, Sector 125, Noida, UP, India
e-mail: sanatan_ratna@yahoo.co.in

B. Kumar
Sunrise University, Alwar, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_22

done using VIKOR technique. The VIKOR technique was developed in 1990 and this method of MCDM identifies a compromising alternative closest to the ideal solution similar to TOPSIS. The novel GRA-VIKOR multi-attribute decision-making model to determine the most preferred supplier in an Indian bicycle manufacturing industry.

2 Literature Review

Alimohammadlou et al. [2] carried out the investigation to identify the parameters for evaluating the resilience of the suppliers from two aspects, i.e., the effectiveness as well as the importance of selecting resilient suppliers in Iran electronic industries. The various analytical tools such as DEMATEL, analytical network process and goal programming were used, and they were used in a fuzzy condition due to the ambiguous/vague nature of the study. The results clearly indicate that the attributes such as human resource management, visibility and the financial position turned out to be the most important parameters. Sari et al. [3] studied the performances of 15 suppliers in the FMCG industry and the evaluation is done by using grey relation analysis. The four parameters selected for evaluating the suppliers are quality, service, delivery time and cost. Sharma et al. [4] analyzed the risks regarding safety and security in the FMCG industry using grey relation analysis. After analyzing and evaluating the various risks involved with food safety and security, it was concluded that the process risk is the main factor having a grey relation grade of 0.300. It was concluded that the study would be helpful for the concerned authorities to take proper steps in order to make the system more efficient. Lee [5] proposed an evaluation model based on hybridization of TOPSIS with GRA which was used for supplier evaluation and selection problem. The attributes for supplier selection were service, quality, price, delivery and flexibility. The researcher further proposed the integration of fuzzy environment for taking into account vagueness and ambiguity of several other factors.

Sayyah Markabi [6] et al. developed a mathematical model for the evaluation and selection of efficient suppliers in the situation of supply and demand uncertainties. The researchers used GRA and data envelopment analysis (DEA) to assess and select the best supplier under various uncertainties. The findings of the study indicated clearly that the proposed model provides satisfactory results while avoiding time-consuming calculation. Also, the proposed model enables the decision maker to make decisions at different levels of risk. Huang [7] et al. proposed a VIKOR-based method to solve the supplier selection problem having conflicting criteria. They reasoned that the supplier selection is a key issue in supply chain management as it can lower the cost to the customers. The weights of the various attributes are determined by using G1 method and the entropy weight method. Rostamzadeh R [8] et al. made use of fuzzy VIKOR for the evaluation of the management practices in green supply chain management. The research is aimed at developing an evaluation model based on VIKOR, to assess the uncertainty of GSCM activities and aims at solving the green multi-criteria decision-making problem. Four organizations were evaluated and ranked on the basis of their performance in GSCM initiatives. The result clearly showed that the major criteria is eco-design followed by green production. Malviya [9] et al. prioritized solutions in order to overcome the various hindrances and barriers of GSCM implementation using a hybrid fuzzy AHP-VIKOR model. The results indicate that the top-ranked solution is "integrate the reverse material flow in SC" and it is of great help to the decision-makers for benchmarking and in order to overcome the barriers.

3 Integrated GRA-VIKOR Approach

The grey relation analysis (GRA) was proposed by Deng Julong of China in 1982. The idea of grey system is a representation of a vague or an ambiguous information system as the grey color lies between black (representing no information) and white (complete information). The GRA tool can be used to calculate the grey relation grades which indicate a parameter‘s prominence or importance. VIKOR was developed during 1990 and similarly to TOPSIS, this method too identifies a compromising solution which is most close to the ideal solution. The VIKOR (Vlse Kriterijumska Optimizacija Kompromisno Resenje) is a very useful tool for solving MCDM problems. In the current research work, the authors aim at combing the two tools for supplier selection in an SME using the GSCM criteria for achieving sustainability. The criteria shortlisting is done by using GRA while final supplier selection is done using VIKOR analysis.

The criterias used for supplier selection in the sustainable SCM are listed below:

C1—Government regulation and environmental legal-compliance.

C2—Use of cleaner technological processes.

C3—Design of products for reduced consumption of materials/energy.

C4—Design of products for reuse and recycling of materials and packaging.

C5—Commitment of GSCM from managers.

C6—Decreased consumption of hazardous/harmful/toxic materials during production.

Six industry experts are consulted, and their opinions are asked to evaluate the six chosen criteria on a scale of 1–5, which is further listed in Table 1.

The difference from the maximum value of the scale is calculated and is listed in Table 2.

Next, the grey relational coefficients are calculated as per Eq. (1) below. It expresses the relation between the reference sequence and sequences to be compared for each effort driver. Here "p" is the distinguishing factor and is taken as 0.50 (Table 3).

Table 1 Criteria evaluation by the industry experts

	C1	C2	C3	C4	C5	C6
R1	5	4	4	4	3	3
R2	5	5	3	3	2	4
R3	4	5	3	3	4	4
R4	3	5	5	3	4	4
R5	5	3	3	3	5	2
R6	4	4	3	4	4	2

Table 2 The difference with reference sequence values

	C1	C2	C3	C4	C5	C6
R1	0	1	1	1	2	2
R2	0	0	2	2	3	1
R3	1	0	2	2	1	1
R4	2	0	0	2	1	3
R5	0	2	2	2	0	1
R6	1	1	2	1	1	3

Table 3 Calculated grey relational coefficients

Expert responses	C1	C2	C3	C4	C5	C6
R1	1	0.5	0.5	1	0.42	0.71
R2	1	1	0.33	0.66	0.33	1
R3	0.5	1	0.33	0.66	0.6	1
R4	0.33	1	1	0.66	0.6	0.55
R5	1	0.33	0.33	0.66	1	1
R6	0.5	0.5	0.33	1	0.6	0.55

$$\xi i\ (K) = \frac{(\Delta \text{min.}\ + p\Delta \text{max})}{(\Delta Xi(K) + p\Delta \text{max})} \tag{1}$$

The next step is to obtain the grey relational grades (GRG). GRG are calculated by taking the arithmetic means of the grey relation coefficients for each criterion. The criteria with the highest GRG shall be the one, with most importance and the one having least GRG would be the least important parameter. The grey relation grades are calculated and listed here in Table 4.

The three-four most important criteria are shortlisted and carried forward to VIKOR for final supplier selection based on the shortlisting criteria. The criteria which are selected are C1 (Government regulation and environmental legal-compliance), C2 (Use of cleaner technological processes), C4 (Design of products

Table 4 Calculated GRG

Criteria	C1	C2	C3	C4	C5	C6
GRG	0.7222	0.7222	0.4722	0.7777	0.5936	0.8042

for reduced consumption of materials/energy) and C6 (Decreased consumption of hazardous/harmful/toxic materials during manufacturing processes).

The four suppliers for the industry under review are evaluated for the four criteria which are shortlisted using VIKOR. The four suppliers are evaluated against the four criteria shortlisted by an industry expert. The suppliers are rated on a scale of 1–5 for each criterion (1 being poor and 5 being excellent). This decision matrix is shown in Table 5. C1, C2, C4 and C6 are the four criteria whereas S1, S2, S3 and S4 are the four suppliers who are to be evaluated. All the four criteria have been given equal weightage, i.e., 0.25.

The values in the decision matrix shown above are normalized in the next step. Normalization is carried out to achieve the unification of all the attributes by bringing the ratings within the range of 0–1. The normalized value of an element of decision matrix is found by using *norm.* the norm for an element of column j is expressed as.

$$Norm_j = \sqrt{\sum_{i=1}^{m} x_{ij}^2} \tag{2}$$

If the attribute is positive/benefit type the normalized value of x_{ij} is, $r_{ij}=\frac{x_{ij}}{Norm_j}$ otherwise for negative type, $r_{ij}=1-\frac{x_{ij}}{Norm_j}$.

The normalized decision matrix is produced and listed in Table 6.

Table 5 Decision matrix

	C1	C2	C4	C6
Attribute weights	0.25	0.25	0.25	0.25
S1	2	4	5	5
S2	4	2	2	3
S3	3	3	4	4
S4	2	5	3	5

Table 6 Normalized decision matrix

	C1	C2	C4	C6
S1	0.348432	0.544959	0.681199	0.577367
S2	0.696864	0.27248	0.27248	0.34642
S3	0.522648	0.408719	0.544959	0.461894
S4	0.348432	0.681199	0.408719	0.577367

Table 7 Maximum and minimum criterion functions for VIKOR

	C1	C2	C4	C6
$f_{\max}$	0.696864	0.681199	0.681199	0.577367
$f_{\min}$	0.348432	0.27248	0.27248	0.34642
$f_{\max}-f_{\min}$	0.348432	0.408719	0.408719	0.230947

Table 8 VIKOR indices for all the suppliers

	S1	S2	S3	S4
Utility Measure (U_i)	0.33	0.75	0.6097	0.4166
Regret Measure (R_i)	0.25	**0.25**	0.2949	0.25
VIKOR index	0	0.5	0.8329	0.1030

Referring to the normalized decision matrix in Table 6 above, the maximum and minimum criterion functions are easily identified as in Table 7.

After the maximum and minimum criterion functions for VIKOR, are found, the utility measure is found by using the following expression.

$$U_i = \sum_{j=1}^{m} \frac{W_j\left(f^{max} - f_{ij}\right)}{\left(f^{max} - f^{min}\right)} \tag{3}$$

The regret measure (R_i) of an alternative (a supplier in this case) is the maximum value of the components present in its expression for utility measure. The utility measure (U_i) and the regret measure (R_i) are listed in Table 8. Finally, the VIKOR indices are found by using the following expression:

$$V_i = \frac{\propto .(U_i - U_{min.})}{(U_{max.} - U_{min.})} + \frac{(1- \propto).(R_i - R_{min.})}{(R_{max.} - R_{min.})} \tag{4}$$

The VIKOR indices are calculated while assuming the value of weight α as 0.5.

4 Result and Conclusion

The above calculations clearly indicate that the best alternative is Supplier 1 (S1) with the lowest VIKOR index followed by S4 and S2, while the supplier S3 is the least preferred one. The use of GRA clearly indicates the most important GSCM criteria while the best supplier is chosen using VIKOR. All suppliers in the different sectors must select the GSCM criteria for sustainable development. Furthermore, in the future work, a greater number of criteria may be chosen for supplier selection and the integrated GRA-VIKOR model may be used in different sectors too for supplier evaluation and selection.

References

1. UlutaG, A., Topal, A., Bakhat, R.: An application of fuzzy integrated model in green supplier selection. Hindawi Mathematical Problems in Engineering. Vol. 2019, Article ID 4256359, p. 11. https://doi.org/10.1155/2019/4256359
2. Alimohammadlou, M., Bonyani, A.: An integrated fuzzy model for resilient supplier selection. Int. J. Supply Chain Manage. **7**, 35–52 (2018)
3. Sari, T., Baynal, K., Ergül, Ö.: Supplier selection with grey relational analysis (2016)
4. Sharma, Y.K., Patil, P.P., Mangla, S.K.: Analyzing risks in safety and security of food using grey relational analysis. Int. J Mech. Eng. Technol. **9**(12), 9–19
5. Lee, H.: Supplier selection problem: integrating grey relational analysis and TOPSIS. In: 2008 Fourth International Conference on Natural Computation, Jinan, pp. 207–211 (2008)
6. Sayyah Markabi, M., Sabbagh, M.: A hybrid method of grey relational analysis and data envelopment analysis for evaluating and selecting efficient suppliers plus a novel ranking method for grey numbers. J. Indus. Eng. Manage. [S.l.] **7**(5), 1197–1221
7. Huang, Y., Yan, Y., Ji, Y.: Optimization of supply chain partner based on VIKOR Method and G1 Method. In: 2008 International Seminar on Future BioMedical Information Engineering, Wuhan, Hubei, pp. 172–175 (2008)
8. Rostamzadeh, R., Govindan, K., Esmaeili, A., Sabaghi, M.: Application of fuzzy VIKOR for evaluation of green supply chain management practices. Ecol. Ind. (2014). https://doi.org/10.1016/j.ecolind.2014.09.045
9. Malviya, R.K., Kant, R.: Prioritising the solutions to overcome the barriers of green supply chain management implementation: a hybrid fuzzy AHP—VIKOR framework approach. J. Decision Syst. **27**:4, 275–320

Assessment of Key Barriers of Sustainable Additive Manufacturing in Indian Automotive Company

Hema Sudarsan Rao, Devarapalli Sai Kishor Reddy, Chandrakant Sharma, Sumit Gupta, Anbesh Jamwal, and Rajeev Agrawal

Abstract Sustainability is an emerging issue that product development engineers must engage with to remain relevant, competitive and most importantly, responsible. The advent of additive manufacturing technologies presents several opportunities that have the potential to benefit designers greatly and contribute to the sustainability of products. Products can be extensively customized for the user, thus potentially increasing their desirability, pleasure and attachment and therefore longevity. This paper presents the key barriers of sustainable additive manufacturing in Indian automotive companies.

Keywords Sustainability · Additive manufacturing · AHP

1 Introduction

Over the past decade, there has been an increased awareness of environmental conservation and conservation of the Earth's resources and the environment and nature. Sustainability has quickly become a challenge that designers and engineers must meet to survive in a more sustainable world. In fact sustainability is currently taught as an integral part of many diplomas in design and engineering, recognizing the growing recognition of the role that sustainability should play in developing our future. However, when considering what is meant by "sustainable" products, many definitions arise, many of which have fundamental omissions each other. This means that sustainability is often simply referred to as the buzzword used in marketing materials, no matter how truly sustainable the product is [1]. The objective of this paper is to identify the key barriers of sustainable additive manufacturing and prioritize them by the help of AHP method.

H. S. Rao · D. S. Kishor Reddy · C. Sharma · S. Gupta (✉)
Department of Mechanical Engineering, Amity University, Noida 201313, UP, India
e-mail: sumitgupta2007@gmail.com

A. Jamwal · R. Agrawal
Department of Mechanical Engineering, Malaviya National Institute of Technology, Jaipur 302017, Rajsthan, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_23

2 Literature Review

2.1 *Sustainable Design Approaches*

It is interesting to study publications on sustainable design methods to help us better understand the factors that affect product sustainability and hopefully generate some new ideas on how to use new technologies to stimulate product design more sustainably. This section of the chapter describes some of the current methods of sustainable design and discusses the relationship between design quality, durability and product sustainability. It also enables new manufacturing technologies, such as AM, to play a more important role in sustainable product development.

2.1.1 Environmentally Friendly Design

Ecodesign seeks to integrate environmental concerns into each product in order to minimize its impact on the environment. This is often achieved at the expense of the economic benefits associated with reducing costs associated with a corresponding increase in efficiency. Eco-design takes into account the environment at every stage of design and production, so each stage has little impact on the environment throughout the life of the product. In most real-world applications, environmental design is usually manifested in the production stages through attempts to use materials with low environmental impact. Environmental design tools, in general, can be divided into environmental assessment tools and environmental design tools [2]. For environmental assessment tools, LCA may be one of the most commonly used tools for assessing the environmental impact of a product. However, due to the nature of life-cycle assessment, the environmental impact of the product is usually assessed in the later stages of the design process after most design decisions are made, rather than in the conceptual planning and planning stages, which have the greatest impact on the true environmental impact. This reduces the effectiveness of life cycle assessment because improvements that may benefit the environment cannot be achieved until subsequent product iterations.

2.1.2 Sustainable Design

Although sustainable product design is a continuation of eco-design, it goes far beyond the principles of eco-design. By embracing environmental design elements, sustainable design also includes economic imperatives, ethics, and other socio-economic aspects of sustainability and uses environmental principles as design methods, thus striving for "triple-end" solutions. Economic sustainability is a relatively simple measure because it has been easy to measure. Measuring social sustainability has somewhat difficult as of the intangible and subjective nature of many factors that are beneficial to society. It is also difficult to determine environmental sustainability, from a product point, because in order to get a real idea of the impact of a product, you need to look at the entire product life cycle, which may become very difficult. Even the use of phrases such as good for the environment used in the above description of the ideal product may be misleading. Is any product environmentally friendly [3]. AM processes are becoming environmentally conscious and sustainable [4].

2.2 Barriers of Sustainable Additive Manufacturing

In Additive manufacturing, Sustainability plays an important role in product life cycle. Hence, for the implementation of additive manufacturing techniques, various barriers are identified. [5] Identified the factors of sustainable additive manufacturing. Table 1 shows the key barriers of sustainable additive manufacturing.

3 Methodology

3.1 Analytic Hierarchy Process (AHP)

AHP is used as a key methodology in this work. AHP is a hierarchy process of implementing various aspects into a hierarchy of importance and thus form a better analysis pattern. AHP but lacks to provide inter-relationship between the various key barriers and only signifies its ranking which can be quite monotonous. However, AHP is recommended as a superior tool in similarity to others due to its wide-ranging applicability and ease in use. Therefore, we decided to implement an AHP methodology to evaluate barriers related to the adoption of Sustainability of Additive manufacturing. The steps listed in AHP are presented as follows:

1. Statement of Purpose: Assessment of barriers to determining of importance in the AM sustainability adoption is defines as the objective of this Sample.
2. Formation of Double Comparisons: Double comparisons are made by collecting data from a group of experts and based on expert opinion; double comparisons of factors are made on the nine-point Sati scale.
3. Calculate endogenous values and eigenvectors and weights of relative importance. To determine eigenvalues and eigenvectors, double-comparison matrices were used in the frame, which are then analyzed to find the relative importance of factors.
4. Coefficient Assessment: "The Coefficient of Coefficient (CR) is calculated to ensure constancy of even comparisons. The expression used to search for KP

Defined as $CR = CI / RI$, where the constancy index is indicated by $(CI) = (\lambda max - n) / (n - 1)$,

Table 1 Key barriers of sustainable additive manufacturing

Barriers	Code of Barriers	Sub- Barriers	Source
Economical Barriers (E)	E1	Improving cost-effectiveness and energy efficiency at higher production volumes	[1]; [6]
	E2	Limited speed and reliability of additive manufacturing technology	[2, 7]
	E3	Individual prosumers may over produce and over consume leading to irresponsible presumption	[8]; [9]
	E4	Avoiding material contamination	[10]; [6]
Social Barrier (S)	S1	Supporting the skill development of prosumers, designers and engineers	[11]; [12]
	S2	Potential for Additive manufacturing to contribute to a materialistic society and consumerism	[2]
	S3	Uncertain performance of products and components due to low maturity of technology	[13]
Environmental Barrier (X)	X1	Integrating sustainability consideration using design for environment or eco-design principles	[10]; [14]
	X2	Lack of knowledge and understanding of the environment performance of material processing techniques	[15]
	X3	Limited recyclability of products at their end of life due to mixed materials	[3]; [16]
	X4	Lack of knowledge and understanding of the environment performance of Additive manufacturing technology, Supply chains and products made through AM	[17]; [18]; [19]; [20]

Depends on the value (n). The value of the commercial register must be less than 0.10 in order to obtain the best consistency."

4 Data Analysis and Discussion

4.1 Barriers for Sustainable Additive Manufacturing (SAM):

In Additive manufacturing, Sustainability plays an important role in product life cycle. Hence for the implementation of additive manufacturing techniques, various barriers are needed to be identified.

4.1.1 Finalization of the Important Barriers to Adopt in SAM

There are 11 barriers to the adoption of Sustainability of Additive Manufacturing identified and collected through the literature. To confirm the identified barriers, the specialists were asked to add or delete any barrier relevant to the adoption of Sustainability of AM. The responses were collected, and several discussion sessions were arranged with the professionals to finalize the reported barriers for SAM in the context of the Indian Automotive industry. The chosen professionals agreed with all identified adoption of literature-based barriers, hence, a total of 11 barriers were identified.

4.1.2 Evaluation of the SAM Adoption Barriers in the Indian Industry to Determine Their Relative Importance Using AHP

A hierarchical structure is formed using expert inputs as shown in Fig. 1. This hierarchical structural has three different levels: Evaluating the SAM adoption barriers for relative importance (Level-1), the three categories of barriers (Level-2) and eleven specific barriers (Level-3).

Pairwise comparisons are derived for both categories of barriers and the specific barriers using expert's inputs. This way a pairwise comparison matrix for categories of barriers was framed and their relative weights are summarized in Table 2.

The pairwise comparisons for specific barriers under each category and their corresponding relative weights are shown in Tables 3, 4 and 5.

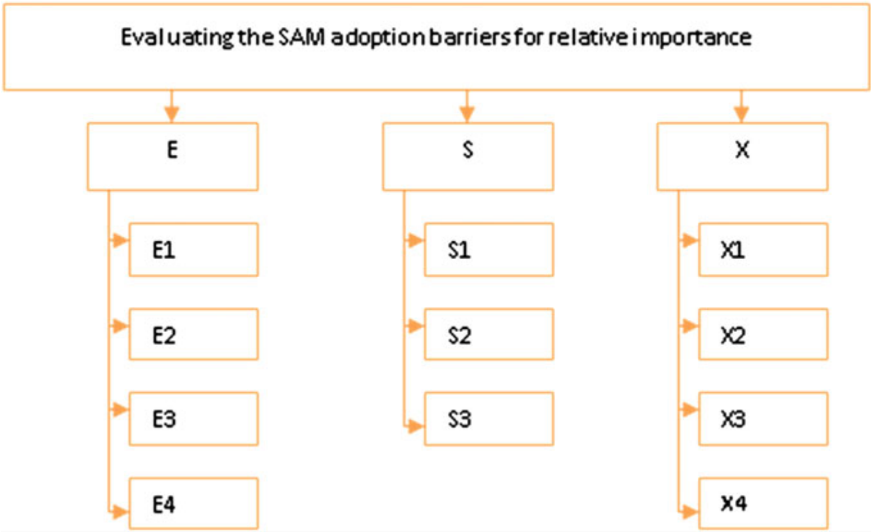


Fig 1 The developed decision hierarchy of barriers to adopting SAM

Table 2 Pairwise matrix for categories of SAM barriers

Maximum Eigen Value = 3.01538

Barriers	E	S	X	Relative weight	Rank
E	1	2	1	1.33	2
S	0.5	1	0.33	0.61	3
X	1	3	1	1.66	1

Table 3 Pairwise matrix for "Economical Barrier" to the implementation of SAM

Maximum Eigen Value = 4.04

Barriers	E1	E2	E3	E4	Relative weight	Rank
E1	1	0.5	0.5	1	0.161	3
E2	2	1	0.5	2	0.27	2
E3	2	2	1	3	0.42	1
E4	1	0.5	0.33	1	0.143	4

Table 4 Pairwise matrix for "Social Barrier" to the implementation of SAM

Maximum Eigen Value = 3.0182

Barriers	S1	S2	S3	Relative weight	Rank
S1	1	3	1	0.443	1
S2	0.33	1	0.5	0.169	3
S3	1	2	1	0.387	2

Table 5 Pairwise matrix for "Environmental Barrier" to the implementation of SAM

Maximum Eigen Value = 4.02						
Barriers	X1	X2	X3	X4	Relative weight	Rank
X1	1	1	3	2	0.36	1
X2	1	1	2	2	0.32	2
X3	0.33	0.5	1	1	0.14	4
X4	0.5	0.5	1	1	0.16	3

4.2 Barriers Ranking and Analysis

The most highly ranking Barrier through the AHP Analysis is "Integrating Sustainability consideration using design for environment or eco-design." This shows how important it is to implement environmental conservation and misexploitation in the early stages of product life cycle. If a product is manufactured using ecodesign policies then the weight may decrease and efficiency of the product may also increase, less utilization of resources and at the end of life cycle, it will be much more easier to recycle the product. In AM product can be started immediately after designing from CAD file. But it is not yet used widely and technology is not yet mature enough for implementation, if applied may cost a lot even in terms of energy and monetary value. To mass produce, more research is needed. Tenth barrier is "Potential for Additive manufacturing to contribute to a materialistic society and consumerism". We live in a time where anything is easily accessible and humankind is never known to be this convenient, but this has led us to produce much bigger environmental footprint and to meet up with the current needs of mankind AM needs to take a huge leap in its technological breakthrough at the cost of less exploitation of the environment. Eleventh barrier ranked is "Avoiding material contamination." As manufacturers are producing complex composition of products it may become very difficult to handle them without contamination. Even the end product needed to fit in with the environment and should contribute a better life cycle (Table 6).

5 Conclusion

In order to use AM with maximum potential, designers need to develop an appropriate set of design methodologies and rules, incorporating the new functionality they offer and taking into account their new set of production constraints. As AM technology continues to evolve from rapid prototypes to production, more and more new materials are emerging and different material technologies are developed to the extent that complex assemblies of many materials can be created, and the product development area must be developed in parallel, and therefore, to better meet the needs New sustainable design trends. This research may be helpful for managers

Table 6 Global ranking of SAM barriers

Categories of Barriers	Relative Weighs	Specific Barrier	Relative Weight	Relative Ranking	Global Weight	Global Ranking
Economical	1.33	E1	1.61	3	0.0026937	9
		E2	0.27	2	0.0066420	5
		E3	0.42	1	0.0140220	2
		E4	0.14	4	0.0002656	11
Social	0.61	S1	0.14	1	0.00845	4
		S2	0.16	3	0.00122	10
		S3	0.38	2	0.00437	7
Environmental	1.66	X1	0.36	1	0.015042	1
		X2	0.32	2	0.010028	3
		X3	0.14	4	0.002925	8
		X4	0.16	3	0.004600	6

researchers and academicians to understand the sustainability factors of additive manufacturing.

References

1. H. Bikas, P. S.: Additive manufacturing methods and modelling approaches: a critical review. Springerlink (2015)
2. Rogers, C. R.: A framework of sustainable supply chain management: moving toward new theory. Int. J. Phys. Distrib. Log. Manage. (2008)
3. Cindy Kohtala a, S. H.: Anticipated environmental sustainability of personal fabrication. J. Clean. Prod. (2015)
4. Agrawal, R., & Vinodh, S.: Application of total interpretive structural modelling (TISM) for analysis of factors influencing sustainable additive manufacturing: a case study. Rapid Prototyping J. (2019a)
5. Gupta, S.: Some Issues In Sustainable Manufacturing: A Select Study Of Indian Manufacturing Companies. Doctoral dissertation, MNIT Jaipur (2016)
6. Agrawal, R., & Vinodh, S.: State of art review on sustainable additive manufacturing. Rapid Prototyping J. (2019b)
7. Gupta, S., Dangayach, G.S., Singh, A.K., Meena, M.L., Rao, P.N.: Implementation of sustainable manufacturing practices in Indian manufacturing companies. An Int. J., Benchmarking (2018)
8. Domnita Fratila, H. R.: Additive manufacturing—a sustainable manufacturing route. In: MATEC Web of Conferences 94 (2017)
9. Jamwal, A., Aggarwal, A., Gupta, S., Sharma, P.: A study on the barriers to lean manufacturing implementation for small-scale industries in Himachal region (India). Int. J. Intell. Enterprise **6**(2–4), 393–407 (2019)
10. Ahn, D.-G.: Direct metal additive manufacturing processes and their sustainable applications for green technology: a review. Springer (2016)
11. Liang Hao, D.R.: Enhancing the Sustainability of Additive Manufacturing. Green Manufacturing, Ningbo (2010)

12. Askary, Z., Singh, A., Gupta, S., Shukla, R. K., & Jaiswal, P.: Development of AHP framework of sustainable product design and manufacturing of electric vehicle. In: Advances in Engineering Design (pp. 415–422). Springer, Singapore (2019)
13. Karel Kellens, R. M.: Environmental impact of additive manufacturing processes:does AM contribute to a more sustainable way of part manufacturing? In: ScienceDirect (2017)
14. Valiaveetil, J. J., Singh, S., Jain, A., & Gupta, S.: Design and development of an online process measurement system for zero defect production. In: Advances in Industrial and Production Engineering (pp. 791–800). Springer, Singapore (2019)
15. Marja Paju, J. H.: Framework and indicators for a sustainable manufacturing mapping methodology. In: Proceedings of the 2010 Winter Simulation Conference (2010)
16. Singh, A., Askary, Z., Gupta, S., Sharma, A. K., & Shrivastava, P.: AHP based model for evaluation of sustainable manufacturing enablers in Indian manufacturing companies. In: Advances in Industrial and Production Engineering (pp. 397–403). Springer, Singapore (2019)
17. Aggarwal, A., Gupta, S., & Ojha, M. K.: Evaluation of key challenges to industry 4.0 in Indian context: A DEMATEL approach. In: Advances in Industrial and Production Engineering (pp. 387–396). Springer, Singapore (2019)
18. Gupta, S., Dangayach, G.S., Singh, A.K., Meena, M.L., Rao, P.N.: Adoption of sustainable supply operation quality practices and their impact on stakeholder's performance and sustainable performance for sustainable competitiveness in Indian manufacturing companies. Int. J. Intell. Enterprise **5**(1–2), 108–124 (2018)
19. Jamwal, A., Agrawal, R., Gupta, S., Dangayach, G. S., Sharma, M., & Sohag, M. A. Z.: Modelling of sustainable manufacturing barriers in pharmaceutical industries of Himachal Pradesh: An ISM-Fuzzy approach. In: Proceedings of International Conference in Mechanical and Energy Technology (pp. 157–167). Springer, Singapore (2020)
20. Jaiswal, P., Kumar, A., & Gupta, S.: Prioritization of green manufacturing drivers in indian SMEs through IF-TOPSIS approach. U.P.B. Sci. Bull., Series D, **80**(2), 277–292 (2018)

Rejection Minimization Through Lean Tools in Assembly Line of an Automotive Industry

Rakesh Giri and Ashok Kumar Mishra

Abstract In order to compete in the 'Automotive Industry' which is the world's largest manufacturing industry, manufacturing managers have to put their efforts in motivating their personnel to increase their efficiency and improve the processes to achieve a common successful goal of improved productivity and quality. In this research, focus has been made to reduce the MUDA work elements associated with the activities in manufacturing cycle at different workstations on the line by using some advanced methods and tools, which have characteristics to prevent or trace the fault in the very beginning of its occurrence. In context of the above, focus has been made to implement the Lean Concepts (Kaizen, 5S and Poka-yoke) to improve the productivity and quality of its product by reducing cycle time, lead time and rejection. In this research, the five steps of DMAIC cycle has been used to synchronize the findings and their effects throughout the manufacturing cycle. The results indicate that after implementing the lean components integrated with DMAIC cycle, productivity has improved, and rejection reduces to Zero from 0.8% at illumination testing station in assembly line of HVAC Switch.

Keywords Quality · Lean tools · Synchronization · DMAIC · Illumination

1 Introduction

In the journey of improving the manufacturing processes, Toyota coined the term 'Lean' to describe the outcomes associated with the Toyota Production System (TPS) management philosophy. Since then, lean manufacturing has evolved beyond automotive into all types of manufacturing in many other industries. In this context, to have improved manufacturing cycle with reduced MUDA (Processing Waste) elements of different characteristics, company planned to work and introduced lean manufacturing theory to improve some of its products. In this course of action, company

R. Giri (✉) · A. K. Mishra
SRM University, Sonipat, Haryana, India
e-mail: rakeshgiri119@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_24

planned to improve the line status and condition of HVAC (Heating Ventilation and Air Control) switch assembly line by using lean tools.

1.1 About the Concerned Organization and Product

Mindarika Pvt. Limited, located in Manesar, Gurugram, Haryana (India), a manufacturer of wide range of automotive switches used in four wheelers. Its production department has reported a considerable loss in productivity performance and quality of its product in assembly line due to poor illumination switches passed from the station and mixing of those with good performance switches. It is one of the reasons which affect quality, productivity, lead time and finally converts into customer's complaint and financial losses to the company.

The main function of HVAC Switch is to control temperature in the passenger cabin of vehicle and its main components are Body, Panel, Gears, Rotor Shafts, Balls, Knobs, PCB, Light Guide and Springs, which are assembled on straight assembly line (refer Fig. 1).

2 Literature Review

Since the evolution of the term 'lean' after world war second, it is being used to improve the productivity and quality in industries. Lean Approach is very effective at eliminating and reducing waste. Lean may be defined as 'a way to do more with less human effort, less equipment, less time, and less space, while coming closure and closure to providing customers exactly what they want'. It is based on the principles to add values to the process or product according to the customer's satisfaction by eliminating the MUDA waste in the manufacturing cycle or service.

DMAIC (Define, Measure, Analyze, Improve and Control) Approach refers to a data driven improvement cycle used for improving, optimizing and stabilizing business process and designs. The DMAIC improvement cycle is the core tool used to drive Six Sigma projects. However, DMAIC is not exclusive to Six Sigma but an integration of Lean and DMAIC approach can be used as a new tool for other improvement applications. A widespread application of this theory has been seen in

Fig. 1 HVAC switch

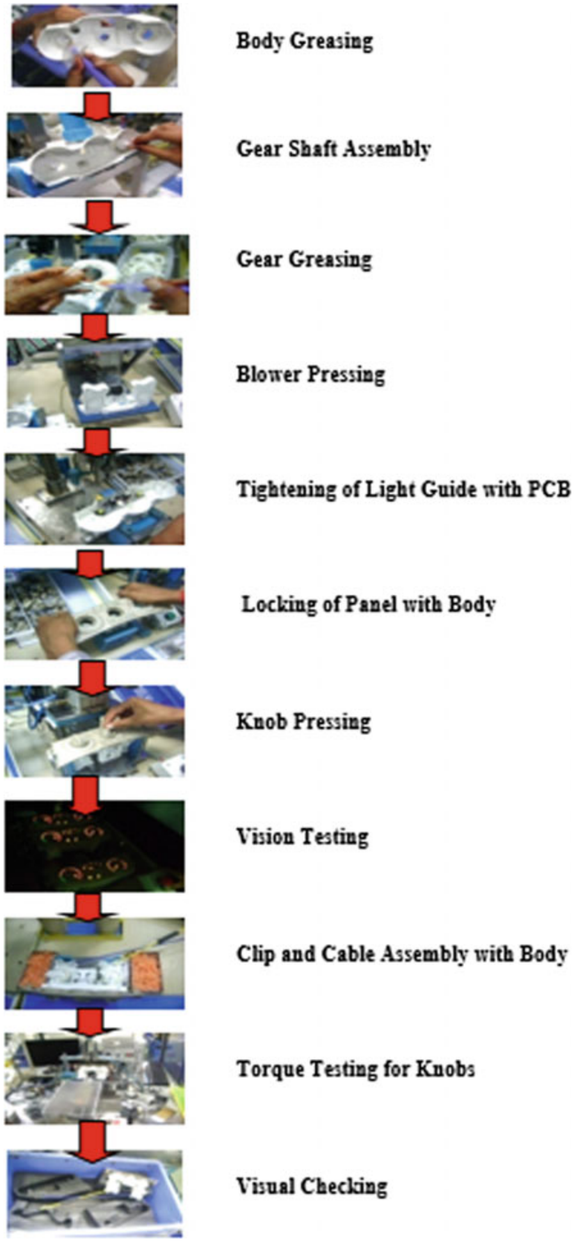


Fig. 2 Process flow diagram

the automotive industry. It produces intense impact on the manufacturing cycle and service with the integration of advanced methods and techniques, which works as a catalyst in finding the solution and reduce the muda elements with the activities of concern. Now, its impact has been spread out from the mass production industry to discrete nature of production. In the way of finding improved methods to improve quality and productivity of the system, many researchers have put their efforts in that direction. The findings of few researchers in brief are mentioned as under:

Warnecke and Huser [1], explained that after implementing the lean theory with its components 'measurement and methods' in an appropriate way, may change the competitiveness of the company in specific fields like management of shop floor activities. Braiden and Morrison [2] studied that company's production capacity may be increased to higher level by implementing lean manufacturing tools. Also, conclude that with this theory up time of the system may be increased by reducing the downtime of the facilities. Matthias Holweg [3], studied and concluded that lean theories may be used to challenge the mass production issues in automotive industries. It may also be used to accept the challenge for different streams of manufacturing and service activities apart from productivity performance and quality of the concern. Colin Herron and Christian Hicks [4], studied that North East Productivity Alliance in England has helped to increase the profit of companies based in north-east England by eight times after implementing the lean theories. Sun et al. [5], studied and concluded after implementing the lean principle with its components 'eliminate, combine, rearrange and simplify', production efficiency of a packing machine manufacturing industry increased to a higher level than the initial phase. Arnout Pool et al. [6] described that if lean theory is applied in an appropriate way then it may impact and improve the operations management field of the industry. Its application started in the automotive industry, now has been showed its importance in discrete industry also. Krisztina Demeter and Zsolt Matyusz [7] concluded that how inventory turnover ratio in the companies may be improved after implementing the lean manufacturing theory and companies may retain their competitiveness for improved results. Jose Romero-Sanchez et al. [8] proposed to implement the Lean methodology, focusing directly on the optimization of production processes using its various tools and a selection of indicators for monitoring the results. To validate, a case study was carried out in a real company that implemented the different Lean tools and the Kaizen matrix in the dyeing and finishing process, a process that presents a high percentage of defects. This allowed them to effectively reduce the number of reprocesses by a significant 8.14%, which allowed the company to save $184,320.42. Karla Bazan-Rios et al. [9] studied and concluded that Lean, Six Sigma, and Theory of Constraints (TOC) are methodologies that focus on continuous improvement. They found that Small Medium Enterprises (SME) have low productivity and by the application of the proposed methodology, it is possible to reduce production times and costs, which allows a 6% increase in productivity and raise the Sigma level in 4 of the SMEs that manufacture furniture in Peru. Abby Ghobadian et al. [10] studied and concluded that in response to hyper-competition, globalization and increasing consumer expectations, many manufacturing firms have embraced lean manufacturing (LM). They commented that Lean manufacturing brings about incremental change relying on administrative, process and routine levers. It is best for mass production industries where process variability is low, and demand is high and stable. Kumar et al. [11], made an investigation in needle missing in bearing of a machine. Initially they found an amount of needle missing as 30%, but when they implemented the Poka-Yoke tool, the case of needle missing reduced to zero and they found that no complaint from the customers. This leads to an increased customer satisfaction, increased sales, enhanced productivity and profit. Premanand et al. [12], studied the impact of Poka Yoke in the company's quality maintenance system. The found that the horns which the industry is using, as a Poka Yoke Tool, have 100% effectiveness in reducing the rejection rates.

3 Problem Identification

Recently Mindarika Pvt. Ltd. has reported a considerable shortfall in production due to rejection and poor quality to meet the increased customer demand. It has been found that this shortfall in production is due to non-value-added activities during processing, which results in poor quality and customer complaints. So, the problem here is the rejection of HVAC Switch during its assembly and actual line production is less than required.

4 Experimental Methodology

- Step 1: Determination of the factors, which affect the quality of product online. For data collection, the major processes have been broken into work elements and placed in sequence and then categorized into different types of work like muda, mura, muri, auxiliary work and value-added work.
- Step 2: Making 'root cause analysis' to determine the parameters, which are responsible for waste or rejection of switch and to find the possibility of work content which is in the form of non-value-added work and which consumes extra time.
- Step 3: Finding the remedial action/solution and suggestions for 'root causes', mentioned in step 2.
- Step 4: Implementation of proposed solutions and ideas online. DMAIC strategy in combination of 5S, Kaizen and Poka yoke will be used to describe steps to solve the problems in HVAC assembly line to improve productivity and quality by minimizing the waste at different workstations by using lean tools.
- Step 5: Collection of new data online after implementing the remedial actions.
- Step 6: Making of comparative statement between initial and final state of the line to reach on conclusion.
- Step 7: Making recommendations about the proposed solution.

5 Objectives

Following are the objective of the study-related assembly line of HVAC switch-

(1) To figure the current status of line with respect to production and rejection rate online at different workstations.
(2) To search factors, which are responsible for rejection at illumination/vision testing station.
(3) To make and implement remedial action for the solution of problems at vision testing station.

In consolidation, our main objective is to reduce rejection rate at vision testing station to a minimum possible value.

6 Experimental Work

6.1 Introduction to Assembly Line HVAC Switch and Process of Assembly of HVAC Switch

HVAC switch is an equipment used in the automobile which is responsible for providing the Air Conditioning, Heating and ventilation to the automobile. It is produced on an assembly line where; workers and machinery are arranged strategically in straight line and switch moves down the line from one station to the next until product is completely assembled. Presently 6 workers have been arranged to perform the different activities to complete processes online. The HVAC assembly line facilitates the associates to do manual operations as well as line is equipped with pneumatic hand and automatic presses to perform the operations. Torque and illumination/vision testing devices are arranged on the line to maintain the quality of the product. Also, a Mock Up station is installed at few meters distance from the last operation on line, where all switches manufactured on line are placed for double check aesthetically and few of them are checked functionally also. Any problem noticed on Mock Up station regarding quality is immediately sent to the line associates to take remedial action to improve the condition of switch. To turn over the inventory in switch assembly, a process flow diagram is shown in Fig. 2.

6.2 Measurement and Analysis Phase

Objective 1 (Measurement Phase): To figure status of line with respect to production and rejection rate online at different workstations. In this phase, concern data were collected and measured online, which may reflect or are reflecting in deviation of quality parameters. The collected data were also discussed with the line operators and production associates and matched with the MIS (management information system) data to reach to objective of this phase. Based on these data, the following figures may be drawn as initial status of line:

1. Line production variates and not more than 640 switches in a shift.
2. Rejection rate 0.8% at illumination testing station.

Parameters identified to improve the assembly line status (refer Table 1):

(1) Rejection at illumination testing station with wrong sticker (Sr. No. 4).
(2) Rejection at illumination testing station due to improper dark room design (Sr. No. 5).

Objective 2 (Analysis Phase): To search factors, which are responsible for rejection at vision testing station.

During this phase of searching the factors which were responsible for rejection and the activities associated with the processes observed and monitored many times with respect to muda word elements. Based on the searching of parameters in this phase, following were considered as issues, on which focus is to be made to improve the line status. To solve the issues regarding this phase, we focused our attention to improve the illumination testing station.

Root Cause Analysis

(A) Root Cause Analysis for Problem ‘Switch Rejection’ Sr. No. 4- in Activity Illumination Testing with Wrong Stickers.

During illumination testing online, it was observed that there is possibility of switch testing with wrong stickers on knobs. If wrong sticker switch reach on illumination testing station, then Dot marking operation will be there on switch and it will

Table 1 Parameters related to switch rejection

S. No.	Parameters/issues	Activity/station	Effect	Rejection/rate (%)
1	Rejection (Body shifting)	Gear shaft assembly with body	–	0.2
2	Rejection (wrong spring used)	Spring and gear shaft assembly	–	0.47
3	Rejection (ball missing)	Gear shaft and ball assembly	–	0.5
4	Rejection (wrong sticker)	Illumination testing	Quality	0.35
5	Rejection (improper dark room)	Illumination testing	Quality	0.45
6	More time and chances of rejection	Shifting FG bin to mock up station	–	–
7	Rejection (asthetical problems)	–	–	0.33

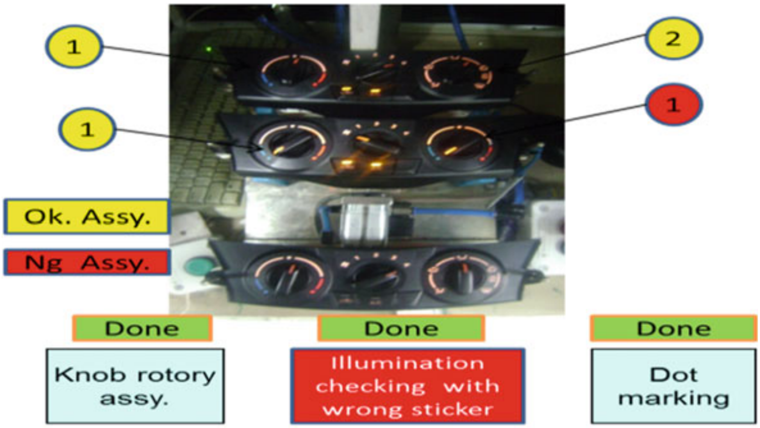


Fig. 3 Illumination testing before improvement

be considered as OK switch, however, it is a 'Not OK' switch. In this condition 'Not OK' switches will mix up with illumination OK switches and may reach to customer end. A rejection rate of 0.35% was found at this station. To prevent occurrence of feeding wrong stickers switch to the next station, it was arranged to have a device or comparing unit online to compare and detect the marking sticker on the switch with a sample piece (refer Fig. 3). Root cause of the problem is not having any detection unit online and effect is poor quality and productivity loss.

(B) Root Cause Analysis for Problem 'Switch Rejection' Sr. No. 5′- in Activity Illumination Testing with Improper Dark Room Design.

It was observed that switch assembly may get reject due to poor illumination passed switches from this station. However, operator must put absolute concentration at this station but due to improper dark room design, a lack in required darkness is there as front side of the dark room is open. Therefore, due to low level of darkness within the area, illumination of the switch may not be checked properly by the operator and illumination 'not good' switch may continue to the next station. A rejection rate of 0.45% was found at this station. To prevent this possibility of passing 'not good' switch to the next station, dark room design may be changed in which high level of darkness is maintained. So, Root cause of the problem is improper design of dark room and effect is poor quality and productivity loss (refer Figs. 4, 5, 6 and 7).

6.3 Solution Development and Implementation Phase (Objective 3)

To Make and Implement Remedial Action for the Solution of Problems at Vision Testing Station.

Fig. 4 Dark room before improvement

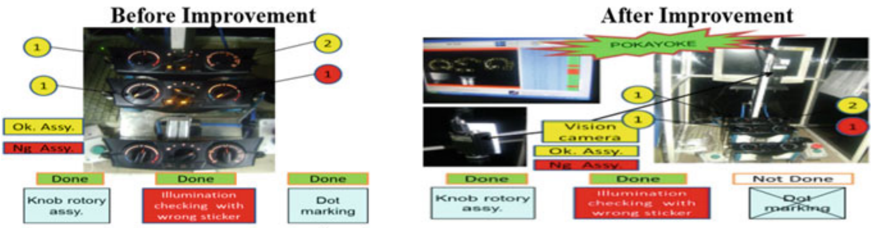


Fig. 5 Illumination testing before and after improvement

Fig. 6 Dark room before and after improvement

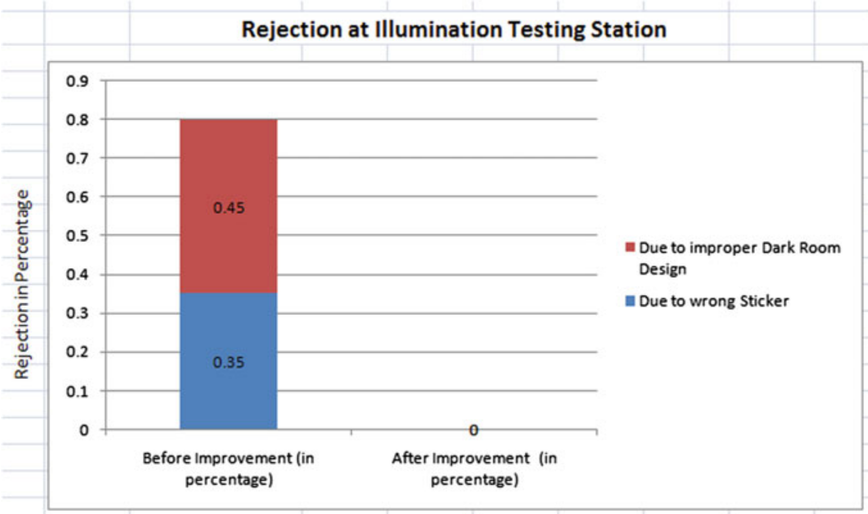


Fig. 7 Rejection before and after improvement

1* Solution of the Problem 'Switch Rejection' Sr. No. 4- in Activity Illumination Testing with Wrong Stickers.

There was a chance of passing switch with wrong sticker/dot marking from the station. On this station parameters like current, continuity, proper illumination, knob functions are checked. In order to prevent occurrence of the problem during illumination testing, a vision camera has installed online, which compares the parameters to differentiate part as 'OK' or 'Not OK' by comparing the illumination of switch with sample switches. Also, Dot marking operation has been synchronized with illumination checking process, which is made on the switch for traceability between checked and unchecked switch. After implementing the solution no occurrence of this problem was observed online.

2* Solution of the Problem 'Switch Rejection' Sr. No. 5- in Activity Illumination Testing with Improper Dark Room Design

Lack of proper darkness within the dark room causes passing of 'Illumination NG' switch from the station. So, to maintain proper darkness within the dark room during illumination testing, the design of dark room has been changed and an automatic sliding door has been introduced. After this new design, we got a required level of darkness within the area during illumination testing. This produces easy testing of switch without passing illumination NG (Not Good) switch from the station.

Table 2 Comparative rejection chart before and after improvement

Rejection before improvement	Rejection after improvement
0.8%	0%

7 Results

As shown above, Lean concepts have been used to explore the problems in the assembly line and by using tools like Kaizen, 5S and Poka-yoke with DMAIC improvement cycle, delay time and rejection have reduced to lower value. Rejection status at illumination testing station after improvement is as under (refer table 2):

- Rejection Before Improvement due to wrong Sticker: 0.35%
- Rejection Before Improvement due to improper Dark Room Design: 0.45%
- Rejection After Improvement due to wrong Sticker: 0%
- Rejection After Improvement due to improper Dark Room Design: 0%

However, in this part of the study, we focused on quality problems at illumination testing station and improved the same successfully. It may be concluded that by integrating the lean approach with advanced methods and techniques in manufacturing system, the quality and productivity of the system may be improved to a higher degree. Also, the findings of this research may be applied to improve the status of different lines within the company in the same way (refer Fig. 7).

8 Conclusion

Mindarika Pvt. Ltd., an automotive industry was facing problems to meet customer demand for its product 'Heating Ventilation and Air Control (HVAC)' switch. A daily production of 675 switches in a shift was needed to meet customer demand, but due to quality problems and rejection at different workstations production was varying in quantity and was limited to 640 switches in a shift. To meet customer's demand, every time company has to pay overtime online, which leads to financial losses and operator's fatigue. In this context, this research has been focused to emphasize the elimination of waste associated with the activities in all forms for all the processes. When waste is reduced by eliminating the Muda work elements, the result is an improvement in customer service, associate's efficiency and the quality performance of the products. The rejection has been reduced to Zero after implementation of the proposed solution i.e. change in the design of Dark Room of Illumination station and Process synchronization of Illumination Station. So, it can be said that the Lean Tools are very effective in eliminating the waste and productivity improvement.

References

1. Warnecke, H.J., Huser, M.: Lean production. Int. J. Prod. Econ. **41**, 37–43 (1995)
2. Braiden, B.W., Morrison, K.R.: Lean manufacturing optimization of automotive motor compartment system. Computer Ind. Eng. **31**(1/2), 99–102 (1996)
3. Holweg, M.: The genealogy of lean production. J. Oper. Manage. **25**, 420–437 (2007)
4. Herron, C., Hicks, C.: The transfer of selected lean manufacturing techniques from Japanese automotive manufacturing into general manufacturing (UK) through changes agents. Robot. Comput. Integr. Manuf. **24**, 524–531 (2008)
5. Sun, X. F., Cheng, G., Li, W.: Work improvement in a packaging machine manufacturing company, a case study. Int. Conf. Indus. Eng. Indus. Manag. (2009)
6. Pool, A., Wijngaard, J., van der Zee, D.-J.: "Lean planning in the semi-process industry", a case study. Int. J. Prod. Econ. **131**, 194–203 (2011)
7. Demeter, K., Matyusz, Z.: The impact of lean practices on inventory turnover. Int. J. Prod. Econ. **133**, 154–163 (2011)
8. Romero-Sanchez, J., Martinez-Vilchez, R., Galvez-Zarate, C., Raymundo-Ibanez, C.: Process management model in dry cleaning and fabric finishes applying Lean manufacturing and Kaizen matrix for the textile sector., 978–1–7281–0883–4/19, IEEE (2019)
9. Bazan-Rios, K., Chavez-Canales, C., Ramos-Palomino, E., Eyzaguirre-Munarriz, J., Mesia, R.: An integrated system: Lean, Six Sigma and theory of constrains, a study applied in wooden furniture industry in Lima, Peru. In: 2019 7th International Engineering, Sciences and Technology Conference (IESTEC)
10. Ghobadian, A., Talavera, I., Bhattacharya, A., Kumar, V., Garza-Reyes, J.A., O' Regan, N.: Examining legitimatization of additive manufacturing in the interplay between innovation, lean manufacturing and sustainability. Int. J. Prod. Econ. **219,** 457–458 (2020)
11. Kumar, B., Rakesh, P.K.: Implementation of Poka Yoke in needle bearing assembly process. Int. J. Eng. Sci. Invention. ISSN (Online): 2319–6734, vol. 6 Issue 11|, November 2017, PP 01–10
12. Premanand, N., Kannan, V., Sangeetha, P., Umamaheswari.: A study on implementation of poka– yoke technique in improving the operational performance by reducing the rejection rate in the assembly line. Int. J. Pure Appl. Math. **119**(17), . 2177–2191 (2018). ISSN: 1314–3395

Implementation of Six Sigma in CNC Turning Machine—A Case Study

G. Shruthi and O. S. Deepa

Abstract This study focuses on implementing the DMAIC methodology of Six Sigma to reduce the quality defects of the products occurring in the manufacturing process within a CNC (Computer Numeric Control) turning component machining company. The study follows the application of the DMAIC technique to investigate the defects, root causes and provide a solution to reduce these defects by evaluating the best process environment which could simultaneously satisfy requirements of both quality and as well as productivity. In this paper, six sigma with fuzzy analytic hierarchy process, for the manufacturing of a CNC turning component called front end cover is selected out of three projects and DMAIC model is adopted to investigate the defects obtained in the manufacturing process and also provides a solution to reduce these defects by improving the performance of the process. Normality test followed by process capability index and control chart has been computed for each major component of the process. Factorial experiments are also carried out to show the efficiency of the machine.

Keywords Factorial experiments · Fuzzy analytic hierarchy process · Process capability index · Regression analysis · Signal to noise ratio

1 Introduction

Six Sigma is considered as a business strategy that enables an organization to increase their profits by improving quality and eliminating defects. Aouag et.al. [1] studied the investigation of effectiveness level in an industrial company via a continuous enhancement-based method. Bilge Bilgen and Mutlu Sen [2] presented a case study based on six sigma methodology. Jirasukprasert studied the defects of reduction in a rubber gloves manufacturing process by applying the DMAIC problem. One of the important factors of achieving success in an organisation is selecting the right six sigma projects. Six sigma is an innovative methodology used to improve

G. Shruthi · O. S. Deepa (✉)
Department of Mathematics, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, India
e-mail: os_deepa@cb.amrita.edu

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_25

the process by using a series of statistical techniques to determine and analyze the manufacturing process. It involves in-depth analysis and strategic decision-making with the goal of finding an optimal solution rather than a rational one. With a view to improving quality, the fundamental concept in Six Sigma is to analyze the variations in both product and process. Motorola Corporation created the six sigma to boost the production efficiency [3]. A systematic factory-in-factory (FiF) framework of the production system is studied by minimising wastes according to the unresolved issues of the current continuous improvement program [4]. An improved modified FMEA model for prioritization of lean waste risk was modelled by the inclusion of the waste-worsening factors and Taguchi loss functions which has enabled the FMEA team to articulate the severity level of waste [5, 6]. Fuzzy Interpretive Structural Modeling (FISM) approach has been used to analyze the interrelationships among health care factors [7–17].

1.1 Selection of Six Sigma Project

Six sigma is a project-oriented approach that helps the organization through a successful project to achieve its strategic objective. Especially when performing six sigma initiations, project generation and priority perform the most critical parts. Six sigma is a tool for the pursuit of operational excellence that has significant value. After various decision-makers had expressed their views, the criterias were finalized. Alternatives for six Sigma project selection should be evaluated to these established criteria. It is not easy generally to express all the constraints with uncertainty and hence it is better to use the fuzzy set theory for selecting six sigma projects FAHP. Fuzzy set and fuzzy logics are important computational tools for modeling and management of an uncertain process in industries and society. Hence six sigma was implemented in order to reduce the overall cost associated with the production process. Even though the application of six sigma has drastically been used in industries and production process, the contribution of DMAIC methodology in the CNC machine is very less.

2 Materials and Methods

CNC turning refers to computer numeric control for shaping material, such as metal, wood or plastic. In CNC turning method, a section of material (wood, metal or plastic) is rotated and a cutting tool is stimulated and moved parallel to the axis of rotation to form accurate diameters and depths.

In this paper, three components are evaluated namely component A (flange production), component B (front end cover production) and component C (pulley production) by discussing with the team members of the company to select the most effective six sigma project alternative. Few questions were discussed with the expert team and

Table 1 TFN scale [7]

Statement	TFN
Very high	(3.5,4,4.5)
High	(2.5,3,3.5)
Medium	(1.5,2,2.5)
Low	(0.67,1,1.5)
Very low	(1,1,1)

based on the responses. Table 2 has been obtained using the triangular fuzzy number as per [7] in Table 1.

In Table 2, the maintenance cost of component A with respect to component B was found to be low and the raw material cost of component B with respect to component C was found to be very high. Hence priority weights are calculated for the three components and is tabulated in Table 4.

Table 3 shows the priority weights of the three components. The priority weights of each six sigma project can be calculated by weights per project(component) multiplied by weights of the corresponding criterion. It is found that the priority weight of the Component B is 0.88 which is more than the other two components priority weights. So, the Component B 'CNC Turning Component (Front End Cover)' machining is selected for the six sigma project.

The program in the form of G-code is loaded into the machine and the workpiece is placed in the jaws in the chuck where the chuck is a type of clamp that holds the rotating workpiece in the CNC machine. Then the cutting tool is placed in the tool turret of the machine. The tool and the workpiece should be kept close. The coolent, lubricant oil and other parameters should be checked before switching on the machine. Figure 1 shows the flow chart for turning operation.

Step 1: Turning 1 Operation

In this process, the outer diameter of the component is reduced from 52 to 50 mm by turning and the size is checked using 50 mm plain ring gauge. Using the grooving tool the groove diameter is increased from 44 to 46 mm and the dimension is checked using digital vernier caliper.

Step 2: Turning 2 Operation

In this step, the Internal diameter is increased from 24 to 25 mm by the boring operation and dimension is checked by using plain plug gauge. Later, the 30 mm groove is changed to 33.7 mm and it is checked by digital vernier caliper as per standards.

Step 3: Inspection

After Step 2, the component is cleaned by air and goes for inspection to check whether there is any handling damage to it and then the component goes to dispatch.

Table 2 Evaluation of the components with respect to the goal

	Component A	Component B	Component C
Maintenance cost			
Component A	(1,1,1)	(0.67,1,1.5)	(1.5,2,2.5)
Component B	(3.5,4,4.5)	(1,1,1)	(2.5,3,3.5)
Component C	(0.67,1,1.5)	(0.67,1,1.5)	(1,1,1)
Raw material cost			
Component A	(1,1,1)	(1.5,2,2.5)	(0.67,1,1.5)
Component B	(2.5,3,3.5)	(1,1,1)	(3.5,4,4.5)
Component C	(0.67,1,1.5)	(1.5,2,2.5)	(1,1,1)
Electricity cost			
Component A	(1,1,1)	(0.67,1,1.5)	(0.67,1,1.5)
Component B	(3.5,4,4.5)	(1,1,1)	(3.5,4,4.5)
Component C	(1.5,2,2.5)	(0.67,1,1.5)	(1,1,1)
Scrap yield cost			
Component A	(1,1,1)	(0.67,1,1.5)	(0.67,1,1.5)
Component B	(0.67,1,1.5)	(1,1,1)	(2.5,3,3.5)
Component C	(1.5,2,2.5)	(0.67,1,1.5)	(1,1,1)
Operator cost			
Component A	(1,1,1)	(0.67,1,1.5)	(1.5,2,2.5)
Component B	(3.5,4,4.5)	(1,1,1)	(2.5,3,3.5)
Component C	(0.67,1,1.5)	(0.67,1,1.5)	(1,1,1)
Raw material cost			
Component A	(1,1,1)	(1.5,2,2.5)	(0.67,1,1.5)
Component B	(3.5,4,4.5)	(1,1,1)	(2.5,3,3.5)
Component C	(5,2,2.5)	(1.5,2,2.5)	(1,1,1)

Table 3 Priority weights of the main criteria

	Maintenance cost	Raw material Cost	Electricity cost	Scrap cost	Operator cost	Programmer Cost	Priority weight
Weight	0.17	0.06	0.26	0.17	0.17	0.18	0.03
Component A	0	0	0	0.19	0	0	0.88
Component B	1	1	1	0.47	1	0.78	0
Component C	0	0	0	0.34	0	0.22	0.1

Table 4 Six Sigma level of different process

Sub-process	Production units	Defects per opportunity DPO	Total DPMO	Six sigma level	Sub-process	Production units	Defects per opportunity DPO	Total DPMO	Six sigma level
Turning 1					Inspection				
Boring	17,160	5			Handling damage	17,057	3	0.00001	**5.7648907**
Grooving	17,155	26			Unwash inspection	17,054	7		
Turning 2					*Overall process*				
Boring	17,129	24	0.00007	**5.3011948**	Turning 1	17,160	31	0.00011	**5.1880266**
Grooving	17,105	48			Turning 2	17,129	72		
					Inspection	17,057	10		

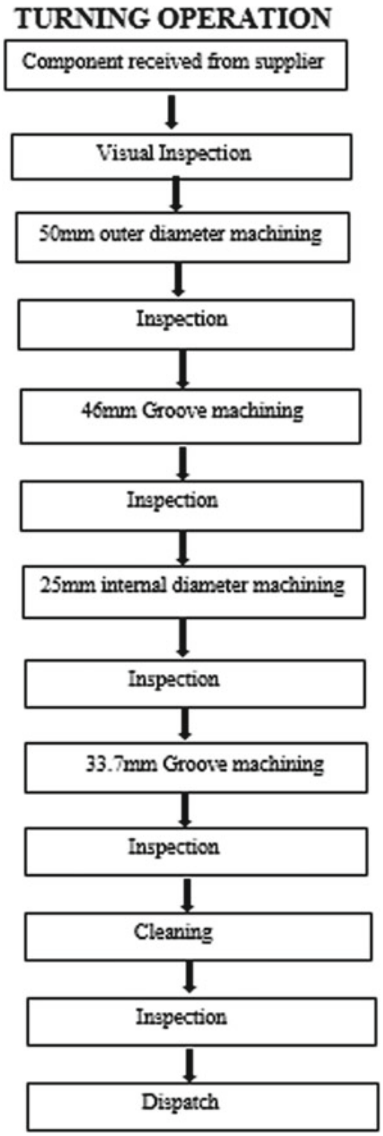


Fig. 1 Flow chart for turning operations

3 Results and Discussion

3.1 Define Phase

In this project, the problem that is selected to be tackled is quality defects on the components. The goal is to reduce the number of defective components.

4 Measure Phase

Here the data regarding production units and the number of defectives at each process level is collected for 26 days. And the DPMO-weighted approach is applied to measure the Six Sigma level of the process (before and after weighting).

In Table 4 six sigma at various levels were computed and compared. In this sub-process, the cost of poor quality is considered. From the measure phase, with the help of the CPQ criterion it was found that the performance of the Turning 2 process was not good due to more number of defectives obtained in that process especially in the sub-process grooving. So, the process capability index for the groove diameter of the components was found. Before finding the process capability index, the normality test for the data is carried out using Anderson–Darling test to find whether the data is normal or not (refer Tables 5, 6, 7, 8, 9 and 10).

Figure 2 shows that the data (groove diameter of the components) is normally distributed as the p-value is $0.235 > 0.05$. So, process capability index is found as shown below. Figure 3 represents the Process Capability Index for the groove diameter of the Turning 2 process. It shows that Cpk value is 0.10 which is less than 1 and many data points are out of specification limits indicating that the performance of the process is very low.

Table 5 Calculation of weights for turning 1

	CPQ Cost of poor quality	$R = CPQi/\Sigma(CPQi)\%$	Combined weight
Boring	100	15	0.15
Grooving	546	85	0.85

$DPMO = \Sigma(Wi \times DPi)/10^6 = 22.85/10^6 = 0.00002285$
The six-sigma level for DPMO is Z = 5.576594945

Table 6 Calculation of weights for Turning 2

		$R = CPQi/\Sigma(CPQi)\%$	Combined weight
Boring	624	33	0.33
Grooving	1296	68	0.68

$DPMO = \Sigma(Wi \times DPi)/10^6 = 40.56/10^6 = 0.0000405$
The six-sigma level for DPMO is Z = 5.883476972

Table 7 Calculation of weights for inspection

	CPQ	$R = CPQi/\Sigma(CPQi)\%$	Combined weight
Boring	78.3	29	0.29
Grooving	190.4	71	0.71

Table 8 Calculation of weights for overall production

Process	CPQ	R = CPQi/ Σ(CPQi)%	Combined weight
Turning 1	646	23	0.23
Turning 2	1920	68	0.68
Inspection	268.7	9	0.09

DPMO = $\Sigma(Wi \times DPi)/10^6$ = 5.84/10^6 =0.00000584 DPMO = $\Sigma(Wi \times DPi)/10^6$ = 56.99/10^6 =0.00005699
The six-sigma level for DPMO is Z = 5.441066887
The six-sigma level for DPMO is Z = 5.358725222

Table 9 Signal to Noise Ratio for Turning Time

Si. no	Speed	Feed	Doc	Turning time				Mean	σ	S/N
1	1500	0.1	1.0	20	20	18	22	20	1.6329	21.7609
2	1500	0.12	0.8	19	20	21	16	19	2.1602	18.8850
3	1500	0.15	0.5	18	18	19	17	18	0.8164	26.8664
4	1800	0.1	0.8	17	15	14	14	15	1.4142	20.5115
5	1800	0.12	0.5	17	17	15	19	17	1.6329	20.3493
6	1800	0.15	1.0	16	18	15	15	16	1.4142	21.0721
	2000	0.1	0.5	19	18	20	19	19	0.8164	27.3360
8	2000	0.12	1.0	16	17	16	15	16	0.8164	25.8433
9	2000	0.15	0.8	17	19	18	14	17	2.1602	17.9189

Table 10 Response table for S/N ratio

Level	Speed	Feed	Doc
1	22.50	23.20	24.85
2	20.64	21.69	19.11
3	23.70	21.95	22.89
DELTA	3.06	1.51	5.75

Figure 4 represents the $\overline{X}$**–R control chart** for the groove diameter of the components in the Turning 2 process and it shows that there is a point out of the control limits which means that the process is not in control.

5 Analyze Phase

From the measure phase, it was identified that the performance of the Turning 2 process was not good, especially its sub-process. Hence Taguchi Design of Experiments is performed.

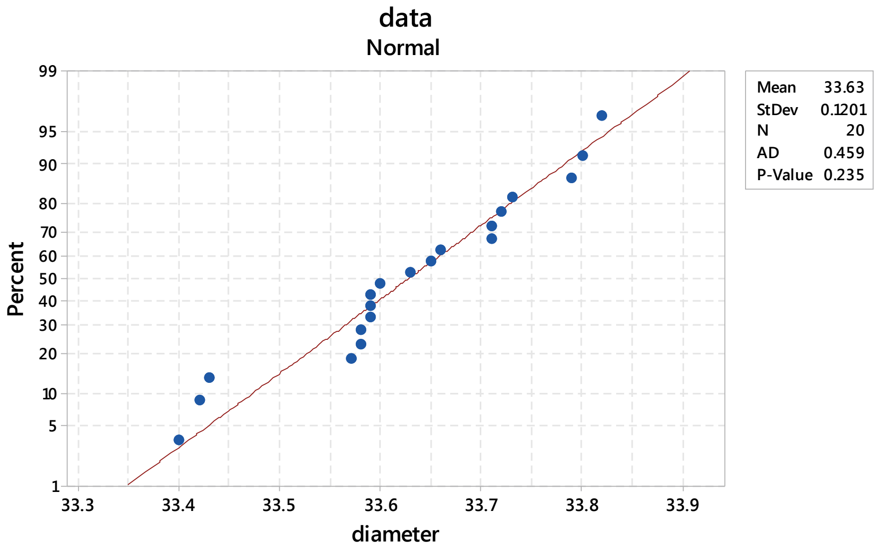


Fig. 2 Normality test for the data

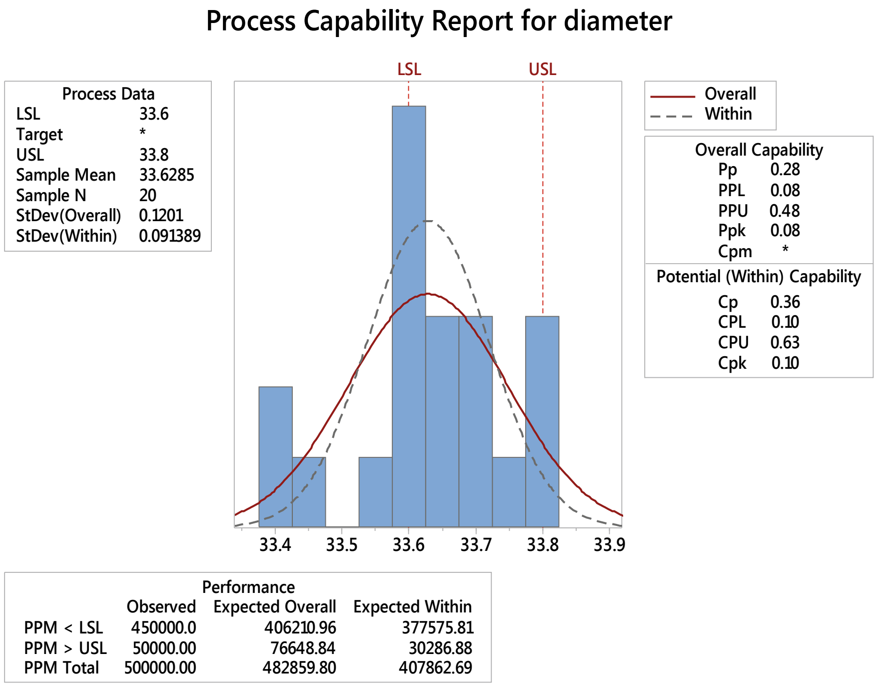


Fig. 3 Process capability index

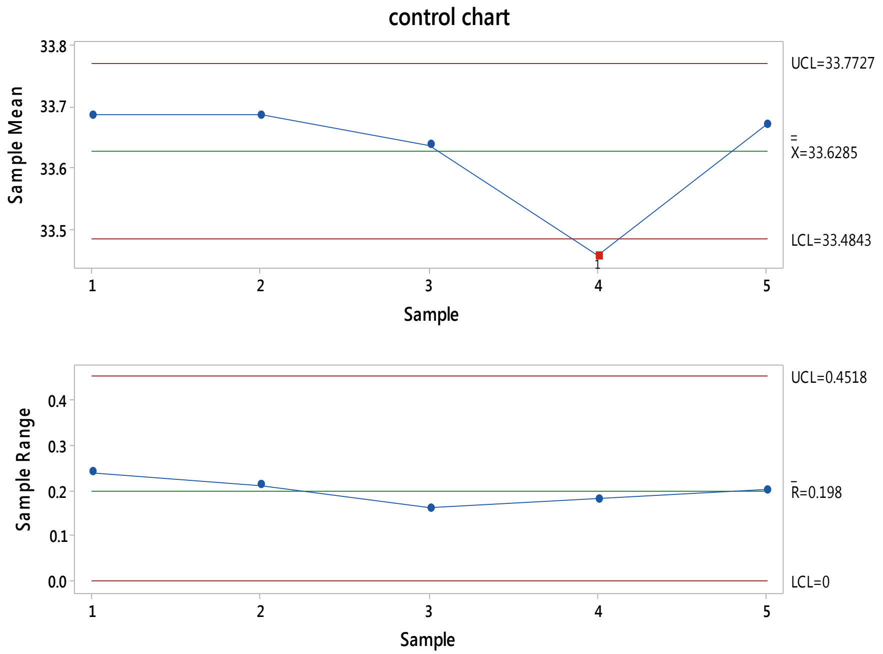


Fig. 4 $\overline{\mathrm{X}}$–R control chart

A study is made on the Turning time of the component by analysing its cutting parameters Speed, Feed and DOC which are the most influencing factors in determining the productivity and product quality.

Using Taguchi method of design of experiment the signal to noise(S/N) ratio is given by S/N $= 10\log\left[\overline{y}^2/\sigma^2\right]$. Based on the analysis, optimum setting for the process is speed 2000, feed 0.1, DOC 0.5. Figure 5 show the signal to noise plot for turning time.

Regression equation is obtained for the above-mentioned combinations of the cutting parameters using Minitab and the following equations are obtained.

- Turning Time = 27.787—0.004 Speed—19.298 Feed—1.491DOC
- Turning Time = 24.263—0.004 Speed
- Turning Time = 19.825—19.298 Feed
- Turning Time = 18.588—1.491 DOC

Based on the analysis it is found that the Standard error of the estimate Speed is 1.538 and it is less than the Standard error of the estimate of the Feed 1.724 which is less than 1.748 the Standard error of the estimate DOC. Hence Speed is the most influencing parameter on the turning time followed by Feed and DOC.

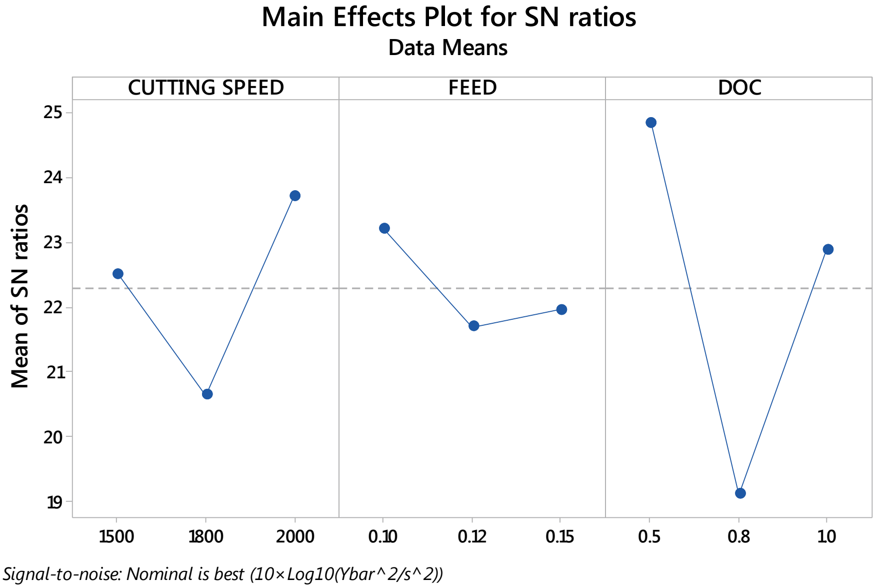


Fig. 5 Signal to noise plot for turning time

6 Improve Phase

In improve phase factorial experiment is carried out. This phase aims at improving the process by implementing the results obtained from the analyse phase. Before implementing the solution from the analyse phase Analysis of Variance is carried out to find the main effects and the interaction effects of the cutting parameters.

From Table 11, it can be concluded that there is significant effect of speed on turning time and no is no significant effect of feed on turning time and DOC on turning time. Also, interaction effect between speed and feed does not affect the turning time, interaction effect between feed and DOC and the interaction effect between speed and DOC affect the turning time at a certain level. Figures 6, 7 and 8 represents the interaction effect of Speed and Feed at three different levels (Table 12).

From the analyse phase, the optimum setting of the input parameters Speed, Feed and DOC was found to be 2000, 0.1, 0.5. By implementing this combination for the Turning process, the number of defectives was found to be less and the product quality was improved and the overall performance of the process became more effective. Table shows the number of defectives of the Turning 2 process before and after improvement. The Turning 2 process was selected and improved because it was found to be having a greater number of defectives (refer Figs. 9, 10, and 11).

Figure 9 shows that the data (groove diameter of the components) is normally distributed as the p-value is 0.897 > 0.05. So, process capability index is found as found as shown below. The above Fig. 10. represents the Process Capability index

Table 11 Tests of between-subjects effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig
Corrected Model	51.556(a)	18	2.864	4.617	0.017
Intercept	8356.481	1	8356.481	13,470.149	0.000
Speed	20.963	2	10.481	16.896	0.001
Feed	2.296	2	1.148	1.851	0.218
DOC	0.074	2	0.037	0.060	0.942
speed * feed	4.593	4	1.148	1.851	0.213
feed * DOC	3.481	4	0.870	1.403	0.316
speed * DOC	20.148	4	5.037	8.119	0.006
Error	4.963	8	0.620		
Total	8413.000	27			
Corrected Total	56.519	26			
R Squared = 0.912 (Adjusted R Squared = 0.715)					

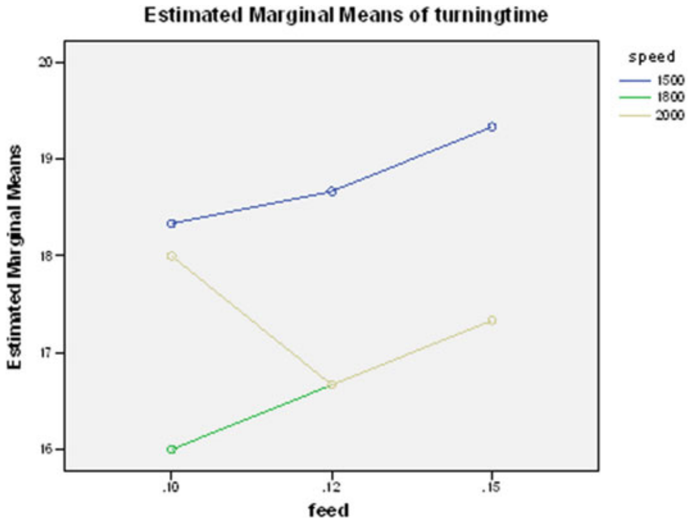


Fig. 6 Feed versus marginal means

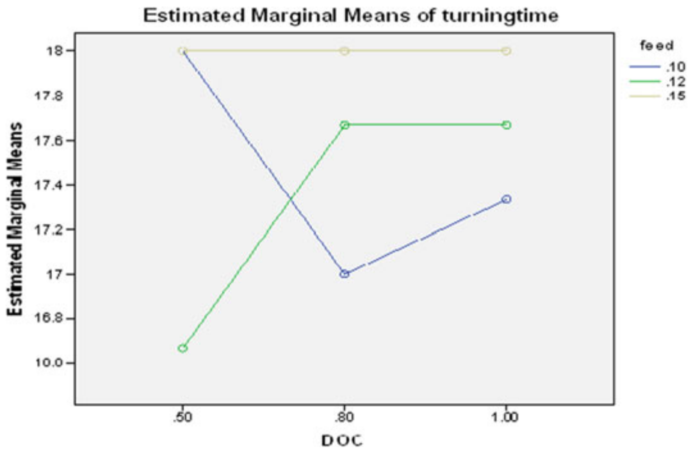


Fig. 7 DOC versus marginal means

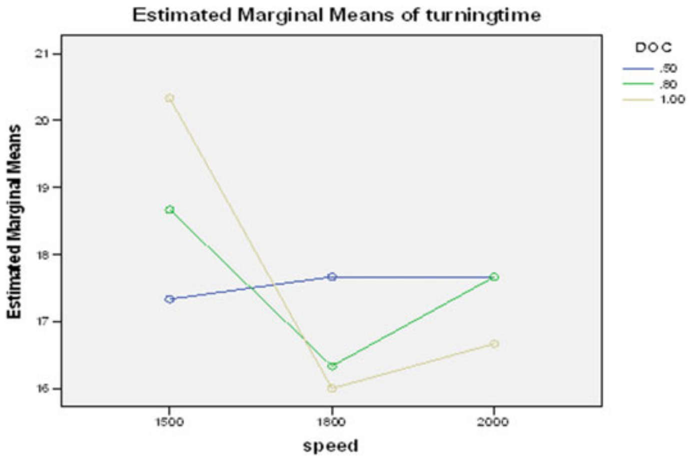


Fig. 8 Speed versus marginal means

Table 12 Number of defectives

Turning 2	Before	After
Boring	24	5
Grooving	48	12

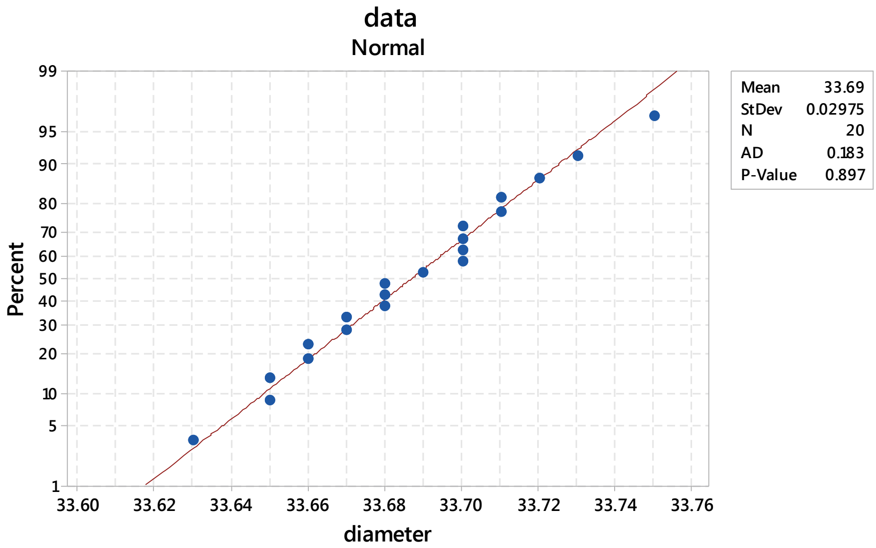


Fig. 9 Normality

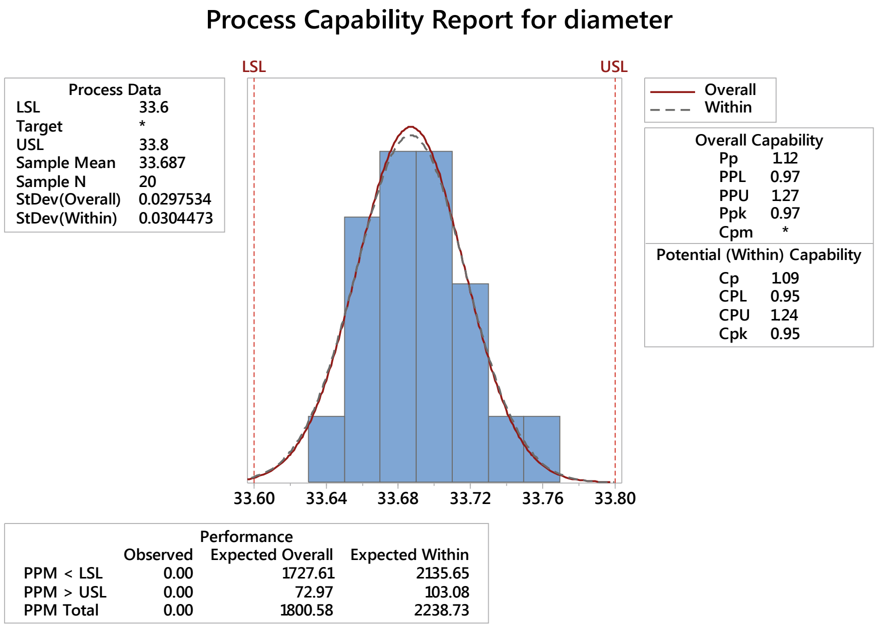


Fig. 10 Process Capability

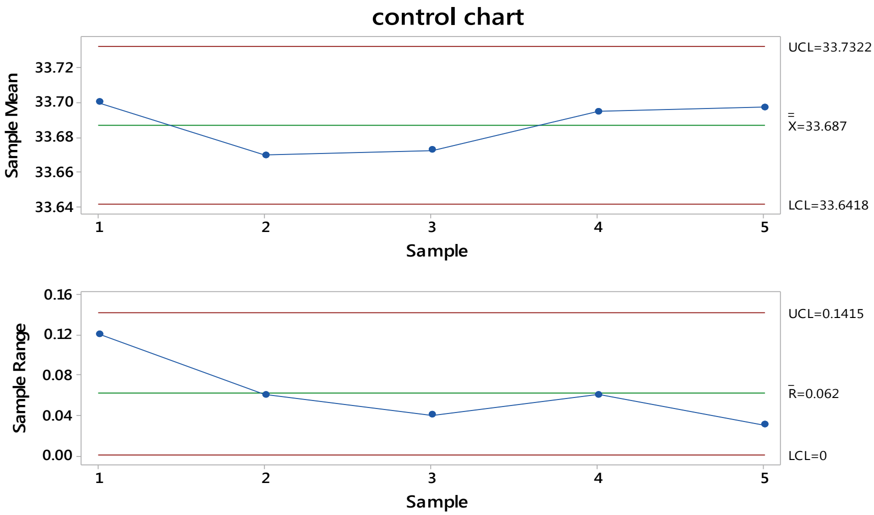


Fig. 11 $\overline{X}$ –R control chart

for the groove diameter of the Turning 2 process after improvement. It shows that the Cpk value is 0.95 which is close to 1 which means the process is capable.

6.1 Control Phase

Control phase is a very important phase for Six Sigma methodology. In this phase, the gains that are made in the improve phase are evaluated to ensure that the process works well, produce desired outputs and maintain quality level. Figure 11 represents the $\overline{X}$ **–R control chart** for the groove diameter of the turning 2 process. It shows that the process is in control as all the points lie within the control limits.

7 Conclusion

In this paper, CNC turning component (front end cover) machining is selected as the six sigma project using fuzzy method and DMAIC model is implemented to identify and reduce the defects occurring in the manufacturing process. In the define phase, a project charter stating the reasons for selecting the project and improvement goals is created by discussing with the team members of the company. In the measure phase, weighted DPMO approach is applied to measure the six sigma level of each process and Turning 2 process is selected for improvement with the help of CPQ criteria and its process capability index was found to be 0.10. In the analyse phase, the optimum combination of the input parameters for the Turning 2 process is found using Taguchi's design of experiments and their optimum combination is Speed 2000, Feed 0.1, Doc is 0.5. The combination was implemented in the improve phase for an experimental run and the process capability index got improved to 0.95 which is close to 1 and the defects are reduced indicating that the manufacturing process has been improved by implementing the optimum combination of the input parameters speed feed DOC as these parameters are considered as the key factors in determining the productivity and product quality. So, the implementation of the DMAIC technique is proved to be successful in improving the performance of the turning process thereby making it more capable of producing the products with good quality and right dimensions.

References

1. Aouag, H., Kobi, A., Mechenene, A.: Analysis of competitiveness level in an industrial company using a continuous improvement-based approach. Int. J. Six Sigma Compet. Adv. **9**(2,3,4) (2015)
2. Bilge, B., Sen, M.: Project selection through fuzzy analytic hierarchy process and a case study on Six Sigma implementation in an automotive industry. Prod. Plann. Control Manage. Oper. **23**(1):2–25, (2011)
3. Customer satisfaction measurement and analysis using six sigma: Behara, R., Fontent, G. F., & Gresham, A. International Journal of Quality & Reliability Management **12**, 9–18 (1995)
4. Ani, M.N.C., Kamaruddin, S., Azid, I.A.: Factory-in-factory concept as a new business model for automotive production system. Int. J. Six Sigma Compet. Adv. **11**(2/3) 2019)
5. Sutrisno, A., Gunawan, I., Vanany, I., Asjad, M., Caesarendra, W.: An improved modified FMEA model for prioritization of lean waste risk. Int. J. Lean Six Sigma **11**(2) (2020)
6. Ajmera, P., Jain, V.: A fuzzy interpretive structural modeling approach for evaluating the factors affecting lean implementation in Indian healthcare industry. Int. J. Lean Six Sigma **11**(2) (2020)
7. Chang, D.Y.: Applications of the extent analysis method on fuzzy AHP. Eur. J. Oper. Res. **95**(3), 649–655 (1996)
8. Goh, T.N., & Xie, M: Improving on the Six Sigma paradigm. TQM Magaz. **16**(4), 235–240 (2004)
9. Jirasukprasert, P., Reyes, J.A., Meier, H., Lona, L.: A case Study of defects reduction in a Rubber Gloves manufacturing process by applying Six Sigma principles and DMAIC problem solving methodology. In: International Conference on Industrial Engineering and Operations Management, Istanbul, Turkey, July 3–6, (2012)
10. Markarian, J.: Six Sigma: quality processing through statistical analysis. Plastics, Additives Compounding **9**(4), 28–31 (2004)
11. Phanden, R. K., & Ferreira, J. C. E.: Biogeographical and Variable Neighborhood Search Algorithm for Optimization of Flexible Job Shop Scheduling. In: Advances in Industrial and Production Engineering (pp. 489–503). Springer, Singapore (2019)
12. Deepa, O.S.: Optimal production policy for the design of green supply chain model. Int. J. Appl. Eng. Res. **10**(2), 1600–1601 (2015)
13. Deepa, O.S.: Application of acceptance sampling plan in green design and manufacturing. Int. J. Appl. Eng. Res. **10**(2), 1498–1499 (2015)
14. Prasenjeet, C.G, Tushar, N.D: Reduction of rework the Six Sigma way:case study of an Indian small scale industry. Int. J. Six Sigma Compet. Adv. **7**(1), 92–116 (2012)
15. Phanden, R. K., Saharan, L. K., & Erkoyuncu, J. A.: Simulation based cuckoo search optimization algorithm for flexible job shop scheduling problem. In: Proceedings of the International Conference on Intelligent Science and Technology (pp. 50–55) (2018)

16. Shruthi, G., Deepa, O.S.: Average run length for exponentiated distribution under truncated life test. Int. J. Mech. Eng. Technol. (IJMET) **9**(6), 1180–1188 (2018)
17. Krishnan, S.M., Deepa, O.S.: Control charts for multiple dependent state repetitive sampling plan using fuzzy poisson distribution. Int. J. Civil Eng. Technol. (IJCIET) **10**(1), 509–519 (2019)

"5 s Housekeeping"-A Lean Tool: A Case Study

Sarthak Jain, Gaurav Chaudhry, Mohd Talha, and Richa Sharma

Abstract The research paper pertains to the implementation of "5S Housekeeping" in the Sheet Metal Workshop of a manufacturer/supplier of Hero MotoCorp Ltd. The objective for the implementation of 5S arises due to reasons like uneasy work environment, excessive wastage, and inefficient workstations in the company. Therefore, in order to efficiently work on the above-mentioned factors arises the need to implement 5S in the organization. The reduction of 7 wastes defined by Toyota is a major part of the process. The effective implementation and follow-through for 5S in the workshop by all staff members work as a catalyst for improving work ethics, fundamental practices, manufacturing performance and in-house capability. After the implementation of this technique, a visible improvement in the working conditions and employee satisfaction is achieved.

Keywords 5S · Lean manufacturing · Optimisation

1 Introduction

In the current scenario, all competitors in the market aim to maximize their profits/benefits; proper waste management and workplace organization are vertical under the same. This can be achieved by strict application of a workplace organization technique, i.e., "5S Housekeeping". As the largest two-wheeler manufacturer in the world, the margin of error in manufacturing processes must be reduced to zero for the organization to keep this favourable spot. Hence the company has introduced and adopted the concept of "5S Housekeeping" which pertains to the detailed procedure for predetermined level of organization and standardization and helpful in reducing waste or any non-value-adding elements.

Manufacturing requires improved efficiency, reduced waste, and delivery response time by adapting principles of Lean thinking. 5S acts as a window to a customer-based strategy that focuses on optimization of Lean techniques. The use of resources

S. Jain (✉) · G. Chaudhry · M. Talha · R. Sharma
Department of Mechanical Engineering, Amity School of Engineering and Technology, Amity University Uttar Pradesh, Sector—125, Noida 201313, India
e-mail: sarthak.jain1996@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_26

that do not deliver the customer value is target for elimination. Complete application of 5S would result in a huge enhancement in productivity, improved safety, cost reduction, etc.

Two primary tools deployed in the framework are "5S" and visual management. 5S system allows inefficiencies to be categorized and addressed separately [1]. It has been stated that successful auditing gives us the opportunity to gain a competitive advantage and quickly develop our business in terms of security [2]. It was observed that 5S tends to increase the performance of equipment and machines by developing personnel's knowledge and skill as well as their sense of responsibility [3]. It deduces that 5S and other lean manufacturing practices satisfy the demands of cost, effective quality, components in many automobile OEM and tier-1 suppliers [4]. It was interpreted that 5S significantly contributed to the progress of the organization in the terms of quality, productivity, effective utilization of space and employee morale [5]. It was concluded that 5S is the essential tool of lean management system [6]. It has been stated that 5S is a lean tool to eliminate or minimize waste, 5S is commonly used by the industrial world, especially the manufacturing industry [7]. It was noticed that 5S was the main tool used to identify the opportunities for improvement as a step zero of lean techniques [8]. It infers that 5S tool not only contributes to a more efficient work environment but also ensures improved occupational safety for the workers [9]. 5S technology in a small-scale ceramics industry to see significant improvements in workflow and general cleanliness [10]. Stated that 5S methodology is a better way to increase production in construction organization [11]. 5S can be linked for improvement in appropriate categories that is preparatory, implementing and improving in a company [12]. 5S program in a stock sector is a beneficial program which is one of the shortcomings of large backlogs of manufacturing products in the manufacturing sector [13].

1.1 Definition of 5S

"5S housekeeping" is a Japanese Lean manufacturing technique invented by Takashi Osadsin in the early 1980s. 5S is a visual workplace organization method defined as a workplace organization method which works to reduce the wastage or removal of any non-value adding processes by proper and efficient organization of the workplace, which makes it a self-sustaining system if implemented correctly.

5S can be used for tool rack management, Tool rack management refers to the arrangement of tools like drill bits, jigs, fixtures, etc., in a way so that it efficiently functions with relation to waste management, inventory management and smooth functioning of the assembly line. Figure 1 represents 5S process in which all steps are elaborated.

The main objectives of implementing 5S at Hero MotoCorp Ltd are

(1) Reduction of waste by proper tool rack management

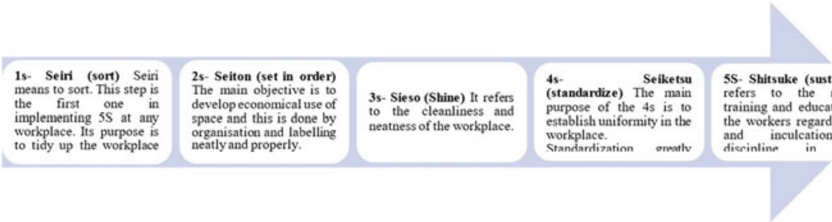


Fig. 1 5S process

(2) Better inventory management for an uninterrupted workflow by implementation of 5S on tool rack.

2 Problem Statements

Sheet metal zone faces the following issue that could be resolved by implementation of 5S:

(1) General lack of cleanliness of workplace
(2) Storage bins and trolleys were lying around
(3) Tool racks were not properly arranged and no labelling
(4) Tiny bits of trash lying in corners

These problems were highlighted after the analysis of the initial 5S audit; 0 refers to no action required and 4 refers to an immediate action. Table 1 present the initial 5S audit.

2.1 Checklist for Initial 5S Audit

3 Methodology

3.1 Case Study

Implementation of “5S Housekeeping” in the Sheet Metal Workshop of a manufacturer/supplier of Hero MotoCorp Ltd. (Gautam Buddha Nagar road, Dadri, U.P) which is one of the world’s biggest two-wheeler manufacturers in the world. The effective implementation and follow-through for 5 s in the workshop by all staff members works as a catalyst for improving work ethics, fundamental practices, manufacturing performance and in-house capability.

Table 1 Initial 5S audit

S. no	Marks	0	1	2	3
IS (SEIRI)-SORT					
1	Shop Floor/Dept. layout clearly showing the location of all Machines, Equipment, Items, etc., made displayed			2	
2	All Machines, Equipment, Items Are Positioned As Per Layout			2	
3	Segregation of Necessary and Unnecessary Items done or not			2	
4	Unwanted/Unused/Damaged/Scrap Material removed to separate place, away from work area			2	
2S (SEITON)-SET IN ORDER					
1	Codification of Machine, Equipment, Tools, Gauges, Items done, A Variable Address system is in place wherever applicable			2	
2	Master List of all Machines, Equipment, Tools, Gauges, Items prepared and displayed			2	
3	Gang ways Marking is clear, and no material is in the gangway		1		
4	Shadow boards, wherever applicable, are available effectively Used		1		
3S (SEISO)-SHINE					
1	Dirt Free Machines, Equipment, Tools, Gauges, Jigs, Fixtures, Measuring Equipment, etc		1		
2	Dirt Free Storage Racks/Pallets/Bins/Floors/Switches/Control Panels/Cables		1		
3	Dirt Free Walls, Ceiling, Floors, Windows, Fans, Light Fittings, Switches, Control Panels, Cables, etc			2	
4	All toilets are in good condition and no bad smell is coming			2	

(continued)

Table 1 (continued)

S. no	Marks	0	1	2	3
4S (SEIKETSU)-STANDARDIZE					
1	Cleaning schedule for each area is made and is effective			2	
2	Condition of Machines, Equipment, Tools, Gauges, Jigs Fixtures			2	
3	Condition of Racks/Cupboards/Pallets/Bins/fans/lighting/switches/control panels		1		
4	Display of Inspection Standards, Safety Standard, PQCDSM, Organisation Structure, Activity Charts, Fixed Meeting Schedule, System Flow Chart, etc			2	
5S (SHITSUKE)-SUSTAIN					
1	Punctuality for Teatime/Meetings/Lunch		1		
2	Internal 5S Audit conducted or Not/Last Audit NCRs Displayed And closed		1		
3	Review of Dept. Activity/Display Boards as preset frequency		1		

Table 2 Before and after images

S.no	Before image	After image	Work done
1	See Fig. 4	See Fig. 5	(a) Sign boarding (b) Labelling (c) Cleaning
2	See Fig. 6 See Fig. 8	See Fig. 7	(a) Collection of data for tool requirement (b) Study of process flow (c) Calculations for tool arrangement (d) Labelling of tool rack
3	See Fig. 9	See Fig. 10	(a) Study of process (b) Organization of workstation (c)Removal of clutter and waste

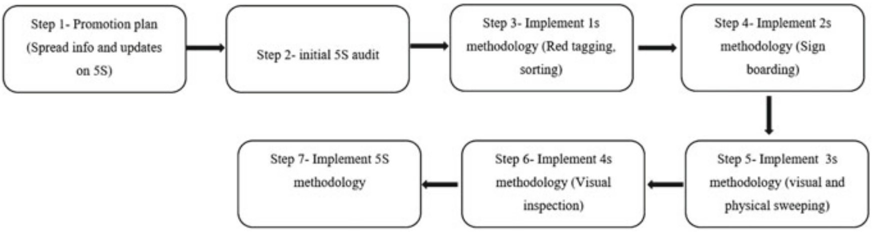


Fig. 2 Roadmap for 5S implementation

3.2 Flow Chart

The roadmap for 5S implementation is shown in Fig. 2. All seven steps are highlighted which are involved in 5S Roadmap.

A top to bottom approach is applied for spreading required information about 5S methodology i.e. starting from the top of the organizational structure and terminating at the bottom of it.

3.3 Organization Structure for 5S (LG Machine Shop)

Figure 3 represents the organization structure for the selected zone.

4 5S Implementation Phase

1S—Seiri (sort) Implementation of 1 s takes place in the following steps.

(1) Sort the items at the tool rack for the zone into wanted and unwanted things

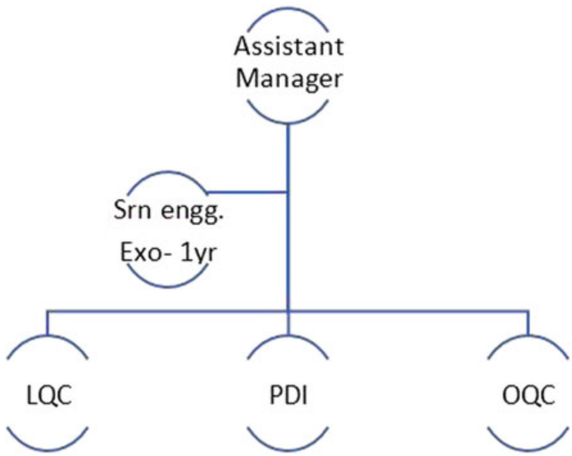


Fig. 3 Organizational structure for selected zone

(2) The unwanted items are removed from the workplace, drill bits and fixtures no longer in use
(3) Only items required are kept

2S—Seiton (set in order) the steps of implementing 2 s are as follows:

(1) Allocation of a place in order of priority, specific locations for tools have been allocated
(2) Label everything so it is easily sorted into its allocated place to reduce clutter

3S—Sieso (Shine) the steps to apply 3 s in the workplace are as follows.

(1) Sweep and clean the workplace daily, the tool rack is cleaned on a daily basis
(2) Assign fundamental points, regions and equipment and make a schedule for their regular cleaning and maintenance

4S—Seiketsu (standardize) the steps to apply 4 s are as follows:

(1) Define a standard way to do a process that everyone has to follow
(2) Ensure that this way is easy to implement and difficult to do wrongly
(3) Ensure that everyone is educated about the method and maintain discipline.

5S—Shitsuke (sustain) the steps to implement 5S are as follows:

(1) Consistency of work should be maintained
(2) Activities related to 5S should be held regularly and participation must be encouraged
(3) Promote team building and foster healthy relationships between the workers.

4.1 Observation

Table 2 represents before and after 5S images during 5S implementation. Figure 4, 6, 8 and 9 are the images before starting 5S implementation. Figures 5, 7 and 10 signifies improvement after 5S implementation.

5 Result

The results obtained after 5S implementation are represented graphically as shown in Fig. 11.

The implementation of various 5S techniques has led to the following changes in the workspace.

- More organized tool layout, which leads to less time wasted in finding the correct tools for a particular task as they are arranged in the order of their utility frequency which reduces the idle time by 0.15 units, which makes the process more cost-efficient.

Fig. 4 Unorganized workspace, no labels and taping

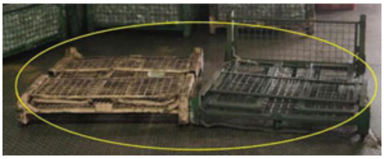


Fig. 5 Workspace has been organized and cleaned

Fig. 6 Tool rack is unorganized and uncleaned

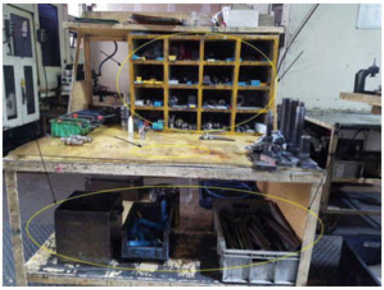


Fig. 7 Tool rack has been arranged

Fig. 8 Unwanted materials and unorganized tool rack

Fig. 9 Cluttered workstation

Fig. 10 Organized workstation

- Inventory management is simplified, and this will result in future cost savings and waste reduction by 0.11 units.
- Due to better storage techniques, more space is available for inventory storage. This has also helped in clearing up of movement channels allowing for greater freedom of movement of workers and materials.
- Correct labelling and demarcation of zones help in preventing possible misplacement of tools and items from their designated place.

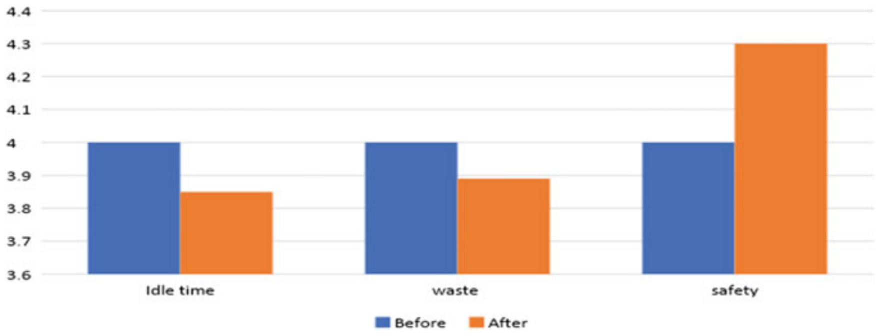


Fig. 11 Organised data for result after implementation of 5S in workshop

- Due to cleaner and more organized workspace, the morale and mood of the employees also improves the safety by 0.13 units.

6 Conclusion

The aim was to demonstrate and implement 5S in a sheet metal workshop, the following can be concluded from the study.

- More efficient usage of workspace area due to proper area management.
- Lesser wastage of time than before when searching and procuring for tools used during the manufacturing process decreasing the cost input.
- Future cost savings due to better utilization of tools and general organization and cleanliness
- Better working environment for the workers due to greater organization of workspace hence increased morale.
- Lesser chance of mistakes by the workers.

References

1. Ab Rahman, M., Khamis, N.K., Mohd Zain, R., Deros, B., Mahmood, W.: Implementation of 5S. 2012 (2010)
2. Yik, L., Chin, J.: Application of 5S and Visual Management to Improve Shipment Preparation of Finished Goods. IOP Conf. Series Mater. Sci. Eng. **530**, 012039 (2019). https://doi.org/10.1088/1757-899X/530/1/012039
3. Kabiesz, P., Bartnicka, J.: 5S system as a manner for improving working conditions and safety of work in a production company. Multidisciplinary Aspects of Production Engineering. **2**, 496–507 (2019). https://doi.org/10.2478/mape-2019-0050
4. Sharma, R., Jagtar, S.: Impact of Implementing Japanese 5S Practices on Total Productive Maintenance (2015)

5. Jadhav, J.R., Mantha, S.S., Rane, S.B.: Roadmap for Lean implementation in Indian automotive component manufacturing industry: comparative study of UNIDO model and ISM Model. J Ind Eng Int **11**, 179–198 (2015). https://doi.org/10.1007/s40092-014-0074-6
6. Ahuja, I., Randhawa, J.: 5S implementation methodologies: literature review and directions. Int. J. Prod. Quality Manage. **20**, 48 (2017). https://doi.org/10.1504/IJPQM.2017.10000689
7. Costa, C., Ferreira, L., Sá, J.: Implementation of 5S methodology in a metalworking company. https://doi.org/10.2507/daaam.scibook.2018.01 (2018)
8. Rizkya, I., Syahputri, K., Sari, R., Siregar, I.: 5S implementation in welding workshop–A lean tool in waste minimization. IOP Conf. Series Mater. Sci. Eng. 505. 012018. https://doi.org/10.1088/1757-899X/505/1/012018 (2019)
9. Mane, A.M. &Jayadeva, C.T.. (2015). 5S implementation in Indian SME: A case study. **5**. 483–498. https://doi.org/10.1504/IJPMB.2015.072327
10. Fernandes, J., Godina, R., Matias, J.: Evaluating the impact of 5S implementation on occupational safety in an automotive industrial unit. pp. 139–148. https://doi.org/10.1007/978-3-030-14973-4_13 (2019)
11. Patel, V., Thakkar, H.: A case study: 5S implementation in Ceramics manufacturing company. Bonfring Int. J. Indus. Eng. Manage. Sci. **4**, 132–139 (2014). https://doi.org/10.9756/BIJIEMS.10346
12. Gupta, R., Khare, M.: 5S Methodology Implementation in the laboratories of University. https://doi.org/10.35940/ijeat.F9555.088619 (2019)
13. Ajay, R., Sridhar, M.B.: Incorporation of 5S methodology in construction practices. Int. J. Chem. Sci. **14**, 127–134 (2016)

Role of Industry 4.0 Technologies in Sustainability Accounting and Reporting-Research Opportunities in India and Other Emerging Economies

Kamlesh Tiwari and Mohammad Shadab Khan

Abstract The GRI standard is a global reporting framework for sustainability accounting and reporting (SAR). In India, SEBI has mandated SAR for listed companies to be integrated with the annual reporting. GRI has developed custom standards for regulatory compliance of multiple countries. The global unlisted small and medium scale manufacturers can also benefit from it. Regulatory, Stock Exchange and Investor pressures are common denominators for SAR in multiple emerging economies. This paper proposes the path of Industry 4.0 adoption. Based on study of the GRI standards and the capabilities of Industry 4.0 technologies, this paper presents the recommended material topics under the triple bottom line objectives that can be targeted through strategic attachments of Industrial Internet-of-Things (IIoTs) with equipment, systems, machinery, and robots using the piping and instrumentation (PI) diagram, real-time data collection and analysis using IIoTs attached to cyber-physical sensors, big data, and artificial intelligence. The recommendations also include a few use case examples and the methods of targeting the material topics in them.

Keywords Sustainability · Accounting · Reporting · Standards · Disclosures · Global reporting initiative · Industry 4.0 · Industrial internet of things · Big data analytics · Artificial intelligence

1 Introduction

In this article, the research opportunities of sustainability accounting and reporting (SAR) in India and several other emerging economies using the Industry 4.0 technologies are presented. Leading Indian companies have joined the Global Reporting Initiative (GRI) in 2017 for adopting global best practices on SAR for achieving responsible business and growth in the future [1, 2]. SAR is an integral component of the SEBI guidelines on reporting of business responsibilities, and GRI has

K. Tiwari (✉) · M. S. Khan
Integral University, Lucknow, India
e-mail: tiwari.kamlesh@yahoo.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_27

released a customized standard for the SEBI requirements based on their global standards document [2]. Harmonization of SAR with annual reporting of companies is a key requirement for manufacturing companies having their plants in India [3, 4]. Recently, some of the studies explored the key challenges in meeting SAR requirements faced by Indian companies and found that commitments are largely prominent in listed companies governed by SEBI [5–7]. Non-listed companies lack in SAR in the contexts of commitment, spending, capabilities, corporate social responsibility (CSR) matrix, and governance. Non-listed companies largely recognize the need for CSR and SAR but lack insight into integrating them with their current business practices, manufacturing systems and operations, logistics and supply chain, and related areas. There is a general view of CSR and SAR being major cost overheads that only large listed companies can bear.

Other emerging economies have also increased reporting amidst government regulations for SAR [13]. Apart from India, SAR-linked regulations are formed in South Africa, Malaysia, Taiwan, New Zealand, South Korea, Norway, Denmark, Brazil, and Singapore [13]. Countries in Latin America and Eastern Europe are slower in SAR but are expected to catch up [15]. Mexico has done extremely level as their SAR reporting has jumped from 58% in 2015 to more than 90% in 2017. New Zealand and Taiwan have also reported similar growth trends. In Europe, the European Commission's directives on non-financial reporting have been the key enabler. While regulatory pressure is the common denominator among all emerging economies, pressures from stock exchanges, and investors have caused the change [15].

The problem is: how small to medium-scale manufacturing companies (SMS-MC) having limited budgets can implement CSR and SAR practices and derive value from them for their business and its functioning? In this article, the evolving framework of Industry 4.0 and its role in ensuring cost- and performance-effective CSR and SAR in SMS-MC is presented. Industry 4.0 is viewed as the fourth industrial revolution caused by widespread proliferation of cyber-physical technologies and systems, and massive-scale data collection and analysis through industrial cloud computing solutions for achieving artificial intelligence (AI) powered automation [8, 9].

2 Background

GRI standards for SAR are a globally accepted design and process framework for public accounting and reporting of triple bottom line sustainability variables related to: economic, environmental, and social reporting domains [10]. GRI standards for SAR require top management commitment and a change in the way sustainability practices are governed and integrated with the business and its enabling practices [11]. Sustainability practices governance requires clear visibility into the data and materiality needs to be collected, clearly targeted and measurable indicators to be defined, the key analytics and reports generation, cultural orientation of employees and contractors, governance of suppliers, and investment of capital [5, 12]. The

KPMG [13] report and research by Rambaud and Richard [14] revealed that there are inconsistencies in these fundamental requirements of corporate sustainability responsibilities and in clarity on how the organization can define and implement practices to protect the future needs of humanity while continuing to grow the business and make profits. Especially, the KPMG [15] and ACT [16] report highlighted the gaps in the formation of credible measurement methods and selection of metrics for SAR although the recognition of global climate change risks is ranked at "very high" among corporate management. Emerging economies and developed countries are facing this challenge equally. Majority of reports are narratives lacking appropriate reference to data banks and their analytics. However, customers across the globe are demanding deeper insights into SAR of manufacturers selling them their favorite products. While the current focus may be limited to personal products of consumers' choices; trends indicate that it will soon spread to wider practices followed by global manufacturers.

One of the reasons for the lack of ineffectiveness in sustainability practices and the resulting SAR may be attributed to the lack of automation [17]. Overreliance on manual processes requires much focus and time of employees thus making it cumbersome for existing operations staff. Adding dedicated staff for SAR will definitely cause additional cost overheads, which is also reported as one of the deterrence factor. A mechanism for making sustainability practices and SAR automated will not only integrate them with the operations processes seamlessly at almost negligible additional costs albeit will also make them effective. Industry 4.0 provides such opportunities as reviewed below.

Key value propositions by Industry 4.0 includes real-time visibility into operations, automation of operations, interoperability, decentralization, modularity, automation of detecting systemic and process gaps, automated repairs and maintenance, and automatic reporting [8, 9, 18, 19]. The Industry 4.0 system works with the help of massive-scale cloud fog computing comprising Industrial Internet-of-Things (IIoT) sensors spread across multiple manufacturing plants and their equipment and machineries, their logistics systems, and their warehousing and internal dynamic systems [20–22]. The IIoT sensors are designed to capture complex physical dynamics, physical variables, and other measurable variables from the attached equipment, machines, and robots, and send the data to cloud-based distributed big data servers through the IIoT gateways. The IIoT sensors use TCP with IPv6 over Internet as their transmission protocol and hence are also referred to as cyber-physical systems (CPS). The sensory data is collected to build a real-time knowledge base for artificial intelligence, which analyses the data and makes decisions about actuations, process tasks, repairs and maintenance, and other field level enforcements. This entire systemic interconnections and interoperability are commonly referred as "smart factory design" under the Industry 4.0 framework.

While research studies do not claim direct benefits of Industry 4.0 on sustainability, there are various opportunities of implied benefits of the Industry 4.0 design in enabling automation and real-time analytics with field actuations for sustainability variables in the triple bottom line model [23–25]. Operational enhancements achieved through Industry 4.0 can indirectly aggregate as benefits in achieving triple bottom line objectives and also in SAR. Real-time visibility and timely field actuations can help in improving accuracy of operations, inventory management, materials movement and feeding, production and logistics scheduling, life-cycle management, production accuracy, systems performance, machines and robotics performance, and warehousing performance [26, 27]. Timely detection of defects can help in reducing emissions, accidents, contamination, wastage of natural resources, and reuse/recycling of resources and regeneration of energy using the recycled resources [28].

A manufacturing company can use the smart factory design for implementing CSR and SAR practices by carefully identifying the targeted variables and define the influence of smart systems on them to gain dual benefits: control on the variables to keep them within acceptable boundaries and time series reporting about the performance of those variables, which can be later transformed into advanced meaningful statistical modeling and analysis. The SMS-MC organizations can directly get in line with large manufacturers in achieving CSR and SAR by investing in Industry 4.0. With all the operational benefits and cost reduction achieved from real-time data collection and analytics, and automated field actuations, the incremental efforts in targeting selected sustainability variables and reporting about their performance will hardly add any costs to the SMS-MC organizations. Seamless integration with operations will also help in cultural acceptance of CSR and SAR practices. In this context, some practices are suggested for using Industry 4.0 technologies for SAR as per SEBI and GRI standards in India in the next section.

3 Role of Industry 4.0 Technologies in Sustainability Accounting and Reporting in India

As discussed in Sect. 1, SEBI has mandated SAR in India and GRI has released a custom standard for India for fulfilling the SEBI guidelines on SAR. These guidelines are mandatory for listed companies in India. Further, stock exchange regulations are found to be a common denominator for every emerging economy witnessing high levels of SAR [15]. However, SMS-MCs can also benefit from these regulatory guidelines and implement them in cost-effective manner using the Industry 4.0 framework. They will need to make one-time investments in digital transformations of their existing plant and machineries and introduce automation and robotics wherever essential. IIoT sensors and actuators will be needed at strategic operations tasks for automating field actuations directed by AI decision-making engines. AI and Big data analytics can be implemented using published cloud-based solutions. One of the examples is the Amazon AWS Anomaly Detection using IIoTs deployed at the field levels and aggregation of data collected from them on the AWS cloud using a multilayered architecture [29]. IBM Blue and Microsoft Azure have also offered similar cloud-based solutions for integrating data from IIoTs and automated AI-based field actuations. In addition to published cloud designs, SMS-MCs can implement self-hosted virtualization using open source platforms such as Eucalyptus and Open Stack cloud software. There are many cost-effective solutions for SMS-MCs for deploying their automation systems either on a personal cloud or publicly available cloud services. At the beginning of their implementation roadmap, SMS-MCs may simply focus on data collection and analytics because accurate field actuations for automation may require maturity of the AI learning algorithms. The data collection and analysis systems can be used for SAR as discussed below.

In the GRI standard, the triple bottom line material goals topics are categorized under economic, environmental, and social topics [30]. Reporting guidelines have been defined for each topic separately for local regulatory compliance to SEBI and similar regulatory bodies in multiple emerging economies. The key suggested material goals to be measured under economic topics are economic performance, indirect economic impacts, and procurement practices. Multiple variables can be defined within the Industry 4.0 framework to collect measurement data for reporting the key performance indicators. For example, variations in working capital inflows into the manufacturing and related processes can be accurately drilled down into individual tasks and the costs consumed by them. Opportunities of reduction of costs can be identified by highlighting the low-to-nil value-adding tasks treating them as wastes. Such tasks can be eliminated from the process maps thus relieving the resources for fulfilling the tasks with higher value addition. For example, automated routing of in-plant vehicles can ensure that each vehicle can select the shortest possible path to reach its destination avoiding collisions with other moving vehicles. This capability can reduce in-plant lead times, reduce energy costs in running the vehicles, and reduce frequency of repairs and maintenance required. The procurement practices can also be aligned with materials movements and consumption accurately thus eliminating need for overstocking, reducing safety stocking, and ensuring just-in-time fulfillment.

In the environment topics, there are many material topics under GRI that can be addressed through the Industry 4.0 design. The key suggested material topics are consumption of energy, consumption of materials, emissions, and waste disposal. The implied benefits of operations improvements highlighted in the previous section can be used for targeting the key performance indicators defined by relevant regulatory bodies and GRI standards under these material topics. Industry 4.0 enhancements are based on data collected from IIoTs attached to the machineries, equipment, and robotics. SMS-MCs can target installation of IIoTs for collecting data on the performance of such indicators by carefully highlighting the attachment points in the piping and instrumentation (PI) diagrams. For example, IIoTs can be attached to the emission vents, drain pipelines, drain discharge pumps, water quality sampling points, air quality sampling points, temperature sensors in heat exchangers, boilers, and furnaces, and plant condensation chambers. A number of variables can be monitored by collecting real-time data from these attachment points. Further, enhancements can be made by effectively reusing natural resources by accurately measuring the contaminations. For example, water feedback loops for reuse in processes can be formed before they are drained automatically after reaching a threshold of contamination. A

SME plant can reduce its wastewater discharge considerably by implementing such strategies using the capability of real-time measurement data and analytics.

In the social topics, the suggested material topics to be targeted through Industry 4.0 designs are occupational health and safety, security practices, employment practices, discriminations, and human rights assessment. Industry 4.0 technologies involving IIoTs attached to human body wearables can be leveraged to collect real-time data about health, safety, and security of employees. For example, the gateways to a shop floor may be converted into automatic checkpoints for ensuring that all employees entering through them have all the safety wearables on their body. In addition to identification checks, the gates can be configured to block a person not wearing the desired safety wearables from entering the shop floor. Further, IIoTs attached to human body sensors can continuously stream data about the health and safety status of employees and generate timely alerts and alarms about possible health and safety issue. For example, a worker showing warnings related to heart and lungs can be quickly withdrawn from the workplace and admitted in the plant's hospital. Any worker cannot work for more than eight hours as the machines can be configured to automatically disable his/her access rights at the end of the shift. Similarly, IIoTs attached to equipment, robots, and machinery can raise early warnings of a possible mishap or major accident by analyzing the time series trends of certain critical variables.

These capabilities need to be planned carefully and implemented along with all the device attachments planned for operations improvements. The one-time costs may be slightly higher and the running costs may be incremental. However, the capabilities related to SAR can be improved significantly in the SMS-MCs to the extent that they can be comparable with the large-scale listed manufacturing companies in India. The government may consider offering some subsidies or tax rebates for companies planning for Industry 4.0 with a clearly laid out plan for improving SAR capabilities. These steps can promote SAR among small and medium manufacturers in India.

The framework may be visualized as per the following diagram. The pressures and the guidance from GRI may be visualized as the key enablers. The challenges may be viewed as the evolving domain required for critical thinking. The Industry 4.0 framework may be visualized as the toolkit to achieve reliable and effective SAR to satisfy the regulatory requirements, investor relations, and achieving the desired level of protection as per the GRI guidelines (Fig. 1).

4 Conclusion

Sustainability in the listed manufacturing industry is mandated by SEBI in India and similar regulatory bodies related to stock exchanges in multiple emerging economies globally. Further, national and regional regulations (such as European Commission directives) and global investors have also enforced need for SAR in emerging economies globally. Global Reporting Initiatives has developed custom standard for SEBI compliance for Indian listed manufacturers and similar regulatory bodies

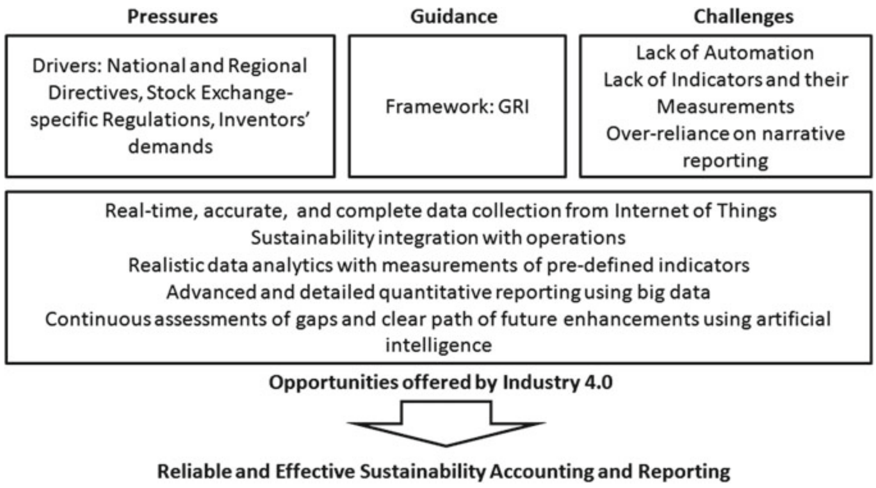


Fig. 1 Proposed framework for SAR using Industry 4.0

globally. However, the unlisted small and medium manufacturing companies in India and other emerging economies can also benefit from the GRI standards for not only improving their operations performance but also targeting the key performance indicators defined under the triple bottom line material topics in the GRI standards. The path suggested in this paper is adopting Industry 4.0 framework. Small and medium manufacturing companies can plan for rollout of Industrial Internet of Things in their plant layouts on their piping and instrumentation diagrams by carefully selecting the attachment points for achieving dual benefits of operations improvements and SAR capabilities.

Acknowledgements Manuscript Communication Number (MCN): IU/R&D/2020–MCN 000802 office of research and development, Integral University, Lucknow.

References

1. GRI: Harmonizing sustainability reporting practices in India. https://www.globalreporting.org/information/news-and-press-center/Pages/Harmonizing-sustainability-reporting-practices-in-India.aspx (2017a). Last accessed 19 Jan 2020
2. GRI: Leading Indian companies join GRI's reporting network, https://www.globalreporting.org/information/news-and-press-center/Pages/Leading-Indian-companies-join-GRI%27s-reporting-network.aspx (2017b). Last accessed 19 Jan 2020
3. KPMG: Corporate sustainability-drivers and enablers-India Sustainability Conclave. http://ficci.in/spdocument/20361/FICCI_Sustainability_Conclave_Report2014_final.pdf (2014). Last accessed 19 Jan 2020
4. Laskar, N., Maji, S.G.: Corporate sustainability reporting practices in India: myth or reality? Soc. Responsib. J. **12**(4), 625–641 (2016)

5. Garg, P.: Development of sustainability reporting index (SRI) with special reference to companies in India. Decision **44**(4), 259–273 (2017)
6. Kumar, K.S.V., Devi, V.R.: Sustainability reporting practices in India: challenges and prospects. In: Twelfth. AIMS International. Conference on Management. 2–5 January 2015. IIM, Kozhikode, pp. 1712–1717 (2015)
7. Majumdar, U., Rana, N., Sanan, N.: Responsible Business Rankings: India's Top Companies for Sustainability and CSR 2017, IIM Udaipur and Futurescape, pp. 6–58 (2017)
8. KPMG: Currents of change. In: The KPMG Survey of Corporate Responsibility Reporting-2015, KPMG Survey of Corporate Responsibility Reporting, pp. 2–48, https://home.kpmg/content/dam/kpmg/pdf/2015/12/KPMG-survey-of-CR-reporting-2015.pdf (2015). Last accessed 17 Jan 2020
9. KPMG: The trend ahead. In: The KPMG Survey of Corporate Responsibility Reporting-2017, KPMG Survey of Corporate Responsibility Reporting, pp. 2–48. https://assets.kpmg/content/dam/kpmg/be/pdf/2017/kpmg-survey-of-corporate-responsibility-reporting-2017.pdf (2017). Last accessed 17 Jan 2020
10. Roblek, V., Mesko, M., Krapez, A.: A complex view of Industry 4.0. Sage Open J 6(2):1–11 (2016)
11. Yao, X., Zhou, J., Zhang, J., Boër, C.R.: From intelligent manufacturing to smart manufacturing for Industry 4.0 driven by next generation artificial intelligence and further on. In: 2017 5th International Conference on Enterprise Systems, 22–24 Sept 2017, Beijing, China, IEEE (2017)
12. Bebbington, J., Larrinaga, C.: Accounting and sustainable development: an exploration. Acc. Organ. Soc. **39**, 395–413 (2014)
13. Stubbs, W., Higgins, C., Milne, M.: Why do companies not produce sustainability reports? Bus. Strategy Environ. **22**, 456–470 (2013)
14. Smith, P.A.C., Sharicz, C.: The shift needed for sustainability. Learn. Org. **18**(1), 73–86 (2011)
15. Rambaud, A., Richard, J.: The triple depreciation line instead of the triple bottom line: towards a genuine integrated reporting. Crit. Perspect. Account. **33**, 92–116 (2015)
16. ACT: 2019 Research Report: An analysis of the sustainability reports of 1000 companies pursuant to the EU Non-Financial Reporting Directive, Alliance for Corporate Transparency, 4–108. https://allianceforcorporatetransparency.org/assets/2019_Research_Report%20_Alliance_for_Corporate_Transparency-7d9802a0c18c9f13017d686481bd2d6c6886fea6d9e9c7a5c3cfafea8a48b1c7.pdf (2019). Last accessed 25 Apr 2020
17. Bini, L., Bellucci, M.: Integrated Sustainability Reporting. Springer International Publishing, Springer Nature, Switzerland AG (2020)
18. Aazam, M., Huh, E., St-Hilaire, M., Lung, C., Lambadaris, I.: Robots and sensor clouds. In: Koubaa, A., Shakshuki, E. (eds.) Cloud of Things: Integration of IoT with Cloud Computing, pp. 77–94. Springer International Publishing, Switzerland (2016)
19. Carvalho, N., Chaim, O., Cazarini, E., Gerolamo, M.: Manufacturing in the fourth industrial revolution: a positive prospect in Sustainable Manufacturing. Procedia Manuf. **21**, 671–678 (2018)
20. Abdmeziem, M., Tandjaoui, D., Romdhani, I.: Robots and sensor clouds. In: Koubaa, A., Shakshuki, E. (eds.) In: Architecting the Internet of Things: State of the Art, pp. 55–76. Springer International Publishing, Switzerland (2016)
21. Khan, M., Wu, X., Xu, X., Dou, W.: Big data challenges and opportunities in the hype of Industry 4.0. In: 2017 IEEE International Conference on Communications (ICC) SAC Symposium Big Data Networking Track, 21–25 May 2017, Paris, France, IEEE Xplore (2016)
22. Trstenjak, M., Cosic, P.: Process planning in Industry 4.0 environment. Procedia Manuf. **11**, 1744–1750 (2017)
23. Kiel, D., Muller, J., Arnold, C., Voigt, K: Sustainable industrial value creation: benefits and challenges of Industry 4.0. In: The XXVIII ISPIM Innovation Conference—Composing the Innovation Symphony, 18–21 June 2017, Austria, Vienna, 1–21, World Scientific (2017)
24. KPMG: The factory of the future: Industry 4.0—the challenges of tomorrow, KPMG Guide Part 1. In: KPMG AG Wirtschaftsprufungsgesellschaft, A Swiss Entity, pp. 1–68 https://assets.kpmg/content/dam/kpmg/es/pdf/2017/06/the-factory-of-the-future.pdf (2016). Last accessed 17 Jan 2020

25. Ren, S., Zhang, Y., Liu, Y., Sakao, T., Huisingh, D., Almeida, C.M.V.B.: A comprehensive review of big data analytics throughout product lifecycle to support sustainable smart manufacturing: a framework, challenges and future research directions. J. Clean. Prod. **210**, 1343–1365 (2019)
26. Birkel, H.S., Veile, J.W., Müller, J.M., Hartmann, E., Voigt, K.: Development of a risk framework for Industry 4.0 in the context of sustainability for established manufacturers. Sustainability **11**(384), 1–27 (2019)
27. Braccini, A.M., Margherita, E.G.: Exploring organizational sustainability of Industry 4.0 under the triple bottom line: the case of a manufacturing company. Sustainability **11**(36), 1–17 (2019)
28. de Man, J.C., Strandhagen, J.O.: An Industry 4.0 research agenda for sustainable business models. Procedia CIRP **63**, 721–726 (2017)
29. Bargaje, A: Detect anomalies on connected devices using AWS IoT device defender. https://aws.amazon.com/blogs/iot/detect-anomalies-connected-devices/ (2018). Last accessed 17 Jan 2020
30. GRI: Consolidated set of GRI sustainability reporting standards. https://www.globalreporting.org/standards/gri-standards-download-center/ (2016). Last accessed 17 Jan 2020

Theoretical Analysis of Isentropic and Alternative Refrigerant Based Cooling System and Low Carbon Economy

Kaushalendra Kumar Dubey, Karan Sharma, RS Mishra, Sudhir Kumar Singh, and Brahma Nand Agarwal

Abstract The current trend of energy supply and its uses are very unstable economically, socially and environmentally. Greenhouse gas emissions are continuing to increase, and it will affect the environment globally. The scope of alternative refrigeration system like vapour absorption (VARS), vapour adsorption and ejector cooling can play significant role in the modern industry with low carbon emission. The experimental setup of 03 Ton of cooling (TR) of dry compression vapour compression refrigeration (VCRS) has been evaluated and compared with single-stage of LiBr-H_2O-based VARS cooling system. The operating condition of condenser, evaporator temperature and pressure have been considered for performance analysis of both systems. The higher value of condenser temperature not suitable for efficient cooling and also decreases the energy performance ratio (EPR or COP) of system. The R134a is commercially useful eco-friendly refrigerant but applicable in VCRS (Energy consumption by VCRS is much more than VARS). The employment of VARS have tremendous potential for space cooling and water chilling application at same range of VCRS operating temperature of condenser with low-grade energy source or solar energy utilization. VARS is low carbon emission and non-toxic technology and able to map decarbonize economy for industrial sector.

Keywords VCRS · VARS · GWP · ODP · Zero carbon emission · Isentropic fluid

Abbreviation

ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning
COP	Coefficient of performance
COPth	Theoretical coefficient of performance

K. K. Dubey (✉) · K. Sharma · S. K. Singh · B. N. Agarwal
School of Mechanical Engineering, Galgotias University, Greater Noida 201308, UP, India
e-mail: dubey.kaushalendra@gmail.com

R. Mishra
Department of Mechanical Engineering, Delhi Technological University, Delhi, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_28

COP_carnot	Maximum coefficient of performance
COP II	Exergetic coefficient of performance
EPR	Energy performance ratio
GHG	Greenhouse gas
GWP	Global warming potential
m_ref	Mass flow rate of refrigerant
m_ss	Mass flow rate of rich solution of refrigerant and absorber
m_ws	Mass flow rate of refrigerant
ODP	Ozone depletion potential
ORC	Organic rankine cycle
P_G	Pressure of generator
P_C	Pressure of condenser
P_A	Pressure of absorber
P_E	Pressure of evaporator
Q_{gen}	Generator heat
Q_{ref}	Refrigeration effect
T_Condenser	Temperature of condenser
T_G	Temperature of generator
T_A	Temperature of absorber
T_E	Temperature of evaporator
TR	Ton of refrigeration
VARS	Vapour absorption refrigeration system
VCRS	Vapour compression refrigeration system
W_{comp}	Compressor work
ξ	1 for refrigerant
ξ_{ss}-ξ_r	Rich solution
ξ_{ws}-ξ_a	Weak solution

1 Introduction

Power is a critical infrastructure for any nation development and due to constant demand of power, environments and ecological hazards associated with this. The generated power or electricity is majorly consumed by the industrial process, specially cooling machineries require massive power supply and are responsible for greenhouse gas (GHG) emissions globally. The environmental safety is essential factor for the cooling industry. The zero or low value of global warming potential (GWP) and ozone depletion potential (ODP) gives the employment of eco-friendly refrigerants and scope of alternative refrigerants also in modern refrigeration techniques. Various research, technological development have been conducted for modern refrigerants, advanced refrigeration systems, etc. The authors investigated the effect of different compression with sub-cooling for VCRS performance. Sub-cooling method gives higher COP with same compressor work [1–3].

The extensive review of alternative refrigerants like nanofluid based refrigerants. Authors concluded that the particle size of conductive material with base refrigerants enhance the heat transfer rate from refrigerants during the operation. Another study conducted the performance analysis of nanofluid refrigerants-based cooling system. The experimental work has been done with the consideration of thermal conductivity, dynamic viscosity and density of nano-refrigerant for Cu, Al_2O_3, CuO and TiO_2 nano-particle and ecofriendly refrigerants as R123,134a, R152, etc. Domestic refrigeration also improves by the CuO-R600-based another nanorefrigerant [4–9]. Climatic condition-based analysis of VCRS is conducted. The COP of winter is more than summer COP due to less compression work and minimum temperature difference between condenser and atmospheric [10, 11]. The different refrigeration systems have investigated the application of combined cooling and power generation, heat recovery purpose. The performance of cooling system not only limited to the size of compressor, evaporator or condenser, it's greatly influence by the selection of refrigerants also. The effect of operating conditions provide another criteria for achieving efficient cooling [12–15]. The several conventional and alternative refrigerants have been invented for the purpose of refrigeration and as well as combined power and cooling generation by using organic rankine cycle (ORC). The commercialize working refrigerants like HFC, HCFC, CFC, n-pantene, iso-butane, etc., designated by the different character of fluids like dry, wet and isentropic. The slope of ds/dT of T-S curve defines all types of fluid. The R134a is considered in isentropic category as shown in Fig. 1 [16]. Globally LiBr-H_2O and H_2O-NH_3 type of VARS commercialize in various range for food preservation, water chilling, space cooling, meat, and fish processing purposes. The key players of this technology are AOSOL, CIMCO, Thermaxglobal have a world wide market and supply to North and Latin America, Europe, Middle East and Africa [17]. The US

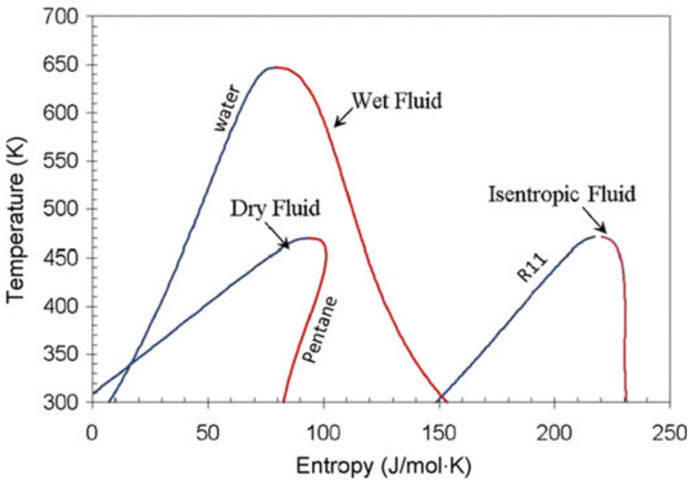


Fig. 1 Temperature-entropy diagram of refrigerants [19]

Table 1 ASHARE classification of refrigerants [19]

Level of flammability	Level of toxicity	
	Low	High
Higher	A3	B3
Low	A2	B2
No flame	A1	B1

patent US20120324925A1 has claimed for commercialization of triple stage of LiBr-H_2O VARS. The proposed system has low, medium and higher temperature source generator which operates by 50–200 °C of thermal energy. Thermax Ltd. is the assignee company of this patent. Another researcher has developed the parabolic trough collector-based adsorption refrigeration system for water chilling application. The activated charcoal and R134a pair of adsorbent-adsorbate have utilized which are non-toxic nature. The ANN soft computing technique is an employee for the comparison with actual results [18]. American society of heating, refrigeration and air-conditioning (ASHRAE) categorize refrigerants in terms of toxicity and its flammability also. Table 1 brief these safety factors also. Present topic of research evaluates the performance of dry saturated compression of R13a-based experimental setup of VCRS with different condenser and cooling temperatures and compare with the LiBr-H_2O VARS system as an alternative and zero carbon emission refrigeration technology.

2 Experimental Setup-VCRS System

The major components of VCRS and VARS are available in Figs. 2, 3 and 6. The laboratory setup of VCRS is experimented at different range of condenser and evaporator temperature. The theoretical examination has performed for VARS and compared further in terms of COP. The property diagram of R134a is shown in Figs. 4, 5, and 6.

2.1 Eco-Friendly Isentropic Refrigerant-R134a

See Figs. 4 and 5.

2.2 VARS System

See Fig. 6.

Fig. 2 Laboratory test rig of refrigeration unit

3 Mass and Energy Equation for VCRS and VARS

Performance evaluation of mentioned VCRS and VARS is dealt with thermodynamics mass and energy balance equation. The COP is basically estimated by the refrigeration effect (Q_{ref}). The compressor work (W_{comp}) and generator heat (Q_{gen}) are the main inputs for the VCRS and VARS operation. The mass and energy equation has been implemented for all utilities in terms of enthalpy-mass flow rate of refrigerant. The pressure and temperature of condenser and evaporator are influencing factors for the performance of refrigeration and AC unit. The equations for all components of the system have been described in energy-equation. Both models have adopted from CP arora refrigeration system [19]. The fundamental assumptions have been considered for the analysis as follows:

1. The thermodynamic process of the refrigeration system is considering steady flow throughout.
2. The mass flow rate at every point does not vary with time in case of VCRS and solution of refrigerant and absorber in case of VARS.
3. The expansion and compression (pump and compressor) are assumed isentropic.
4. The proposed VCRS is considered as dry saturation compression.

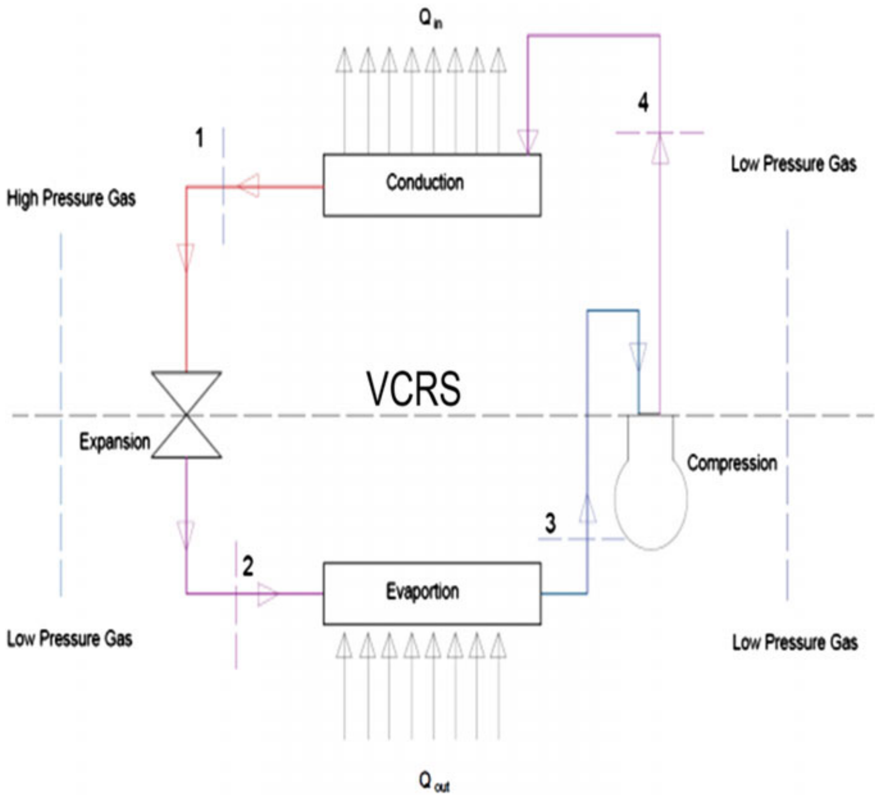


Fig. 3 Components of basic refrigeration system

3.1 VCRS Components Consideration

W_comp	Compressor work
Q_cond	Condenser heat rejection of VCRS
Q_ref	VCRS refrigeration effect
Q_evp	Refrigeration effect

3.2 VARS Components Consideration

T_G	Temperature of Generator
T_A	Temperature of Absorber
P_G	Pressure of Generator
P_A	Pressure of Absorber
m_ref	mass flow rate of refrigerant
m_ss	mass flow rate of rich solution of refrigerant and absorber

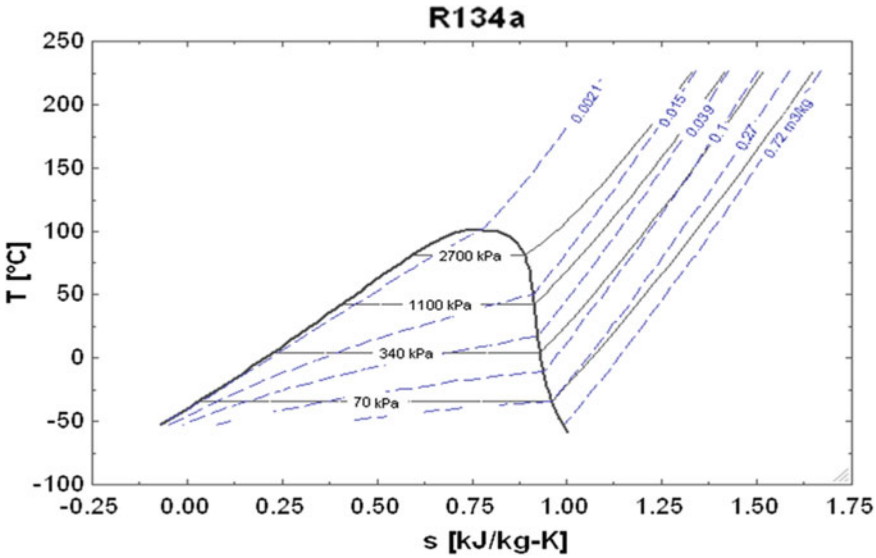


Fig. 4 Temperature-entropy plot of R-134a

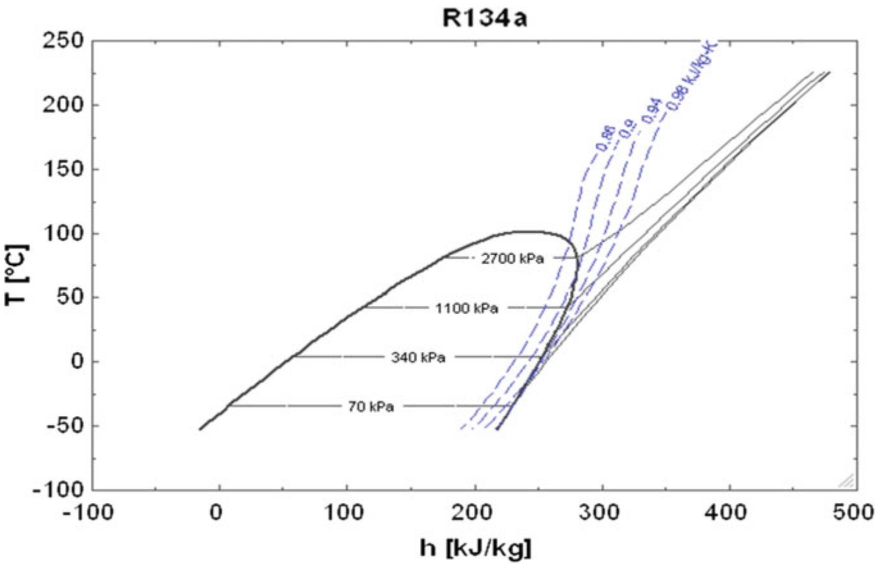


Fig. 5 Temperature-enthalpy plot of R-134a

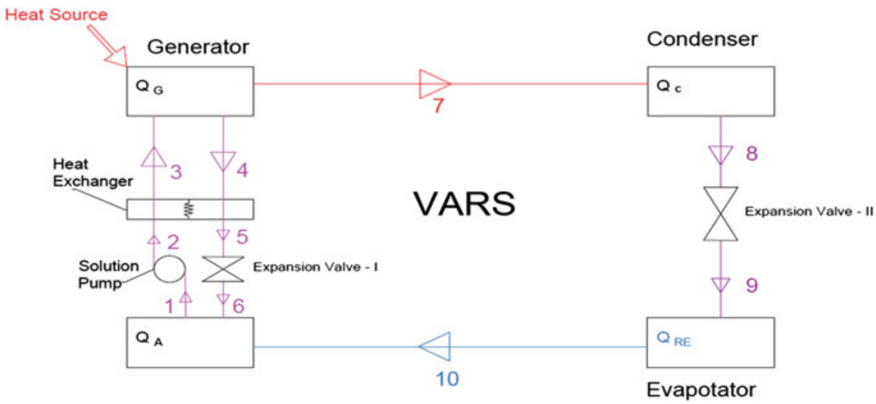


Fig. 6 Components of basic vapour absorption refrigeration system

m_ws	mass flow rate of refrigerant
T_C	Temperature of Condenser
T_E	Temperatureof Evaporator
P_C	Pressure of Condenser
P_E	Pressure of Evaporator
ξ	1 for refrigerant
$\xi_{ss} = \xi_r$	rich solution (flow from Generator to Condenser)
$\xi_{ws} = \xi_a$	week solution (flow from Generator to Absorber)
	(Sp heat for ξ_a and ξ_r will be same)

Applying energy balance equation for all utilities of proposed cooling and power system. Table 2 is explains the governing equation of all components.

4 Energy and Carbon Economy of 03 TR VARS Cooling System

The 01 ton of refrigeration effect of energy star rating of conventional VCRS air-conditioner consumes 1.5 unit (01 unit = 01 KWh) of power supply [20]. The occupancy of meeting hall can be cool by LiBr-H_2O VARS system without any high-grade energy and compressor work consumption. The cost of system not only limited to production cost; its also includes the lost energy cost during the operation. The carbon emission cost has valuable participation for the complete costing of system. Table 3 provides comprehensive evaluation of energy-saving and carbon emission of VARS system.

Table 2 Governing equation of VCRS and VARS

VCRS cooling system components equation		VARS cooling system components equation	
Compressor work (W_compressor)	m_ref (h2–h1)	Generator heat (Q_gen)	m_ref × h7 + m_ws × h4-m_ss × h3
Condenser heat rejection (Q_cond)	m_ref (h2–h3)	Condenser heat rejection (Q_cond)	m_ref × (h7–h8)
Expansion work (W_exp)	h3 = h4 (isenthalpic process)	Expansion work (W_exp)	h8 = h9 & h5 = h6 (isenthalpic pocess)
Refrigeration effect (Q_cooling)	m_ref (h1–hf4)	Refrigeration effect (Q_cooling)	m_ref (h9–h10)
COP_th	Q_cooling/W_comp	COP_th	Q_cooling/Q_GEN
COP_CARNOT	TO/(TC-TO)	COP_CARNOT	$\left(\frac{TE}{TC-TE}\right)\left(\frac{TG-TA}{TG}\right)$
COP_II	COP_th/COP_CARNOT	COP_II	COP_th/COP_CARNOT
		Heat of absorption (Q_Abs)	m_ref × h10 + m_ws × h6 − m_ss × h1
		Regenerative heat exchanger (Q_HEX)	QHEx_hot = m_ss (h3–h2) = QHEx_cold = m_ws (h4-h5)

5 Result and Discussion

The compressor of VCRS is consuming more power when it operates for higher condenser temperature. If compressor work is more, then cooling effect will decrease and further COP cannot be achieved. Figures 7, 8, and 9 will explain the effect of higher rate of heat rejection through condenser on compression work and COP with different evaporation temperature. The Carnot COP is slightly above the theoretical COP of VCRS, the refrigerant flow rate also effectively more when it operates for low evaporator temperature. The operating pressure at condenser line is more, this pressure difference causes the flow rate of refrigerants. COP and mass flow rate variation with evaporation and condenser temperature is explained in Figs. 10, 11, and 12. Table 4 discusses the effect of operating temperature on both. When higher temperature of VCRS system increases the COP is decreasing due to excess superheating of refrigerant but VARS gives improved COP when generator temperature (higher temperature of VARS) is more. The VARS is consuming less energy and control the carbon emission due to the utilization of dumped feat of the plant. Figure 13 explains the variation of energy consumption and carbon emission between VARS and VCRS.

6 Conclusion

The performance of VCRS system decreases with the condenser temperature increment. Compressor work also increases, and refrigerants are achieved superheated.

Table 3 The comprehensive estimation table of energy and economy

Energy and carbon emission estimation			
S. No.	Energy saving and carbon emission parameters	Conventional VCRS cooling system	VARS cooling system
1	Energy consumption (08 h daily)	08 × 03 × 1.5 = 36 unit daily	No electricity is required (only heat source like, hot air, steam or solar heating are required)
2	Carbon emission (daily and yearly	Carbon emission estimation (as per EPA—707 g of CO_2 per unit) 36 unit × 750 grams = 27 kg of CO_2 daily = 10 ton of CO_2 in one year	No emission (GWP and ODP values are much low) [16]
3	Cost of energy saving (daily and yearly)	No	36 unit × 20 INR = 720 INR = 10USD daily or 3600 USD yearly (commercial tariff of electricity as per BSES,01 UNIT = 20INR) [21]
4	Cost of carbon emission saving	No	10T CO_2 × 20 USD = 200 USD yearly (the possible Cost of TCO_2 globally is about 20 USD/TCO_2 as per World Bank data) [20]
5	Total saving (energy saving with carbon emission)	More energy consumption with more carbon emission	Yearly 3800 USD saving is possible

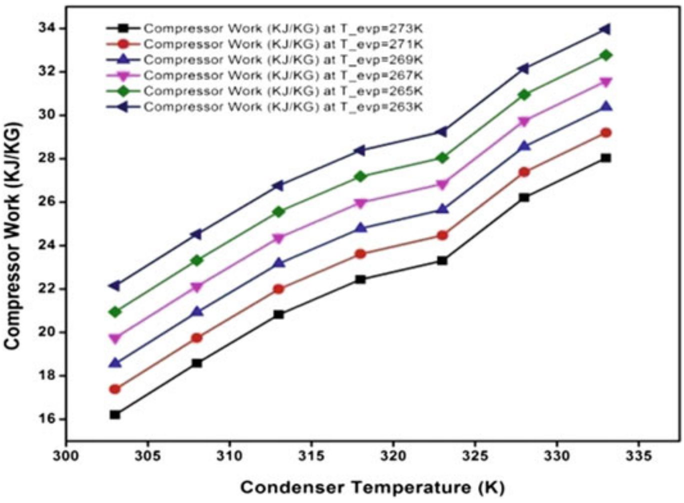


Fig. 7 Effect of T_condenserin (compression work)

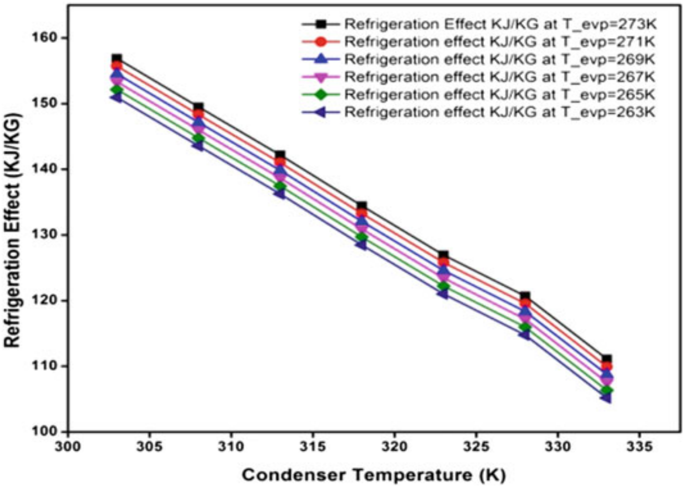


Fig. 8 Effect of T_condenserin (refrigeration effect)

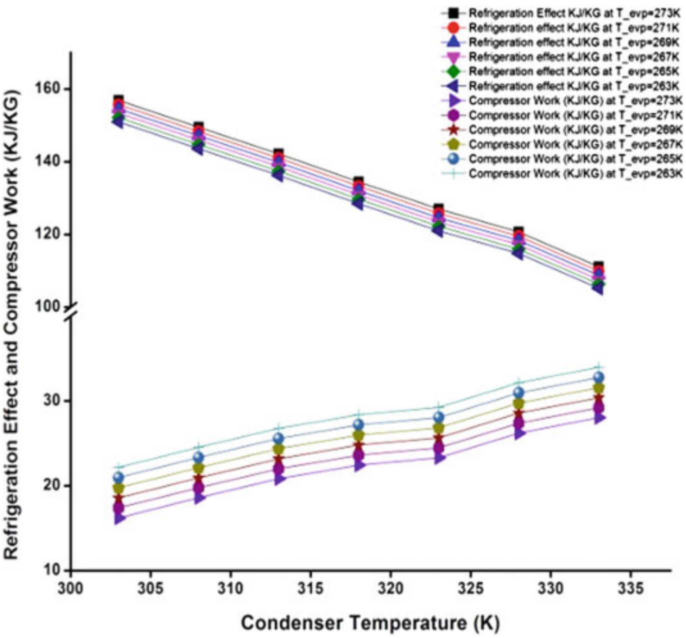


Fig. 9 Effect of T_condenser in compression work

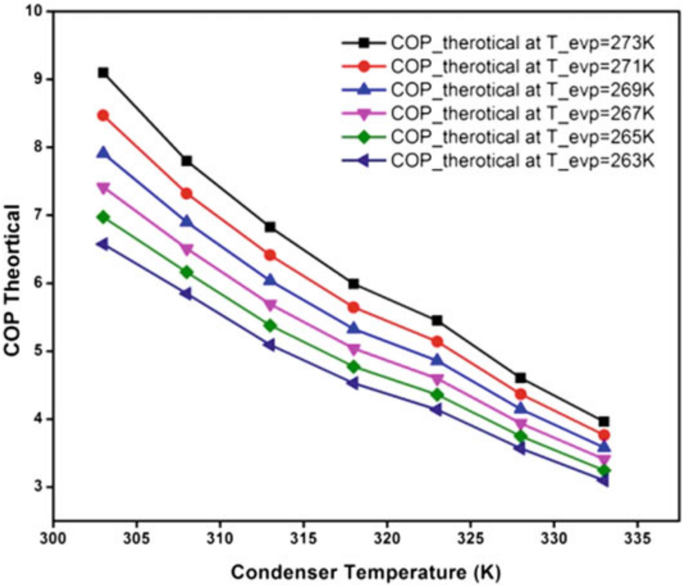


Fig. 10 Effect of T_condenser theoretical COP

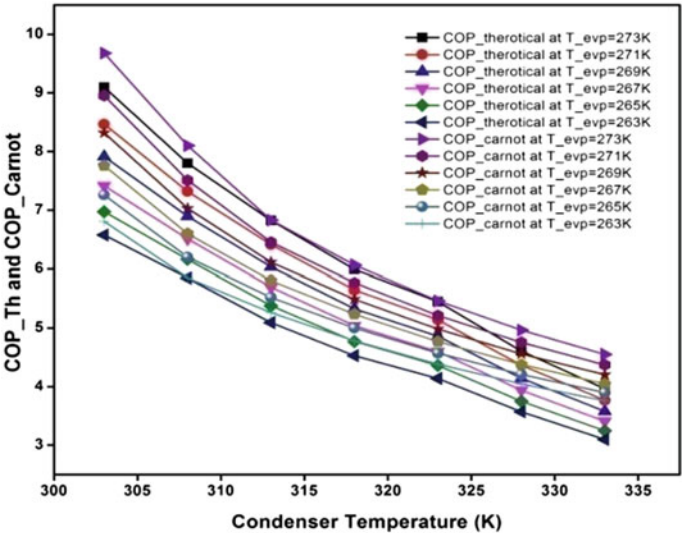


Fig. 11 Effect of T_condenser in COPth and COP_II

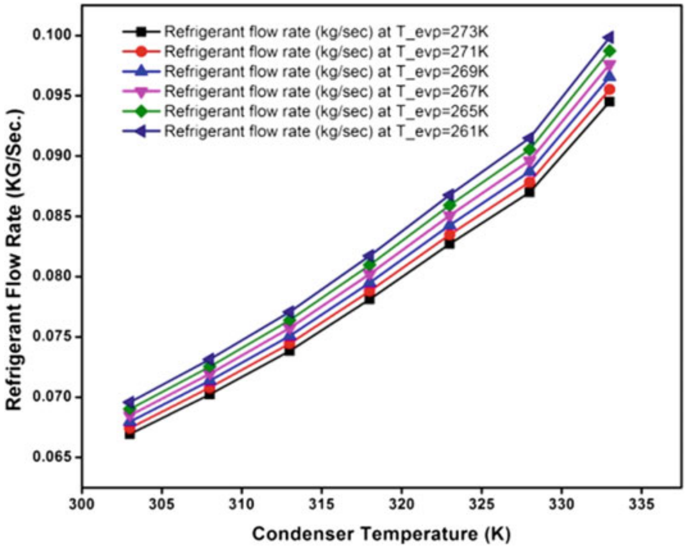


Fig. 12 Effect of refrigerant mass flow rate with T_evaporation

Table 4 Effect of operating temperature in COP of VARS and VCRS

T_operating (K)	COP_VCRS	COP_VARS
303	9.1	0.42
308	7.8	0.63
313	6.82	0.83
318	5.99	1.02
323	5.44	1.2
328	4.60	1.38
333	3.96	1.56

Heat rejection will increase due to the excess superheating and pressure drop across the evaporation and condenser line also persist due to the suction and delivery process before and after compression. The higher temperature of generator of VARS improves the COP, refrigerants need high thermal source for superheating. If the source temperature of generator is high, VARS can work on multiple stages of refrigeration and gives more cooling effect. The VARS does not need high-grade energy or electricity for operation, it saves power supply and earns carbon economy in terms of carbon emission reduction. This study also estimates the energy and carbon saving by 03 TR of refrigeration of both VCRS and VARS. A proposed single stage of VARS able to earn 3800 USD yearly and this alternative technology can play key role for decarbonize roadmap for the cooling industry.

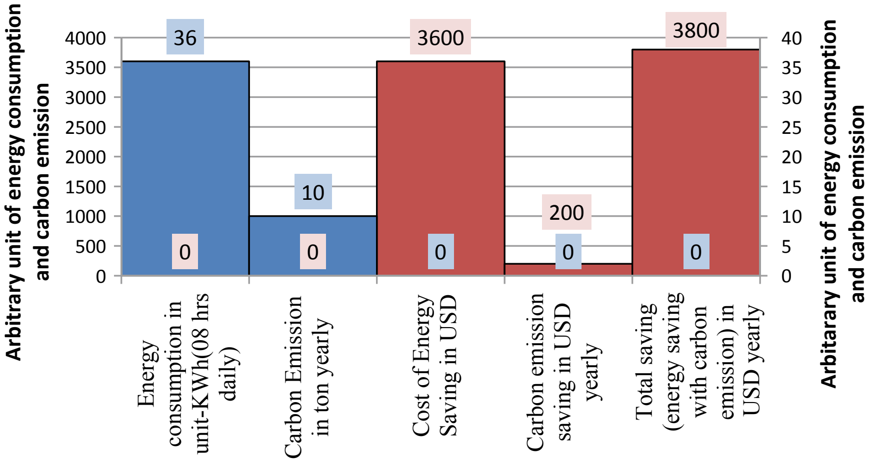


Fig. 13 Comparison of energy consumption and carbon emission between VCRS and VARS

References

1. Upadhyay, N.: To study the effect of sub-cooling and diffuser on the coefficient of performance of vapour compression refrigeration system. Int. J. Res. Aeronaut. Mech. Eng. **2**(6), 40–44 (2014)
2. Christian, J.L.H.: Refrigerant charge reduction in vapour compression refrigeration cycle via liquid–to-suction heat exchanger. Int. J. Refrig. **52**, 93–99 (2014)
3. Upadhyay, N.: Analytical study of vapour compression refrigeration system using diffuser and subcooling. J. Mech. Civil Eng. **11**(3), 92–97 (2014)
4. Sidik, N.A.C., Mohammed, H.A., Alawi, O.A., Samion, S.: A review on preparation methods and challenges of nanofluids. Int. Commun. Heat Mass Transf. **54**, 115–125 (2014)
5. Alawi, O.A., Sidik, N.A.C., Mohammed, H.A.: A comprehensive review of fundamentals, preparation and applications of nanorefrigerants. Int. Commun. Heat Mass Transf. **54**, 81–95 (2014)
6. Mishra, R.S., Jaiswal, R.K.: Thermal performance improvements of vapour compression refrigeration system using eco friendly based nanorefrigerants in primary circuit. Int. J. Adv. Res. Innov. **3**(3), 524–535 (2015)
7. Senthilkumar, A., Praveen, R.: Performance analysis of a domestic refrigerator using Cuo-R600a nano-refrigerant as working fluid. In: International Conference on Recent Advancement in Mechanical Engineering &Technology JCHPS Special Issue 9, pp. 30–33 (2015)
8. Singh, K., Lal, K.: An investigation into the performance of a nanorefrigerant (R134a + Al_2O_3) based refrigeration system. IJRMET **4**(2) (2014)
9. EPA: AVERT, US national weighted average CO_2 marginal emission rate, year 2017 data, EPA, Washington, DC. Available at: https://www.epa.gov/energy (2018)
10. Chembedu, G., Combined vapour compression refrigeration system with ejector usage: a review. IOSR J. Mechan. Civil Eng. (IOSR-JMCE) **14**(2) 81–83 (2017). Ver. III, e-ISSN: 2278-1684, p-ISSN: 2320-334X. www.iosrjournals.org
11. Harshavardhan Reddy K., et al.: Improvement of energy efficiency ratio of refrigerant compressor. Int. J. Sci. Technol. Res. **2**(5) (2013)
12. Upadhyay, N (2014) To study the effect of sub-cooling and diffuser on the coefficient of performance of vapour compression refrigeration system. Int. J. Res. Aeronaut. Mech. Eng. **2**(6) (2014)

13. Shireesha Mary Ch. et al.: A review: increase in performance of vapour compression refrigeration system using fan. Int. J. Eng. Appl. Sci. **2**(4) (2015)
14. Shuxue, X., Guoyuan, M.: Experimental study on two-stage compression refrigeration/heat pump system with dual-cylinder rolling piston compressor. J. Appl. Therm. Eng. **62**, 803–808 (2013)
15. Veera Raghavalu, K., Govindha Rasu, N.: Review on applications of nanofluids used in vapour compression refrigeration system for COP enhancement. IOP Conf. Series: Mater. Sci. Eng. **330**, 012112 (2018) https://doi.org/10.1088/1757-899x/330/1/012112
16. Arora, C.P.: Refrigeration and air-conditioning, 3rd edn. Tata McGraw Hill Publishing India Pvt Ltd. (2017). ISBN: 9789351340164, 9789351340164
17. Available at: https://patentimages.storage.googleapis.com/8b/08/ab/44bdb96723b2b8/US20120324925A1.pdf
18. Baiju, V., Muraleedharan, C.: Performance prediction of solar adsorption refrigeration system by Ann. Int. Sch. Res. Netw. ISRN Thermodyn. Article ID 102376, 8 (2012). https://doi.org/10.5402/2012/102376
19. Available at: https://www.maximizemarketresearch.com/market-report/global-vapour-absorption-refrigeration-system-market/10931/. Cited on 17 May 2020
20. Available at: https://www.edgebuildings.com/wp-content/uploads/2017/04/170
21. Available at: https://economictimes.indiatimes.com/industry/energy/power
22. Chen, H., Goswami, D.Y., Stefanakos, E.K.: A review of thermodynamic cycles and working fluids for the conversion of low-grade heat. Renew. Sustain. Energy Rev. **14**, 3059–67 (2010)

Role of Artificial Intelligence in Railways: An Overview

Neeraj Kumar and Abhishek Mishra

Abstract The worldwide increase in population joined with urbanization and a more appeal for versatility has pressurized the railroad systems of the world. The solution to this problem is to develop the infrastructure or enhancing the software with the integration of the internet for providing better services to the passengers. The combination of these three aspects of a railway system formed the Artificial Intelligence (AI). The objective of this work is to explore the role of AI in railway Transportation. The overview concludes by addressing the challenges and limitations of AI applications in railway transportation.

Keywords Artificial intelligence (AI) · Simulation · Information flow system

1 Introduction

Railway is a significant transportation player being 2.5 times cheaper than a road, shipping, and aviation and produces lesser air pollution compared to road traffic [1]. The information flow system is the soul for operation for any organization. The operation efficiency of a vast-wide infrastructure like railways depends on efficiency and capability of the capable information flow system, which aids the proper planning and control to ensure the developed plan. Advancement in technology made AI a good area of research for both railway and academia. As to cover the increasing demand for transporting passengers and freight, the first method is to expand and make a reliable infrastructure which is a costly process. The second method is to focus on building smart algorithm-based software with the integration of machine learning and AI. This is the reason numerous businesses are currently researching the possibility of administrations dependent on AI around the world. In 1995 Dougherty [2] studied the role of neural network in transportation which is one of the AI techniques. We have to examine first about the data required for the simulation and mathematical modeling for the railway system (RS) is available or not. AI for a railway system

N. Kumar (✉) · A. Mishra
Department of Mechanical Engineering, National Institute of Technology Delhi, New Delhi 110040, India
e-mail: neeraj@nitdelhi.ac.in

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_29

Table 1 Classification of railway planning activities

Independent inputs	Planning activity	Output
Commodity and demand data (origin–destination) Stops of train and speed of the train Network performance indicator Sensitivity analysis parameters	Network design (Line planning)	Establish route Route changes Service strategy Operating strategy
Number of trains and the type of trains Passenger data Subsidy available	Frequency settings Route frequency Line frequency	Railway capacity and service frequency
Sets of line and demand by time of day (Desired frequency) Times for first and last trips Minimum headway and buffer time Free Running times	Timetable development	Total travel times Trip departure times Trip arrival times
Timetable including maintenance time Trip and connection Shunting and composition Schedule constraints Cost structure	Train or rolling stock Scheduling	Rolling stock duties or schedules
A sequence of a train trip Work duties include work-shifts Operational cost structure	Crew planning Crew roistering Crew pairing	Crew schedules

(RS) has to need of enormous extent of linkable data. Table 1 summarised the sum of basics data required in the railway planning process. Infrastructures details like tracks, crew rosters, and interlocking systems are digitalized nowadays. So the time requirement is to build a hybrid system that coordinates simultaneously with the hardware and software based on AI. Hitachi [3] developed an AI-based technology to reduce the power consumption operating railway rolling stock. An integration of different railway components with AI displayed in Fig. 1.

2 Application of AI in Railway Transportation

There is a long-range service spectrum that AI can provide depending upon the level of Efficiency and need. Now some applications to railway engineering are studying [4]. Figure 2. Shows the various areas of railway transportation, where the role of AI is increasing day by day. The feasibility of some of the primary requirements of railways which Artificial Intelligence can provide is discussed below.

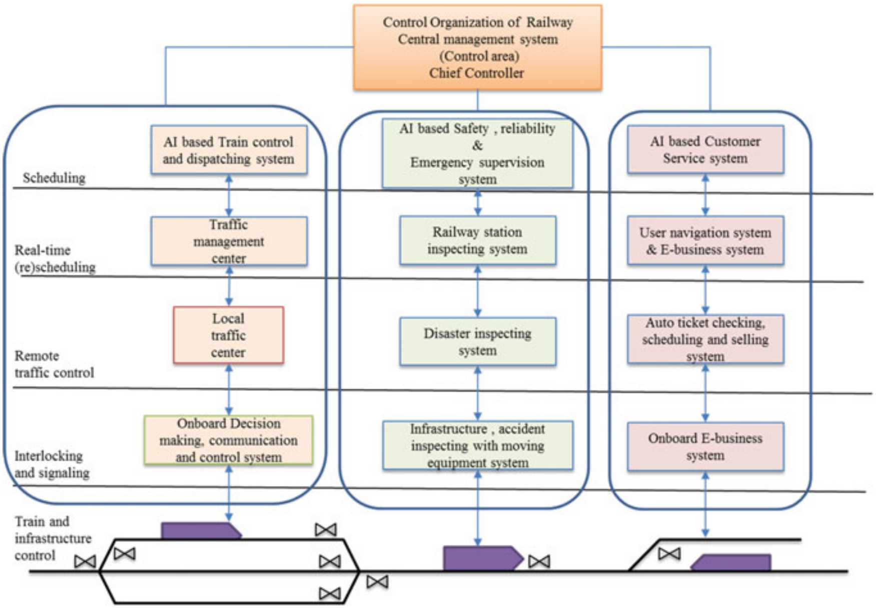
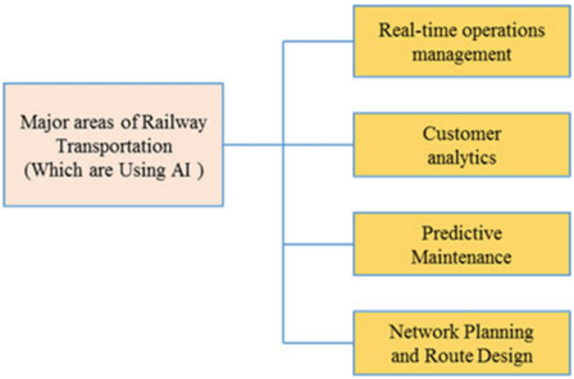


Fig. 1 An integration of different railway component with AI

Fig. 2 Various sectors of railway transportation in which AI has a greater role



2.1 Real-Time Operation Management and Train Scheduling

Lack of predictive maintenance data, sudden failure creating conflict between the regular running schedules of trains. It takes great efforts to develop a train schedule, and the situation becomes more complex where rescheduling is called and that too in the world's second-most complex railway network like Indian Railway. Unpredicted events like technical breakdown, equipment failures, a sudden increase in passenger demand, track accidents, changed weather conditions causing disruption to segments track, varying speed trains running on tracks, different train types, train bypassing, siding causes the lateness of the train, triggering a chain reaction in all railroad lines and connections, and hence generating the need of continuous scheduling and rescheduling to a reshuffling of train orders, re-routing the trains, make unplanned stops, break connections, and delay or cancel scheduled services also. In 1973, Szpigel [5] published his work on the implementation of optimization in the field of train schedules. This work was inspired by eastern Brazil long single-track railway lines which were utilized to transport the iron ore bidirectional. The problem was formulated in the form of job shop scheduling with constraints like no more than one job at a single machine. A branch and bound (B&B) technique was used for solving the conflicts and lower bound for the remaining delay generated by relaxing the leftover conflicts. The objective of this work was to schedule jobs (trains) in minimum completion time that is minimizing the sum of travel time. Higgins et al. [6] proposed a model which is slightly different than that of Szpigel [5]. The main objective of developing this model was to provide the operator with a tool that can help to plan railroad operations and can perform the train dispatching function. A B&B solution technique was used with subsets of constraints like overtaking, enforce speed, and permit stops for safe operation. The objective of the problem was to minimize the delay in train and train operating costs. Higgins et al. [6] further used the study as a decision support tool to schedule trains in an optimal way for the Australian railway. Most of the literature represents the exact methods, simulation techniques, constraint programming, and meta-heuristics approaches to solve train scheduling problems [7, 8]. Recently the scenario is shifting toward AI, machine learning, and deep learning [9, 10].

Train scheduling is a very critical component of real-time operations management [11]. Various mathematical techniques and algorithms are used with conventional optimization approaches to solve train scheduling problem. Due to the low convergence speed of such algorithms and techniques, Artificial Intelligence (AI) plays a significant role in solving train scheduling problem (TSP). Martinelli and Teng [11] used an AI-based Neural Network approach to solve TSP and obtained a fast and accurate solution in a shorter time. Figure 3 shows the basic structure of a neural network to solve real-time train problems. Cucala et al. [12] developed a model for high-speed railway lines based on fuzzy knowledge. They succeed in obtaining the optimized timetable by reducing the delays and shaved the energy consumption up to 6.7% of the real railway line in Spain. A railway line connecting different zones that have different control sections, containing single multiple tracks on which all types of trains run between the stations. Due to the limited capacity of tracks between the stations, it is important to have a fast and corrective way of scheduling trains. Initially scheduling in railways is done according to the First Come First Serve policy. Shortest Job First method was also implemented with different train priorities. The high-level decision making plays an important role in scheduling problem, but good insight is implemented in low levels decisions. Moreover, these decision-makers are depending upon the action which is taken by the dispatchers [13]. These persons are taking care of the microscopic movements in departure and arrival of a train. Schedule and timetables give an insight into the high-level planning

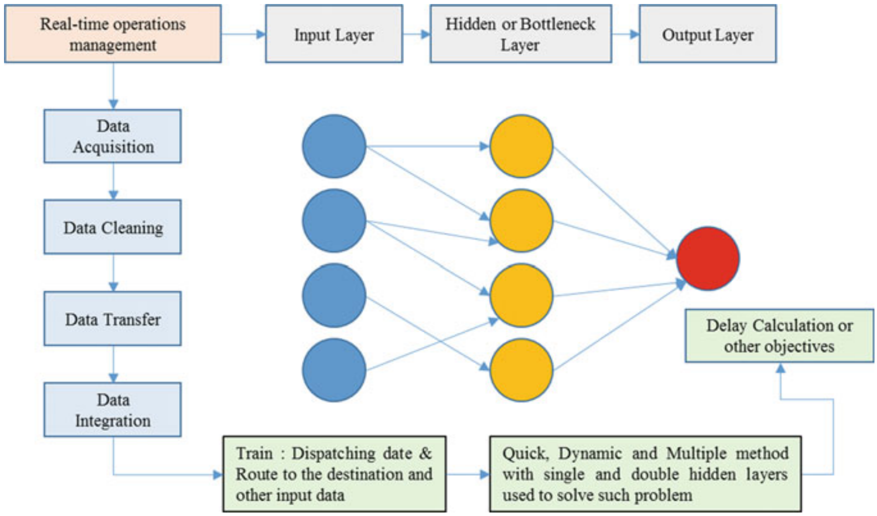


Fig. 3 Basic structure of neural network technique to solve a real-time train problem

of the dispatchers. The tracks occupancy, time used in changing in the tracks, and the signal are given is not specified by these dispatchers. Moreover, the allocation time is significantly depending upon these factors. Mees [14] defined a model for single-track train problem as a network structure where each of the segments was an arc (a siding was studied as an extra arc), isolated by nodes (track crossing points or stations). The network was in the form of time–space with a settled schedule time period and headways were obtained by permitting just a single train per arc at a time segment. Petersen et al. [15] considered a similar approach by proposing a dispatch algorithm to calculate the segment transit times and to determine the meet-pass locations to minimize the total travel times. The graph-based models [16] or the iterative optimization approaches [17] are used for the computation of the timetables which are work at a low level and feasible. The real-time decision making is the heuristics [18] problems which gives the sensitivity of the small local delay which are resulted from the overall network [19, 20]. Nowadays, AI has been significantly used in remote condition monitoring as shown in Fig. 4. It is required to develop the microscopic heuristics schedule which gives optimum results. Artificial intelligence gives the nearest results to the optimal value by using different training algorithms. The key factor used in a microscopic real-time schedule strategy is the resolution of conflicts that occur in the path [21]. Most of the railway does not use these artificial intelligence algorithms instead of the more focused on the training providing to the dispatcher so that decisions will be taken by dispatcher efficiently [22]. The mimic conflict is resolved by using supervised learning by the controller [23]. The decision taken is more erudite and results in better results outcome by the artificial intelligence algorithm than the decision making by the expert humans. The conflicts are not only the signaling the light red and green but also manage the speed of trains [24]. The

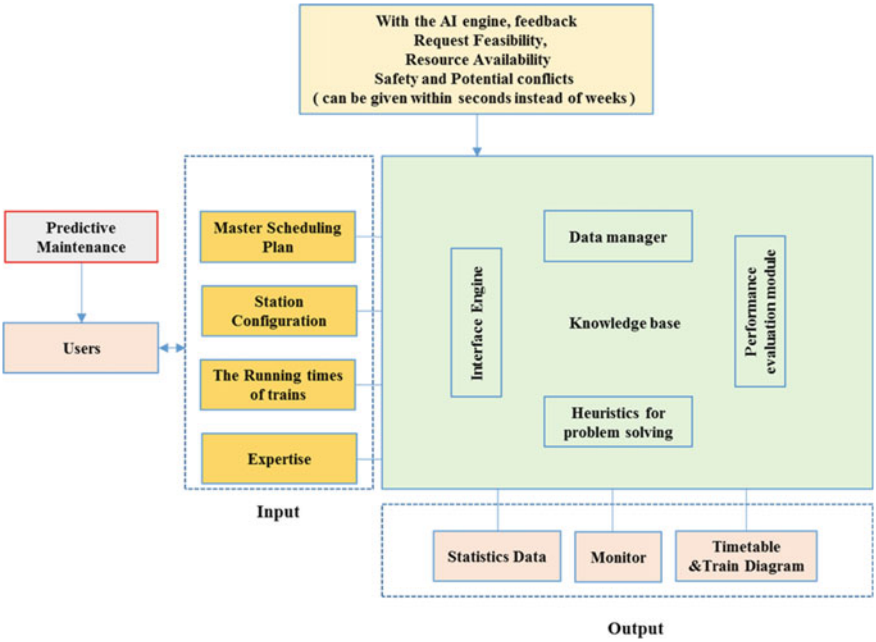


Fig. 4 AI-based system for train maintenance problem

results obtained from the perspective of the train crew is the speed of the train are play an important role in total energy consumption. The speed is noted in between two stations. Dynamic programming is used to calculate the speed profile in single trains [25, 26]. These types of studies are used in an automatic control system and these are used in light rail projects. The requirement of such systems is the movement of trains with safety like obstacle detection on track. The last requirement suggests that the decisions like power setting or speed of the train are restructured in scarce sequential steps with small errors.

3 Open Challenges and Conclusions

Computer-based intelligence or AI looks to be an incredible solution technique for practically all the zones of RS stated above. To sum up, the focuses made in this work, it is critical to take note of the idea of the specialized challenges inside every component of the RS as well as the future of AI in railway transportation (Fig. 5). (i) Dynamic scheduling algorithm must be developed that can adopt all possible infrastructure changes as well as unknown event quickly. (ii) As we know operating rules are changes from country to country. Any developed methodology must include national rules and AI-based dimensions to avoid faults. (iii) Due to the generation of

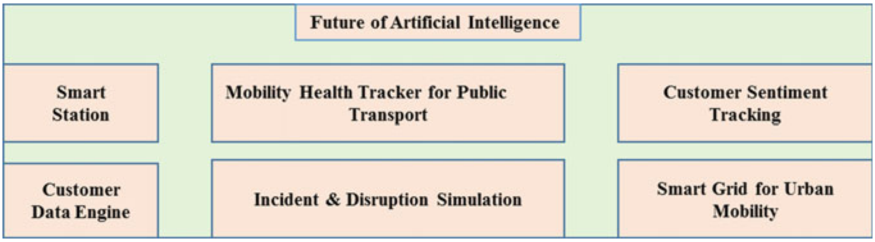


Fig. 5 Future of AI in railway transportation

a large amount of data, there must be AI-based solutions need to integrate with the railway system. The AI is limited to some specific task and based on data sets, so it cannot go beyond this in case of emergencies like humans.

References

1. Affrin, K., Reshma, P., Kumar, G.N.: Intelligent rescheduling trains for air pollution management. In: ICREM 2017: 19th International Conference on Railway Engineering and Management, p. 201 (2017)
2. Dougherty, M.: A review of neural networks applied to transport. Transp. Res. Part C: Emerg. Technol. **3**(4), 247–260 (1995)
3. Furutani, R., Kudo, F. and Moriwaki, N.: Case study of energy efficiency in railway operations. Hitachi Rev. **65**(6), 129 (2016)
4. Horwitz, D., El-Sibaie, M.: Applying neural nets to railway engineering. AI Expert **10**(1), 36–43 (1995)
5. Szpigel, B.: Optimal train scheduling on a single line railway. 344–351 (1973)
6. Higgins, A., Kozan, E., Ferreira, L.: Optimal scheduling of trains on a single line track. Transp. Res. Part B: Methodol. **30**(2), 147–161 (1996)
7. Narayanaswami, S., Rangaraj, N.: Scheduling and rescheduling of railway operations: a review and expository analysis. Technol. Oper. Manage. **2**(2), 102–122 (2011)
8. Vilela, P., Cachoni, M., Vieira, A., Christofoletti, L.: Train circulation planning: quantitative approaches. In: Joint Rail Conference American Society of Mechanical Engineers Digital Collection (2017)
9. Nakhaee, M.C., Hiemstra, D., Stoelinga, M., van Noort, M.: The recent applications of machine learning in rail track maintenance: a survey. In: International Conference on Reliability, Safety, and Security of Railway Systems. Springer, Cham, pp. 91–105 (2019)
10. Wen, C., Huang, P., Li, Z., Lessan, J., Fu, L., Jiang, C., Xu, X.: Train dispatching management with data-driven approaches: a comprehensive review and appraisal. IEEE Access **7**, 114547–114571 (2019)
11. Martinelli, D.R., Teng, H.: Optimization of railway operations using neural networks. Transp. Res. Part C: Emerg. Technol. **4**(1), 33–49 (1996)
12. Cucala, A.P., Fernández, A., Sicre, C., Domínguez, M.: Fuzzy optimal schedule of high speed train operation to minimize energy consumption with uncertain delays and driver's behavioral response. Eng. Appl. Artif. Intell. **25**(8), 1548–1557 (2012)
13. Sinha, S.K., Salsingikar, S., SenGupta, S.: An iterative bi-level hierarchical approach for train scheduling. J. Rail Transp. Plann. Manage. **6**(3), 183–199 (2016)
14. Mees, A.I.: Railway scheduling by network optimization. Math. Comput. Model. **15**(1), 33–42 (1991)

15. Petersen, E.R., Taylor, A.J., Martland, C.D.: An introduction to computer-assisted train dispatch. J. Adv. Transp. **20**(1), 63–72 (1986)
16. Caimi, G.C.: Algorithmic decision suport for train scheduling in a large and highly utilised railway network. ETH Zurich (2009)
17. Dollevoet, T., Corman, F., D'Ariano, A., Huisman, D.: An iterative optimization framework for delay management and train scheduling. Flex. Serv. Manuf. J. **26**(4), 490–515 (2014)
18. Corman, F., D'Ariano, A., Marra, A.D., Pacciarelli, D., Samà, M.: Integrating train scheduling and delay management in real-time railway traffic control. Transp. Res. Part E: Logist. Transp. Rev. **105**, 213–239 (2017)
19. Corman, F., D'Ariano, A., Hansen, I.A.: Evaluating disturbance robustness of railway schedules. J. Intell. Transp. Syst. **18**(1), 106–120 (2014)
20. Khadilkar, H.: Data-enabled stochastic modeling for evaluating schedule robustness of railway networks. Transp. Sci. **51**(4), 1161–1176 (2017)
21. Corman, F., D'Ariano, A., Pacciarelli, D., Pranzo, M.: Bi-objective conflict detection and resolution in railway traffic management. Transp. Res. Part C: Emerg. Technol. **20**(1), 79–94 (2012)
22. Şahin, İ.: Railway traffic control and train scheduling based on inter-train conflict management. Transp. Res. Part B: Methodol. **33**(7), 511–534 (1999)
23. Dündar, S., Şahin, İ.: Train re-scheduling with genetic algorithms and artificial neural networks for single-track railways. Transp. Res. Part C: Emerg. Technol. **27**, 1–15 (2013)
24. D'Ariano, A., Pranzo, M., Hansen, I.A.: Conflict resolution and train speed coordination for solving real-time timetable perturbations. IEEE Trans. Intell. Transp. Syst. **8**(2), 08–222 (2007)
25. Lu, S., Hillmansen, S., Ho, T.K., Roberts, C.: Single-train trajectory optimization. IEEE Trans. Intell. Transp. Syst. **14**(2), 743–750 (2013)
26. Yin, J., Chen, D., Li, L.: Intelligent train operation algorithms for subway by expert system and reinforcement learning. IEEE Trans. Intell. Transp. Syst. **15**(6), 2561–2571 (2014)

Selection of Turbine Seal Strip Material by MCDM Approach

Shwetank Avikal, Akhilesh Sharma, Anup Kumar Mishra, Rohit Singh, Amit Kumar Singh, and K. C. Nithin Kumar

Abstract The process of selecting a material among various available materials is a tedious process. Depending upon the applications and the need of the product, the most suitable materials are to be analysed on various parameters before making a decision for the selection of best material. Multiple-Criteria Decision-Making (MCDM) approaches have been used widely to solve similar types of decision-making problems. This paper focuses on the use of Analytical Hierarchy Process (AHP) and Modified-TOPSIS for selecting suitable stainless steel (SS) material for turbine seal strips. In the current work, five materials have been considered and compared for different material properties such as: toughness, yield strength, coefficient of thermal expansion, limit strain, creep strength and resistance to oxidation. Material AISI 316 SS is found to be the most feasible material for the seal strip of turbines.

Keywords Turbine · Seal strip · Modified-TOPSIS · Mechanical properties · Material selection

1 Introduction

In order to prevent pressure and steam losses and to maintain the efficiency of the turbine, it is important to have an air-tight seal between the rotors and stators. Poorly sealed gaps between the stationary parts and the rotors result in less power output, increased turbulence, irregular flow and decreased turbine efficiency. Turbine seal strips play an important role in generating more power for the same input values [1,

S. Avikal (✉) · R. Singh · A. K. Singh
Department of Mechanical Engineering, Graphic Era Hill University, Dehradun, India
e-mail: shwetank.avikal@gmail.com

A. K. Mishra
School of Pharmacy, Graphic Era Hill University, Dehradun, India

K. C. Nithin Kumar
Department of Mechanical Engineering, Graphic Era Deemed to be University, Dehradun, India

A. Sharma
Department of Management Studies, Graphic Era Hill University, Dehradun, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_30

2]. Therefore, selecting the most reliable and suitable material for similar applications is a critical process [3, 4].

MCDM techniques are important because of their systematic approach for selecting the most suitable material for various engineering applications [5, 6]. Dweiri et al. [6] used Expert choice software to select the appropriate material for designing a key. Jahan et al. [7] have applied VIKOR for the selection of suitable material for different engineering applications. Jeong et al. [8] have concluded that AHP is a useful and rational tool for the material selection process. Mutlag et al. [9] used the AHP tool to carry out performance analysis of air conditioning system by using four alternative refrigerants R290, R410, R404, and R22. Uguraand et al. [10] used the AHP tool to list suitable materials for the wall. Singh et al. [11] used TOPSIS in the area of pulp and paper making industries for selecting suitable fibres as raw materials. AHP method is used by Kumar et al. [12] for the selection of robotic arm material. Singh et al. [19] have used a Fuzzy AHP and TOPSIS-based approach for the selection of sedan car from the Indian market.

This paper focuses on selecting a reliable and suitable material for the turbine seal strip. For this purpose, AHP and Modified-TOPSIS are used to select the desired material. AHP and M-TOPSIS are powerful methods used for solving complex decision-making problems because it gives an advantage to the decision-maker to score each criterion comparing it to other criteria as per their own judgement [19, 20].

2 TOPSIS and Modified-TOPSIS

2.1 Topsis

This method was first formulated and used by Hwang and Yoon [13]. In TOPSIS, different attributes are ranked with respect to the closeness of hypothetical positive ideal and a negative ideal solution. Considering "k" dimensional Euclidean space which incorporated different domain set and alternatives. Therefore, a point is needed to assign a representative element for each defined alternative. A Point is needed to assume either in increasing or decreasing mode for each utility in order to define zenith and nadir point. The solution of such MCDM-based approach is purely dependent on relative distance from ideal solution, i.e., at the same time, a point is either closest to the zenith point and at farthest from the nadir point. The closeness value of such method is measured by a Euclidean distance [14–16]. The following six steps have to be followed to solve the problem by TOPSIS method Lin et al. [17].

Step 1: During this stage, a normalized decision matrix is framed. Let's ZD represents normalized decision matrix having a define element called ZDir which measures relative performance of formulated design matrix.

$$\mathrm{ZD}_{ir} = \frac{c_{ir} - \min(c_{ir})}{\max c_{ir} - \min c_{ir}} \quad (i = 1,\ 2 \ldots k;\ \ r = 1, 2, \ldots, s) \tag{1}$$

where c_{ir} measure the performance of ith alternative with respect to rth criterion.

A non-beneficial criterion is shown as follows:

$$\mathrm{ZD}_{ir} = \frac{\max c_{ir} - (c_{ir})}{\max c_{ir} - \min c_{ir}} \quad (2)$$

Step 2. In this step, weight is provided to each attribute and evaluate weighted decision matrix.

Let TD represent a weighted decision matrix, then TD = $\{\mathrm{J}_{i,r}|i = 1, 2, n; r = 1, 2, \ldots s\}$

$$J_{ir} = Ti\frac{c_{ir}}{i\sqrt{\sum_{r=1}^{s} c_{ir}^2}} \quad (3)$$

where Ti is the weight of ith criteria.

Step 3. In weighted decision matrix (TD), there is a need to determine the ideal solution which is either positive or negative such as PI and IN, respectively.

$$\mathrm{PI} = \{(\max J_{ir}|i \in J) \quad (4)$$

$$\mathrm{NI} = \{(\min J_{i,r}|i \in J) \quad (5)$$

where $J = \{1, 2,\ldots, k\}$.

Step 4. Each evaluated design alternative is deviated from PI and IN solution. This deviation is measured by the Euclidean method approach. Let Sr+ and Sr− be the distance of ith design alternative from PI and NI, respectively.

$$\mathrm{Sr+} = \sqrt{\sum_{i=1}^{k}(S_{i,r} - S_i^+)^2} \quad r = 1, 2, 3, 4\ldots s \quad (6)$$

$$\mathrm{Sr+} = \sqrt{\sum_{i=1}^{k}(S_{i,r} - S_i^-)^2} \quad r = 1, 2, 3, 4\ldots s \quad (7)$$

Step 5. In this step, firstly need to calculate the relative closeness of each competitive design alternative. Let CR represent an n-dimensional column vector for determining the coefficient value of each competitive design alternatives. Let CR_r be the element of the column vector.

$$\mathrm{CR}_r = \frac{S_r^-}{S_r^+ - S_r^-} \quad 0 \le \mathrm{CR}_r \le 1 \quad (8)$$

2.2 M-Topsis Method

Ren et al. [18] provide the solution using the M-TOPSIS approach when the alternative is facing rank reversal problem and evaluation failure problem. In first, we calculate the distance between alternatives and a reference point and evaluate the value for calculating quality alternatives. While applying the M-TOPSIS technique primarily, there is a need to find the difference between (+) ideal solution and (−) ideal solution. Finally, for evaluating the rank of all alternatives, an ideal reference point is constructed which measures the distance from each alternative. The following steps are followed in the M-TOPSIS method.

Steps 1–4 follow the same procedure as followed in the TOPSIS method.

Step 5: Establish S+ , S− plane. S+ in the *x*-axis and S− in the *y*-axis. The point (S+ , S−) represent each alternative. Assume the point A min (S+) and max (S−) which is considered as an optimized ideal reference. The distance from each alternative point A is calculated. Calculate the relative closeness from the ideal solution.

$$\mathrm{CR}_r = \sqrt{\left(S_r^+ + - \min\left(S_r^+\right)\right)^2 + \left(S_r^- - \max\left(S_r^-\right)\right)^2} \tag{9}$$

where $r = 1, 2, 3 \ldots s$.

Step 6: Let a matrix of rank *t*, which is represented by Rank CR in increasing order. Two alternatives *ty* and *tx*, CRy-CRz, where $y = z$ is considered for calculating CR.

$$\mathrm{CR}_r = S_r^+ + - \min\left(S_r^+\right) \quad r = x,\ y. \tag{10}$$

Step 7: Ranking of design alternatives is considered as per the closeness to the ideal solution. Design alternatives are ranked in increasing order as per closeness to ideal solution from higher to lower. Therefore, higher order rank would be considered as a recommended design alternative.

3 Material Selection

The material selection process depends on various technical parameters and criteria which needs to meet the requirement of the formulated problem. Ranking of the parameters used for the turbine seal strips based on a different criterion, i.e., creep strength (A1), resistance to oxidation (A2), thermal expansion coefficient (A3), yield strength (A4), limits strain (A5) and toughness (A6). Out of the following technical attributes, five alternatives were chosen for the seal strips of labyrinth SS material such as 304 (M1), 310 (M2), 316 (M3), 321 (M4) and 430 (M5). While applying the MCDM approach, we found that A3 is a non-beneficial parameter while the rest of them seems beneficial.

Table 1 Weight of criteria calculated by AHP

Criterion	A1	A2	A3	A4	A5	A6
Weights	0.372	0.154	0.077	0.034	0.061	0.302

The weight of each criterion has been evaluated by the pairwise comparison matrix method using AHP. The weights of each criterion have been shown in Table 1. The results of AHP shows that criterion no 1 (A1) has the maximum weight among all the criterion and A4 has the minimum weight.

Five alternative materials have been selected for the study. The mechanical properties of all these material with respect to their selected criterion have been shown in Table 2. In these mechanical properties/criteria, only criterion no 3 (A3) is cost criteria and all other criteria are benefit criteria. The data given in Table 2 has been normalized by using equation no 1 and given in Table 3.

The normalized decision matrix has been multiplied with the weights of respective criterion with the help of Eq. 3 to form weighted decision matrix. The evaluated weighted decision matrix is given in Table 4.

The positive and negative solution for each alternate material has been calculated by using equation no 4 and 5. These idle solution matrices have been shown in Tables 5 and 6.

The distance of each alternate from their positive and negative ideal solution has been evaluated by equations no 6 and 7 and the relative closeness to all the selected materials from their ideal solutions has been calculated by using equation no 9. The alternates have been ranked by using equation no 10 according to their

Table 2 Decision matrix

	A1	A2	A3	A4	A5	A6
M1	87	75	62	100	100	100
M2	96	100	67	73	65	57
M3	100	77	63	95	95	100
M4	100	78	62	88	88	91
M5	21	72	100	63	43	68

Table 3 Normalized decision matrix

	A1	A2	A3	A4	A5	A6
M1	0.835443	0.107143	1	1	1	1
M2	0.949367	1	0.868421	0.27027	0.385965	0
M3	1	0.178571	0.973684	0.864865	0.912281	1
M4	1	0.214286	1	0.675676	0.789474	0.790698
M5	0	0	0	0	0	0.255814

Table 4 Weighted decision matrix

	A1	A2	A3	A4	A5	A6
M1	0.310785	0.0165	0.077	0.034	0.061	0.302
M2	0.353165	0.154	0.066868	0.009189	0.023544	0
M3	0.372	0.0275	0.074974	0.029405	0.055649	0.302
M4	0.372	0.033	0.077	0.022973	0.048158	0.238791
M5	0	0	0	0	0	0.077256

Table 5 Positive idle solution

	A1	A2	A3	A4	A5	A6
M1	0.003747	0.018906	0	0	0	0
M2	0.000355	0	0.000103	0.000616	0.001403	0.091204
M3	0	0.016002	4.11e−06	2.11e−05	2.86e−05	0
M4	0	0.014641	0	0.000122	0.000165	0.003995
M5	0.138384	0.023716	0.005929	0.001156	0.003721	0.05051

Table 6 Negative idle solution

	A1	A2	A3	A4	A5	A6
M1	0.096587	0.000272	0.005929	0.001156	0.003721	0.091204
M2	0.124725	0.023716	0.004471	8.44e−05	0.000554	0
M3	0.138384	0.000756	0.005621	0.000865	0.003097	0.091204
M4	0.138384	0.001089	0.005929	0.000528	0.002319	0.057021
M5	0	0	0	0	0	0.005968

relative closeness. The distance of alternates from their ideal solutions, their relative closeness, and their rank has been shown in Table 7.

It has been seen that the alternate 3 (M3) has the minimum relative closeness and hence gets the first rank in the ranking process. Alternate A4 has the second rank, A1 has the third rank, A2 gets the second rank, and A5 gets the fifth rank. The highest

Table 7 Relative closeness and ranking

	S+	S−	Sr	Rank
M1	0.000566	0.001925	0.049914	3
M2	0.03217	0.009598	0.20437	4
M3	0	0	0	1
M4	0.000118	0.001351	0.038323	2
M5	0.119686	0.170212	0.538421	5

rank indicates that the material M3 is the most suitable material for producing seal strips of turbines.

4 Conclusions

In this study, we address the problem of selection of turbine seal strip material and consider the selection of suitable material, for producing a seal strip of turbines, as a multi-criteria decision-making problem. An AHP and Modified-TOPSIS based MCDM approach has been proposed for solving the same problem. AHP has been used for calculating the weight of decision-making criteria, i.e., mechanical properties and Modified-TOPSIS has been used for assigning the ranks to the alternate materials. The results show that the criteria/mechanical property A1 (Creep strength) has the highest weight and the highest impact on decision making. Modified-TOPSIS found that the alternate material M3 (SS316) is the most suitable material for producing turbine seal strips based on selected material properties. In this study, we provide an examination of different materials using both tangible and intangible information. Hence, this analysis helps decision-makers to select an appropriate material for turbine seal strip. Many other MCDM techniques may also be employed in solving the same and similar decision-making problems in a better way. In future, researchers may also integrate the above approach with Fuzzy Logic to deal with the uncertainty in making judgments and some more effective parameters may also be considered for the study.

References

1. Scarlin, B. et al.: Materials for advanced steam turbines and boilers. ASME, PWR **21**, 93 (1993)
2. Bloch, H.P.: A practical guide to steam turbine technology. McGraw-Hill, New York (1996)
3. Lucas, G.M., Streeter, R.T.: Steam turbine abradable seal erosion and wear test. In: American Society of Lubrication Engineers. Annual meeting. 39, Chicago, 7 May 1984
4. Sawyer, J.W.: Turbomachinery maintenance handbook, 1st edn. ASME, New York, USA (1980)
5. Jaganmohan, A., Hons, B.E., Shlyakhim, P.: Steam turbines: theory and design. Mir, Moscow (1970)
6. Dweiri, F., Al-Oqla, F.M.: Material selection using analytical hierarchy process. Int. J. Comput. Appl. Technol. **26**(4), 182–189, 813 (2006)
7. Jahan, A., Edwards, K.L.: VIKOR method for material selection problems with interval numbers and target-based criteria. Mater. Des. **47**(5), 759–765 (2013)
8. Do, J.Y., Kim, D.K.: AHP-based evaluation model for optimal selection process of patching materials for concrete repair: focused on quantitative requirements. Int. J. Concr. Struct. Mater. **6**, 87–100 (2012)
9. Mutlag, S.A., Hasan, H.M.: Decision making in materials selection: an integrated approach with AHP. Anbar J. Eng. Sci. **7**(4), 399–407 (2019)
10. Uguraand, L.O., Baykanb, U.: A model proposal for wall material selection decisions by using analytic hierarchy process (AHP). In: ICCESEN 2016, Acta Physica Polonica A, vol. 132, pp. 577–579, Turkey (2017)

11. Anupam, K., Lal, P.S., Bisht, V., Sharma, A.K.: Raw material selection for pulping and papermaking using TOPSIS multiple criteria decision-making design. Environ. Progr. Sustain. Energy **33**(3), 1034–1041 (2014)
12. Kumar, D., Rahman, J., Chan, F.T.S.: A fuzzy AHP and fuzzy multi-objective linear programming model for order allocation in a sustainable supply chain: A case study. Int. J. Comput. Integr. Manuf. **30**(6), 535–551 (2017)
13. Hwang, C.L., Yoon, K.: Multiple attribute decision making: methods and applications. Springer, Heidelberg (1981)
14. Chand, M., Avikal, S.: An MCDM based approach for purchasing a car from Indian car market. In: IEEE Students Conference on Engineering and Systems (SCES) 2015, pp. 1–4, India (2015)
15. Chamodrakas, I., Leftheriotis, I., Martakos, D.: In-depth analysis and simulation study of an innovative fuzzy approach for ranking alternatives in multiple attribute decision making problems based on TOPSIS. Appl. Soft Comput. **11**(1), 900–907 (2011)
16. Altekin, F.T., Kandiller, L., Ozdemirel, N.E.: Profit-oriented disassembly-line balancing. Int. J. Prod. Res. **46**(10), 2675–2693 (2008)
17. Lin, M.C., Wang, C.C., Chen, M.S., Chang, C.A.: Using AHP and TOPSIS approaches in customer-driven product design process. Comput. Ind. **59**(1), 17–31 (2008)
18. Ren, L., Zhang, Y., Wang, Y., Sun, Z.: Comparative analysis of a novel M-TOPSIS method and TOPSIS. In: Applied Mathematics Research Express, Volume 2007, 2007, abm005, 01 Jan 2007, 10 p
19. Singh, R., Rashmi, R., Avikal, S.: A MCDM based approach for selection of a sedan car from Indian market. In: Harmony Search and Nature Inspired Optimization Algorithms, pp. 569–578 (2019)
20. Avikal, S., Jain, R., Mishra, P.K.: A Kano model, AHP and M-TOPSIS method-based technique for disassembly line balancing under fuzzy environment. Appl. Soft Comput. **25**, 519–529 (2014)

Impact of Six Sigma in Dairy Production for Enhancing the Quality

O. S. Deepa and Sreeja M. Krishnan

Abstract This paper proposes the implementation of six sigma for improving the quality of milk production process. Six sigma focuses on establishing world class business performance by means of statistical and systematic approach. It is a business strategy that emphasises on customer necessities, financial enhancements and overall productivity. The growing demand for milk and milk products had made the producers to enhance their livelihood by increased production. This paper illustrates the application of six sigma in diary products by systematic role of DMAIC by using gauge R&R and quality function deployment. Various six sigma tools were also used to show the efficiency of the work. In this study, the use of six sigma creates a competitive spirit among producers, which will boost them to manufacture milk at low cost.

Keywords DMAIC · Dairy products · Control charts · Financial implementation

1 Introduction

Six sigma is a blend and synergy among two important constant development methodologies. There does a reasonably substantial and expanding mass of indication associated with the interests of performing six sigma. LSS is an efficient data-driven procedure that assimilates two dominant business enhancement strategies lean manufacturing and six sigma with the intention of eradicating wastes and dropping down the process variation. Integration of six sigma and lean six sigma has been a powerful management strategy across all services. The usage of LSS is done by many manufacturing industries extensively, however, the application in small and medium scale industry is more difficult task. But customers' expectations are constantly changing and evolving and hence organisations must improve their product to remain competitive. Only few documented researches were done in dairy products and hence this paper tries to fill in the gaps by providing a case study thereby increasing customer

O. S. Deepa (✉) · S. M. Krishnan
Department of Mathematics, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, India
e-mail: os_deepa@cb.amrita.edu

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_31

satisfaction and overall improvement in the company's performance. Analytic hierarchy process is considered as the most optimal method in Lean six sigma and six sigma by considering major criteria's [1, 2]. Lean Six sigma was also implemented to reduce overall effect by considering environmental impact [3]. Lean six sigma is applied to medical records in hospital so as to less the turn-around—time and hence overall performance of the hospital department is increased [4]. Literature survey has been done for the lean six sigma based on manufacturing industry [5]. More studies have also been made on green lean six sigma [6–8]. Lean six sigma considers leadership as main success factor and the characteristic has been determined in [9]. More studies were made on six sigma and lean six sigma [10–18]. Six sigma methodology is used in the improvement of grinding processes and in aerospace technology for defect reduction [12–15]. Control charts are used to check whether the system is in control or not. Control charts have been extensively used in attribute sampling plan and variable sampling plan [13, 14, 16–21] and is mostly used in industries to monitor the production process. An improved modified FMEA model for prioritisation of lean waste risk was modelled by the inclusion of the waste-worsening factors and Taguchi loss functions, which has enabled the FMEA team to articulate the severity level of waste [1]. Fuzzy Interpretive Structural Modelling (FISM) approach has been used to analyse the interrelationships among the health care factors [16]. Lean, six sigma and its influence on potential and realised absorptive capacity.

2 Case Study

To make an organised decision on dairy products, the authors have undergone the following stages in a case study methodology and the team member includes the members of different groups such as Quality control, Production, Engineering and Accounts. DMAIC technique of the case study is explained in Fig. 1.

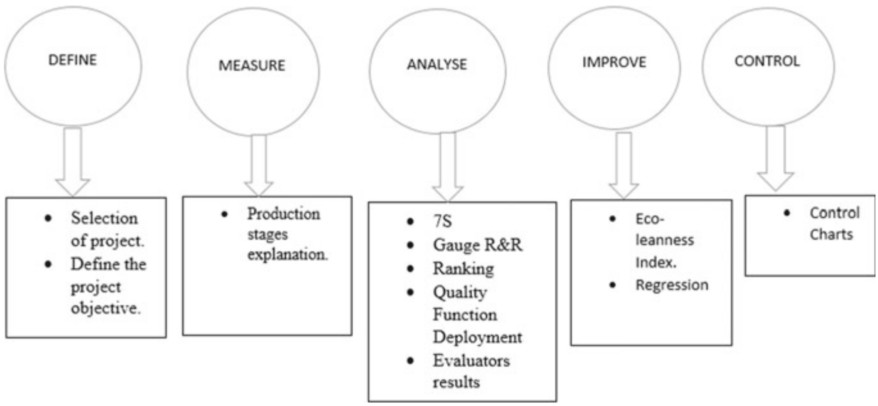


Fig. 1 DMAIC

3 Implementation of LSS

The proposed work is a combination of Six Sigma and Lean Six sigma. The selection of dairy products was restricted due to practical reasons.

3.1 Define Phase

The idea of the define stage is to determine the difficulty and also to explain the extent of the design. A peculiar connection plan is required to make out a fair knowledge of the organisation projects and predefined assignments that have to create in the timeline. The industry fully accepts that using LSS methods would bring both environmental as well as operational profits. This assisted in giving individual knowledge and perception about the plan to the workers.

A dairy industry in the district of central Kerala state has been selected for the study which manufactures five major products: Milk (2 types), Curd, Ghee, Sambharam (Butter milk). About 2702 primary milk co-operative societies are linked with this dairy and almost 7 lakh farmers are the members of this organisation. In this paper, DMAIC methodology has been implemented to produce milk and ghee.

There are mainly two types of milk:

1. Pasteurised milk: It is the fat-free milk and it is a toned milk, which contains 3.0% fat and 8.5% SNF (Solid No Fat). This is conveniently packed in 500 ml and 1 L sachets.
2. Sterilised flavoured skimmed milk: This is prepared from the pasteurised milk and sweetened with the sugar cane and flavoured with cardamom.

The goal of this paper is to decrease cycle time, reduce inventories and increase the production by improving the quality the products.

3.2 Measure Phase

The Measure stage points at an understanding of the contemporary nature of the operation and to recognise the important criteria concerning the quality.

The raw milk is first collected from the society. The milk is then classified into two such as toned milk and homogenised milk. In homogenised milk, fat globules are broken down so as to prevent it from forming creamy layer whereas in toned milk, skimmed milk powder is added to minimise the fat content in the milk. In the homogenised milk, pasteurisation is done at 72 °C followed by homogenisation and then cooling at 4 °C. The milk is then transferred to a storage tank named silo, where the milk gets cooled completely. Silo is a 60,000-capacity tank. Once the tank is fully cooled, it is ready to pass to the over tanks of various capacity and then transferred for filling via four heads. 500 ml and 1000 L of packets are made. 1000 L through one head is produced per hour, i.e., 4000 L are produced in 4 heads per hour. From the 4 heads, 8000 packets (1/2 L packets of milk) are produced from which 7500 packets will be the output and in remaining 500 packets, there will be a chance of defects.

The cream is separated from the milk and is used to generate Ghee. It is then pumped and stored in a tank and then heated in ghee vat up to 118 °C. It is then pumped to a settling tank and kept for cooling for about 24 h and is passed to a clarifier where minute dust particles are removed. Then, it is passed to a storage tank and then for filling. While pumping, there is a chance for the cream to split out. Thus, this split out cream is considered to be the waste. Cream depends on fat and so if fat increases waste will decrease.

3.3 Analyse Phase

The Analyse stage points at knowing the source problem and explains the difficulties and methods. It also describes enterprise development that must be performed to execute method developments. Based on the effects of the measured phase, the possible reasons for the process change are considered. The total cost for 7 months was classified as energy cost, system cost and material cost.

3.4 Gauge R&R

The Gauge Repeatability and Reproducibility is a technique to check the variation in the data by the corresponding factors. It also gives an idea of the capability of the system. By finding out the variation in the system, the improvement of the quality of the product can be given importance.

On discussion with the expert team, it has decided to consider the following ten factors for analysis.

1. Quality
2. Production
3. Equipment handling
4. Work Environment
5. Testing
6. Skilled workers
7. Customer satisfaction
8. Defects
9. Cost
10. Sales.

Table 1 Range scale

Scale	Range
Very strong	9
Strong	7–8
Medium	4–6
Very low	1
Low	2
Fairly low	3

Table 2 ANOVA table

Source of variation	SS	DF	MS	F	*P*-value	*F* critical
Sample	178.0667	9	19.78519	31.23977	7.56648E−13	2.210697
Columns	1.033333	2	0.516667	0.815789	0.451861932	3.31583
Interaction	5.633333	18	0.312963	0.494152	0.940364523	1.960116
Within	19	30	0.633333			
Total	203.7333	59				

Based on the expert term, the linguistic variables strong, medium, low are selected to judge the performance rating of six sigma project and is presented in Table 1.

Twenty questions were asked to experts based on ten factors. It was decided to find whether there is any significant difference based on questions or between experts. In order to validate the significance, Gauge R and R method was used and the results are tabulated in Table 2.

For the type of questions that are asked relevant to the production, the p value is almost close to 0 hence it is significant whereas for experts' opinion, the p value is 0.45 which is insignificant. Therefore, the questions contribute the variation. Since variation is more on questionnaire, the authors have decided to rank the questions to identify the key cause. Ranking for the three cost was done to identify the cost that affects the production and hence it is clear that cost is given priority in the production. That is cost effects more in the production of the dairy. In order to know more on cost and to decide the type of cost, ranking based on quality function deployment is suggested by the team members.

3.5 Quality Function Deployment (QFD)

From Table 3, it is found that production planning ranks first followed by equipment capability. Hence production planning and equipment capability are considered for next step.

Table 3 Quality function deployment

	Importance	% of importance	Production Planning	External support	Equipment capability	Manufacturing strategies	Software usage	1	2
Quality	5	27	Strong	Average	Strong	Strong	Strong	4	3.5
Production	4	21.62	Average	Weak	Average	Weak	Average	2	4
Defects	2	10.81	Weak	Weak	Weak	Average	Weak	3	2.5
Sales	4	21.62	Average	Average	Strong	Weak	Weak	4	3
Customer satisfaction	3.5	18.91	Average	Average	Weak	Average	Weak	3	4
		Importance	440.26	235.02	413.4	375.4	326.92		
		% of importance	24.58	13.12	23.08	20.96	18.25		

1 and 2 represent the other dairy products from customers

3.6 Experts Review

The questionnaire for production planning and equipment capability was then divided into three categories mainly Financial implementation, Operational implementation and Progressive implementation. Under each category, sub-categories were also there. For example, the subcategory of Financial performance will have cost spend for both production planning and equipment capability. The subcategory of Operational performance will be skilled workers and the sub-category for Progressive implementation is the reason for quality improvement.

Experts were asked to perform their analysis based on the three categories. All the experts gave their importance to financial performance. The operational performance and Progressive performance are the next rated. Thus, the eigenvalues are calculated from the respective priority weights of the expert's opinion. The maximum of eigenvalue λ_{max} is calculated in order to find the Consistency Ratio (CR). From the observed value of CR, the acceptance of the decision taken by the experts is fixed. The CR operation is mainly computed in two ways: first, the maximum eigenvalue is found and second, the Consistency Index (CI) is found at:

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n - 1}$$

Here $n = 3$ and the value of n is calculated from Random Consistency Index (RI) shown in Table 4. From Table 5, CR for each evaluator is ≤ 0.1, which shows good consistency. The overall priority weight for the category based on the expert opinion is given in Table 6. Clearly, the Financial implementation is given the high priority in the production. The authors have made a detailed study on cost for each month and is depicted using 7S histogram, Pareto and Scatter plot as in Figs. 2, 3 and 4. As financial implementation ranked high, the entire cost is divided into three factors namely system cost, energy cost and material cost.

Thus,

Table 4 Random consistency index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 5 Consistency ratio

Category	Expert 1	Expert 2	Expert 3
Financial implementation	0.581	0.652	0.723
Operational implementation	0.109	0.096	0.0704
Progressive implementation	0.309	0.250	0.206
Consistency ratio (CR)	0.0031	0.0158	0.0827

Table 6 Overall priority

Category	Overall priority	Rank
Financial implementation	0.652	1
Operational implementation	0.0918	3
Progressive implementation	0.255	2

$$CR = \frac{CI}{RI}$$

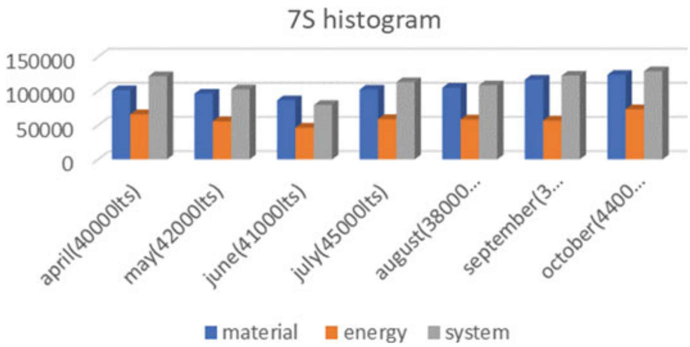


Fig. 2. 7S Histogram

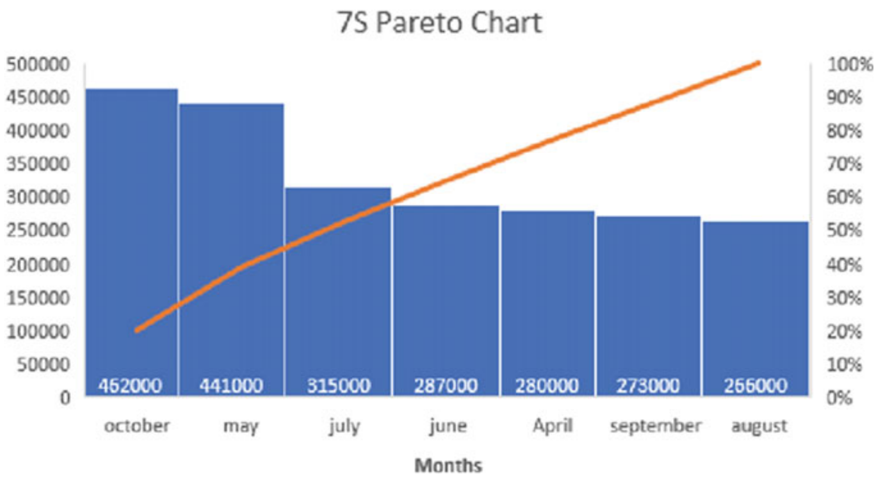


Fig. 3. 7S Pareto chart

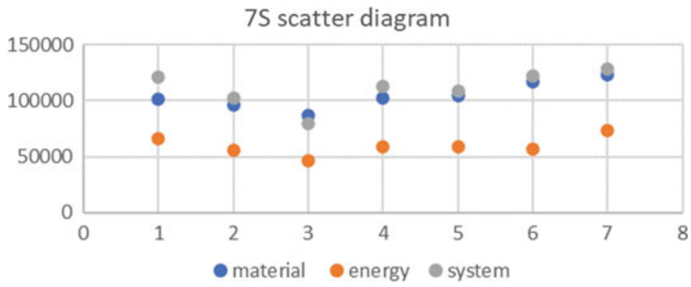


Fig. 4. 7S Scatter diagram

3.7 7S

The data were collected based on cost that is material cost, energy cost and system cost of 7 months. The total cost of September was leading compared with others. The Pareto chart analysis was executed to check the defects that matter for the production. The analysis was based on the cost performance and its corresponding litres of 7 months. From the figure, the defects for the month of October are more significant corresponded to other months.

The team identified the root cause for high cost and developed many solutions to reduce the cost. Just in time and total productive maintenance was proposed to develop so as to reduce the cost. As the cost effects more, the team divided into material cost (includes materials like packing cost, transportation cost etc.), System cost (includes repair cost, Administration cost etc.) and energy cost (electricity cost). Reducing the cost in August, September and October may contribute a significant reduction in the overall cost.

The Scatter plot gives an idea about how the variability of factors affects each other. It always has a large group of data. Closer points will form a straight line indicating high variability which in turn results in high correlation. On discussion with experts it was found that material cost is given much importance in production. Hence QFD is done for questions based on Material cost.

3.8 Improve Phase

The proposed development actions need to be performed in such a way that any process in the implementation method is controlled correctly and its results must be accurately reported.

3.9 Control Phase

In this phase, it is important to accurately record and regulate the systems in order to emphasis whether the cost related to the production process is in control or not. Performance standards must be created to judge the performance of the operation after improvements. Control charts are a relevant mechanism for monitoring method performance. Care was taken during the waiting time and the control limits were estimated based on cost.

All the three control charts related to system cost, energy cost and material cost as in Figs. 5, 6 and 7 are found to be in control and thus the whole process is in control and this help in a sustainable production.

Fig. 5 Control chart material cost

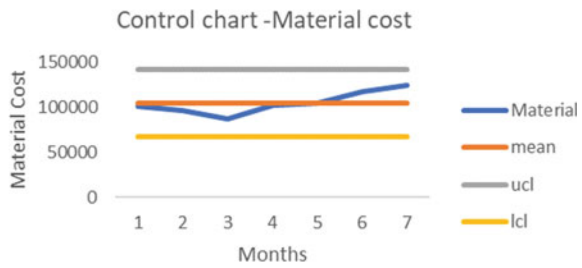


Fig. 6 Control chart energy cost

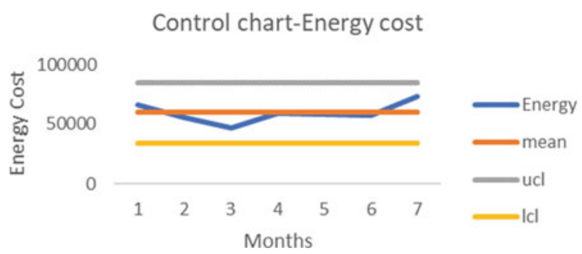
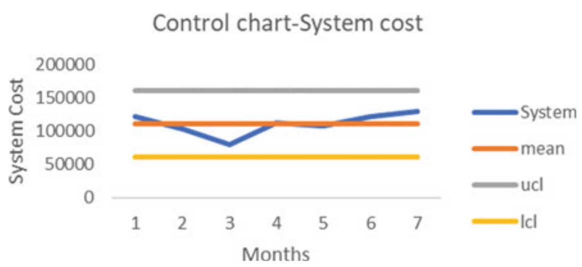


Fig. 7 Control chart system cost



4 Conclusion

From the DMAIC methodology, the define phase helped to know about the types of milk used in the industry. The measure phase mainly focused on the production process of milk and ghee in-order to understand the current nature. Analyse, is where the data are analysed with various statistical methods. The questionnaire was made based on the discussion with the Quality control, Production control and Engineering department. Using Gauge R&R method, analysis of variance is tabulated, and it was found that questions regarding the factors affecting the products contribute variation. Hence to know more on the type of cost, rating is done using Quality Deployment Function method and found that for production planning and equipment handling rating is high. Hence the questionnaire is then divided into three as financial performances, operational performances and progressive performances. By the method of consistency ratio and ranking, the highest priority is observed in financial performance. Thus, to know which cost gives more contribution, the cost is divided into three as material cost, system cost, and energy cost. Through 7S histogram and 7S pareto chart, it was found that the month October is more significant in case of cost and defects. Hence in improve phase the waste appears during pumping is reduced and control chart is plotted. Hence this result will be helpful in all branches of diary production for the betterment in the production of milk and ghee.

References

1. Sutrisno, A., Gunawan, I., Vanany, I., Asjad, M., Caesarendra, W.: An improved modified FMEA model for prioritization of lean waste risk. Int. J. Lean Six Sigma **11**(2), 233–253 (2020)
2. Alhuraish, I., Robledo, C., Kobi, A.: Assessment of lean manufacturing and Six Sigma implementation with decision making based on the analytic hierarchy process. IFAC-Papers Online **49**(12), 59–64 (2016)
3. Ben Ruben, R., Vinodh, S., Asokan, P.: Implementation of lean six sigma framework with environmental considerations in an Indian automotive component manufacturing firm: a case study. Prod. Plan. Control **28**(15), 1193–1211 (2017)
4. Bhat, S., Gijo, E.V., Jnanesh, N.A.: Productivity and performance improvement in the medical records department of a hospital. Int. J. Prod. Perform. Manage. **65**(1), 98–125 (2016)
5. Cherrafi, A., Elfezazi, S., Chiarini, A., Mokhlis, A., Benhida, K.: The integration of lean manufacturing, six sigma and sustainability: a literature review and future research directions for developing a specific model. J. Clean. Prod. **139**, 828–846 (2016)
6. Chugani, N., Kumar, V., Garza-Reyes, J.A., Rocha-Lona, L., Upadhyay, A.: Investigating the green impact of lean six sigma, and lean six sigma: a systematics literature review. Int. J. Lean Six Sigma **8**(1), 7–32 (2017)
7. Alhuraish, I., Robledo, C., Kobi, A., Azzabi, L.: Analytic hierarchy process used to estimate the performance of companies that implement lean manufacturing and Six Sigma IJSSCA **10**(¾), 179 (2017)
8. Kumar, S., Luthra, S., Govindan, K., Kumar, N., Halem, A.: Barriers in green lean six sigma product development process: an ISM approach. Prod. Plan. Control **27**(7–8), 604–620 (2016)
9. Laureani, A., Antony, J.: Leadership characteristics for lean six sigma. Total Qual. Manage. Bus. Excellence **28**(3–4), 405–426 (2017)

10. Ani, M.N.C., Kamaruddin, S., Azid, I.A.: Factory-in-factory concept as a new business model for automotive production system. Int. J. Six Sigma Compet. Adv. **11**(2/3) (2019)
11. Muraliraj, J., Kuppusamy, S., Zailani, S., Santha, C.: Lean, six sigma and its influence on potential and realized absorptive capacity. Int. J. Lean Six Sigma **11**(1), 84–124 (2020)
12. Noori, B., Latifi, M.: Development of six sigma methodology to improve grinding processes. Int. J. Lean Six Sigma **9**(1), 50–63 (2016)
13. Deepa, O.S.: Optimal production policy for the design of green supply chain model. Int. J. Appl. Eng. Res. **10**(2 Special Issue), 1600–1601 (2015)
14. Deepa, O.S.: Application of acceptance sampling plan in green design and manufacturing. Int. J. Appl. Eng. Res. **10**(2 Special Issue), 1498–1499 (2015)
15. Psomas, E.: The originality of the lean manufacturing studies: a systematic literature review. Int. J. Lean Six Sigma **11**(2), 254–284 (2018)
16. Ajmera, P., Jain, V.: A fuzzy interpretive structural modeling approach for evaluating the factors affecting lean implementation in Indian healthcare industry. Int. J. Lean Six Sigma **11**(2), (2020)
17. Trehan, R., Gupta, A., Handa, M.: Implementation of Lean Six sigma framework in a large scale industry: a case study. Int. J. Six Sigma Compet. Adv. **11**(1) (2019)
18. Thanki, S.J., Thakkar, J.J.: Value-value load diagram a Graphical tool for lean-green performance assessment, production. Plan. Control Manage. Oper. **27**(15), 1280–1297 (2016)
19. Shruthi, G., Deepa, O.S.: Average run length for exponentiated distribution under truncated life test. Int. J. Mechan. Eng. Technol. (IJMET) **9**(6), 1180–1188 (2018)
20. Phanden, R.K., Demir, H.I., Gupta, R.D.: Application of genetic algorithm and variable neighbourhood search to solve the facility layout planning problem in job shop production system. In: 2018 7th International Conference on Industrial Technology and Management (ICITM), pp. 270–274. IEEE (2018, March)
21. Krishnan, S.M., Deepa, O.S.: Control charts for multiple dependent state repetitive sampling plan using fuzzy poisson distribution. Int. J. Civil Eng. Technol. (IJCIET) **10**(1), 509–519 (2019)

Kaizen Implementation in Rolling Mill: A Case Study

Rahul Sharma, Abhishek Kumar, Rajender Kumar, and Tarsem Singh

Abstract The operational issues in the Rolling Mills industries such as productivity; resource consumptions; wastes creation and breakdown etc., bound the researchers to do research in rolling industries. That is why, it has never been taken in the mainstream for the research work. The present paper aims to enhance the operational efficiency and efficacy of rolling mill industry with Kaizen implementation. The existing data such as miss roll production, spare part consumption, productivity and breakdowns were collected for the study. These data further used for finding the operational efficiency of rolling mill and while analyzing it were observed that the rolling mill is performing lesser than its original working capacity. Thus, Kaizen approach was suggested for the implementation in rolling mill industry and on analyzing the data after the Kaizen implementation, it is observed that the productivity of rolling mill goes by 30% increment whereas the 70% decrease reported in miss roll. In addition, the spare part consumptions are also reduced because of lesser number of breakdowns.

Keywords Rolling mills · TPM · Kaizen · Miss roll · Productivity · OEE · Planned maintenance

1 Introduction

Continuous improvement in manufacturing sector has great importance in virtue of globalization competitive environment, low product life and many others [1–9]. Kobestu-Kaizen being a total productive maintenance (TPM) pillar caters equipment, worker, material and energy for optimum utilization by eliminating 16 major loses. It aims to optimize the resources in manner to reducing further capital investment [10–12]. The enduser focuses on products quality, on time delivery and cost, which

R. Sharma · A. Kumar (✉) · R. Kumar
Mechanical Engineering Department, FET, MRIIRS, Faridabad, Haryana, India
e-mail: abhishek.fet@mriu.edu.in

T. Singh
Rolling Mills, Starwire India Ltd, Faridabad, Haryana, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_32

raises the need for quality system, in turn lean manufacturing especially Kaizen plays an important role in improving and increasing quality and productivity in a continuous manner [13–16]. The present work is to identify the effectiveness and then implementation Kaizen in steel industries especially rolling mills along with identification of preventive maintenance for reducing production cost and increase plants profits. Using TIMED PDCA (plan do check act), present work has explored possibility to increase productivity and motivate workers to adapt Kaizen themes (to eliminate, to reduce and to increase) at present scenario [9, 11, 17]. "Muda", i.e., removal of unwanted waste from all the areas of production system along with quality and safety are major objectives to keep in mind while working on Kaizen it emphasis on making a task simpler, re-engineering to accommodate Kaizen team members ideas, work processes speed and efficiency, making safe work environment and continuous improvement in the products. Kaizen aims to eliminate muda that costs for 95% waste in an industry [9, 13, 14, 18–31]. In nutshell, Kaizen word symbolizes continuous improvement and helps any industry to grow, by eliminating the major problems faced by modern industries [23]. The ideology behind Kaizen states that many small changes can make a greater difference with a big change in industries. Kaizen culture refers every shop of a plant to conduct 5 Kaizen/month, which helps the industry to grow at a rapid pace with moving toward the lean manufacturing, which eliminates the wastes of the production system and leads towards the idea of maintenance-free industry [12, 13].

2 Literature Survey

Kaizen is an internationally acknowledged method of continuous improvement through small steps and has the potential to be used as a strategic tool with a vision to reach and surpass the company's objectives. It is a step by step improvement process, which involves small changes implemented over a period of time by all the team members of the organization. The literature reveals the relation between machine, process, and employee was established to review on the organizational performance [20, 27]. OEE is set as a monitoring value that tells about the fact to accrue the overall view of any plant success. The cost-saving helps reducing the spare part cost consumption/metric ton along the effect of decrease in the breakdown and increase in production. This case study targets in finding that introduction of TPM and Kaizen in rolling mills of Star wire increase its saving by reduction in spare part cost as compare to previous years in turn profitability. The silent features of Kaizen were also reported such as increased productivity, reduced production cost, and reduced overall maintenance cost, minimized maintenance management and many more [2, 3, 8, 10]. The quality and maintenance of manufacturing systems are closely related functions of any organization. Today's competitive environment requires much more effective equipment management [18]. The various studies reported earlier reveal the contribution of Kaizen in the manufacturing context [25]. Kaizen implementation in Indian Rolling industry was reported in 2013 in which the Rolling mill diagnoses were reported [17]. In addition, the quality of steel rolling industries can be increased through Kaizen was also reported. The report reveals the findings, i.e., best way to improve the quality and productivity in any plant is to go through the ideology of TPM [26, 30]. The study concluded that the Rolled product is influenced by various factors like incoming material, mechanical and electrical equipment, lubrication, control strategies, maintenance of the equipment [2]. The application of Kaizen was also reported in Ethiopia, which reveals that the major manufacturing companies are align toward the Japanese culture of Kaizen implementation. This would help then companies to improve and grow at a rapid pace [6].

3 Research Gap

In India, the steel industry had gone through a lot of changes and improvement since its inception. Substantial investment has been made to the process to improve the product quality and the efficiency of the machines used in the industries. Rolling mills show a remarkable progress in past 100 years that has made the process smooth, easy to understand and the conditions have been made safer to work on the mills [5]. Though, the rolling Mills industries are striving for the efficiency and efficacy portion. The present problem is formulated to find the solution of the followings:

(a) Productivity Enhancement of Rolling mill Industries
(b) Reduction in breakdowns
(c) Consumption of spare parts.

4 Methodology

In general, the Kaizen is done to eliminate major 16 losses of production but in this research only five losses have been covered as per Kobestu Kaizen manual as follows:

1. Setup and adjustment loss—stoppage losses that accompany setup changeover.
2. Cutting blade and jig change losses—stoppage losses cause by changing of cutting blade.
3. Minor stoppage and idling loss—loss occurred when equipment is idle due to jamming of some work.
4. Defects and rework—losses due to defects and rework.
5. Motion losses—man hour loss arriving due to difference in skill level of the operators [18, 21].

After the selection of target losses, Kaizen have been applied on the areas of the shop involved with major sources of breakdown/losses affecting the production in rolling mills. The miss roll being the main problem in rolling mills observations was made for the areas of the rolling mill causing main reason of miss roll generation

[21]. OEE is the product of three factors that determine the level of working in a plant [5, 8]. Summary of Kaizen at rolling is given in appendix.

1. **Availability**: It is the ratio of total time when a machine is expected to run to the time it actually ran. It shows us the amount of running time, total and how much falling behind set time

$$A = (\text{Total run time} - \text{downtime})/\text{Total run time}$$

2. **Production Rate**: It is the ratio of total production to that of the targeted production, which reflects the percentage of falling behind from the actual target that could be achieved. The machine is run in way that it avoids wastage and any lag in the production line, hindering the overall production rate. It can be formulated by

$$P = \text{Actual production}/\text{Targeted production}$$

3. **Quality Rate**: It is the ratio of good products (defect free) to that of total products. It tells us the amount by which production falls behind in the quality end of our production. It can be formulated as

$$Q = \text{Good products}/\text{Total products}$$

These three factors of OEE stipulate three facts, first about the available time we have and the usage of that time, second about the maximum capacity of machine and third about the quality of our products and how much it can be improved for less rejection and defects. It is given by OEE = $A * P * Q$.

5 Case Study

The calculation done to quantify the losses and improvement has been segmented for four parameters here (refer Figs. 1 and 2).

1. OEE
2. Productivity: production/mill running hrs
3. Breakdown and miss rolls
4. Spare part consumptions.

Analysis of above-listed parameters has been given below.

Calculating OEE: Input Data (December month data)

- Mill run time (round bars) = 137.83 h
- Total production (round bars) = 401.504 MT
- Miss roll (round bar) = 0.75%

Fig. 1 Month-wise graph for OEE

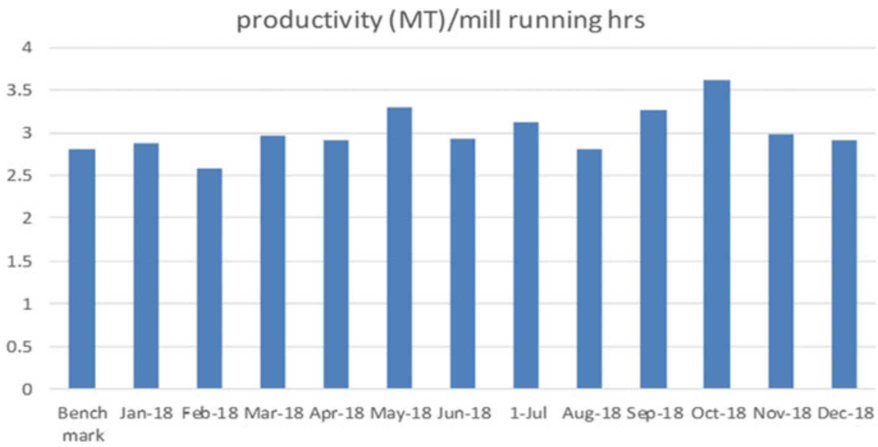


Fig. 2 Productivity of Mill in each month

- End cutting (round bars) = 2.080%
- Total days of round bar production = 15
- Total time available = number of production days for a material * total number of hours per day, i.e.,
  =15 * 11 (11 h/day production) = 168 h
- Target of production is 3.4 Mt/mill running hr. (3.4 is the TPM target which is MT/running hr.) as per the data achieved in previous years
- It gives us 3.4 * 137.83 = 468.622 MT, it is the total production in ideal condition.
- Miss rolls (MT) = miss roll % * total production/100
  = 0.75 * 401.504/100 = 3.01 MT
- End cutting (MT) = end cutting % * total production/100
  = 2.08 * 401.504/100 = 8.35 MT
- Now, Availability (A) = Mill running time/total available time
  = 137.83/165 = 0.8353

Table 1 Monthly OEE details

January 18	64	July 2018	76
February 18	57.73	August 2018	72
March 2018	78.55	September 2018	67
April 2018	67.05	October 2018	71
May 2018	67.48	November 2018	65
June 2018	78.32	December 2018	69

- Production rate (P) = Total production/ideal production
  = 401.504/468.622 = 0.8567
- Quality rate (Q) = {total production − (miss rolls + end cutting)}/total production
  = {401.504 − (3.01 + 8.35)}/401.504 = 0.9717
- Now for OEE = $A * P * Q$
  OEE = 0.8353 * 0.8567 * 0.9719 = 69.54
- Similarly data for the previous months were also calculated and the results are as follows (Table 1).

5.1 Production Per Mill Running Hours

As per the data given for total production and total mill running hrs., from January 2018 to December 2018, the production per mill running hr. have been calculated using following equations:

Productivity = production/mill running hours (i.e., for month of Dec mill running = 137.83 h and production is 401.504 MT so the productivity is 401.504/137.83 = 2.913).

Now highest productivity came in the month of October 2018, i.e., 3.625 MT/hr seen in Fig. 3. Therefore to find out how much we have increased our production we calculate (Best achieved-benchmark) * 100/benchmark = (3.625 – 2.8 1/2.81) * 100 = 29%

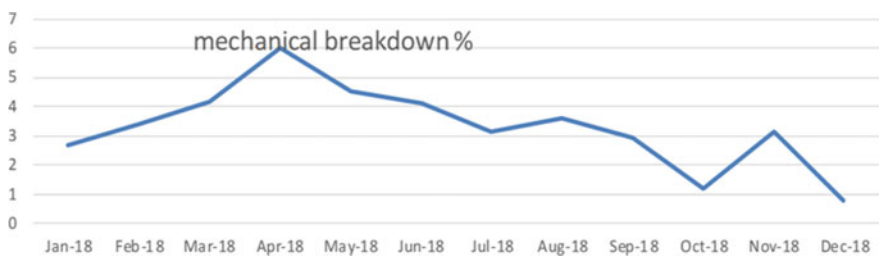


Fig. 3 Breakdowns of Mill in each month

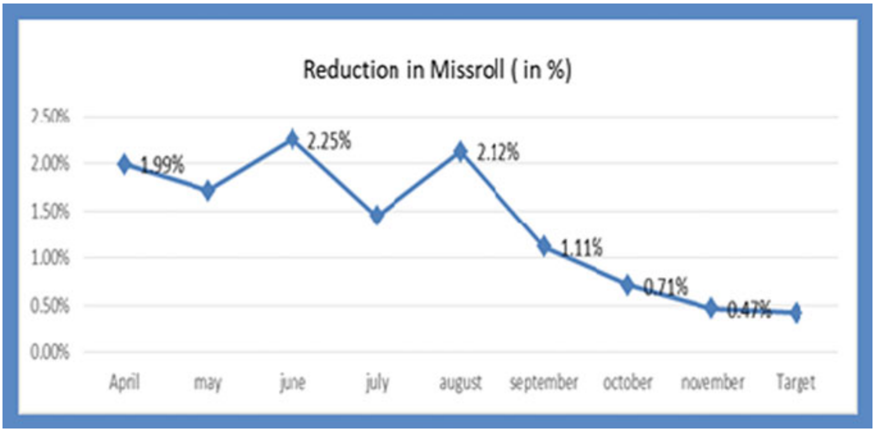


Fig. 4 Miss-roll data

Note: 2.81 is the benchmark of 2018

Therefore, it is observed an increment in the productivity about 29%.

5.2 *Breakdown/Miss Roll %*

Similarly, the break down data by total mill running time and total breakdown are calculated as follows:

In December 2018, the total mill running time/available time (for all products, i.e., round bars, blade steel and bulb bars) = 200.75 h.

$$\text{Total breakdown hours} = 1.59$$

$$\text{So breakdown \%} = \{\text{total breakdown time/total available time}\} * 100$$

$$1.59/200.75 * 100 = 0.79$$

It has been observed that there is reduction in breakdowns due to different Kaizen and TPM work in the shop as seen in Fig. 4 now about the miss rolls after the Kaizen was done these are the data of the subsequent months.

5.3 *Miss Rolls*

The data related to Miss roll after the Kaizen are collected and reported in Table 2.

Table 2 Miss roll data

April	May	June	July	August	September	October	November
1.99%	1.71%	2.2%	1.44%	2.12%	1.11%	0.71%	0.47%

The result of the Kaizen reflects, in case of the miss roll % reduced from highest being 2.25% in June'18 to 0.47% in November'18. It shows a 1.71% drop in miss roll production.

If we see the effects of miss roll % reduction in terms of material saved and the cost related to it comes out to be Miss roll % * total production = total material saved from being rejected

$$1.71 * 435(435 \text{ is production in Nov) it comes to be } 7.4385\,\text{MT}$$

Now saving in ton = 7.43 ton.

5.4 *Total Saving*

Further purchase cost of a final material is Rs 300–400 per kg according to the grades and the yield of the product is 70%. Therefore the amount we saved by that Kaizen can be calculated by

$$\begin{aligned}\textbf{Total saving} =\ & \text{reduction in miss roll (kg)} * \text{yield } \% * \text{ purchase cost} \\ & \text{(vary b/w Rs 300}-\text{Rs 400/kg as per grade differences)} \\ =\ & 7.43 * 1000 * 0.7 * 300 \\ =\ & 1,560,300 \text{ (Considering Rs 300/}- \text{ as purchase cost)} \\ =\ & 7.43 * 1000 * 0.7 * 400 \\ =\ & 2{,}080,400 \text{ (Considering Rs 300/}- \text{ as purchase cost)} \\ & \text{Total saving is appx } 15\,\text{L} - 20\,\text{L (Rs)}\end{aligned}$$

5.5 *Reduction in Spare Part Consumption*

The reduction in amount spend in spare part with the help of Kaizen techniques, considerable amount of saving has been done as shown by analysis (refer Fig. 5).

The red line shows you the benchmark of the spare part consumption which is set as 383 Rs/MT and considered as the benchmark for the spare part cost for finding the total saving done in the year of 2018.

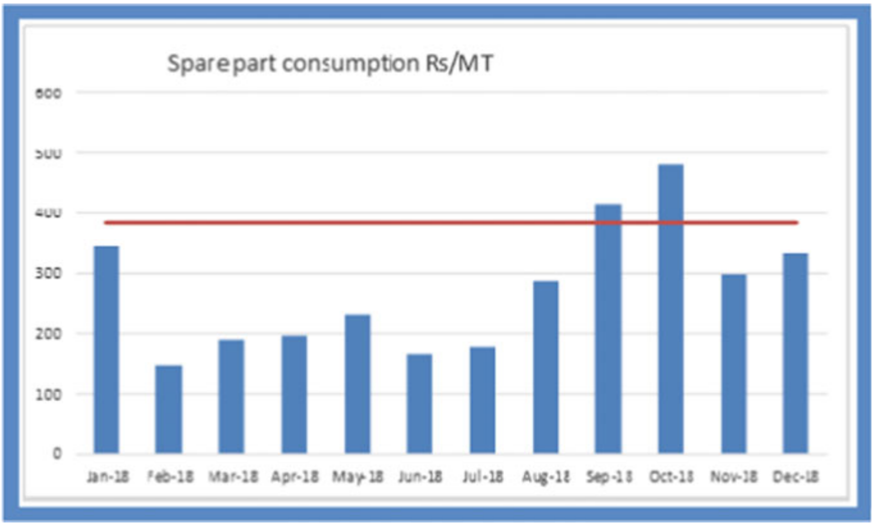


Fig. 5 Spare-part consumption data

$$\text{Total saving} = \text{production (in that month)} * \{\text{benchmark} - \text{that month spare part (RS/MT)}\}.$$

The money saved in the year from rolling mill is Rs. 842406/- from mechanical spare part reduction (refer Table 3).

5.6 *Discussion*

In the present study, it has been observed that the maximum OEE achieved by rolling mill is 78.55 (March'18) and 78.32 (June'18) as per the data given by the company authorities where production of round bars only there were no special demands of bulb bar and blade steel which makes availability of machine for round bars all the time. On the other hand in February'18 due to less production and high breakdown time, the OEE is least. Kaizen was applied in the month of April–June keeping in mind the breakdown area hence by the decrease in breakdown and increase in mill availability, in turn stabilizing the OEE. The 85% OEE value is considered world-best standard for production system.

In case of productivity: production/mill running hours in Feb'18 customer requirement was of different products hence increase in set up time leading toward to lower productivity and more idling time for the mill. On an average production/mill running hours remains near to benchmark keeping the annual average more than 3, i.e., more than 2.81 that was the bench march of 2018. After applying Kaizen on repeated stand,

Table 3 Saving/month (in Rs)

Month	Monthly production (MT)	Benchmark value in Rs/MT	Spare part consumption Rs/MT	Saving/month (in Rs)
January	566	383	347	20,376
February	480	383	148.7	112,464
March	796	383	188.2	155,061
April	603	383	197	112,158
May	633	383	233	94,950
June	716	383	167	154,656
July	696	383	178	142,680
August	666	383	286	64,602
September	590	383	417	−20,060
October	589	383	480	−57,133
November	435	383	299	36,540
December	512	383	332	26,112
Total saving				842,406

belt guard of hot shear machine and introduction of pinch roller and less number of different products required, peak values of productivity is seen in Oct'18.

In case of results of mechanical breakdown, it has been observed that it has peak value in the month of April'18 due to installation of new mill at the shop floor after which applying Kaizen at ejector changing bearing which suited our needs etc., it was lower down to 79% in Dec'18 during this period the total mill running hours was 200.75 and total breakdown was just 1.59 h. Furthermore, the 10% reduction in mechanical breakdown is achieved from the past year as the benchmark. On the other hand, in case of miss roll shown in fig no., there it has been reduced to 1.71% in the month of November, it was lowest with 47% providing saving of 15–20 L only by avoiding miss roll generation. It has been observed that after Kaizen implementation in hot saw, hot shear and pinch roller.

Spare part consumption has been shown in figure no. Clearly shows that consumption was good enough below the control line leaving few instances. In case of Sept'18 and Oct'18, it passed the control line because of annual purchase for mill inventory under preventive maintained and due to few parts completed their productive life and hence needed to be replaced.

As seen Kaizen have affected the majority of the area that could be bettered. Leading toward future Kaizen reduced the capital that is required to run a plant and reduced the breakdown that resulted in money saving. Rolling mills are one of the high risk areas as it requires red hot metallic rods passing through the mill at very fast pace injuries in the shops are hard to avoid but with proper Kaizen implementation at specific accident-prone areas have led to zero accidents in 2018 that is itself quite a big achievement [24, 26].

6 Conclusion

In the industrial terminology, the continuous changes in the shop floors management, i.e., implementing the advanced tools like Lean, Kaizen, 5-S will help the industries to have huge benefits both tangibles and nontangibles. In the rolling mill industry, the cost involved for operations is one of the big influencers (which is considered as the hidden factor in the present study). The implementation of Kaizen approach in the present study reveals the benefits to the rolling industry such as reduction in breakdown and misses rolls; enhanced OEE; the quality improvement and, the reduction in spare part consumption etc. These tangible benefits result the productivity improvement and thus the cost-saving of the industry.

Appendix: Summary of Kaizen at Rolling

	Kaizen 1	Kaizen 2	Kaizen 3	Kaizen 4	Kaizen 5	Kaizen 6	Kaizen 7
Kaizen theme	To reduce the breakdown and bearing consumption	To reduce mechanical ejector breakdown of breakage of chain of ejector	To increase safety on the mill stand	To eliminate time caused by manual operation	To reduce the inspection time	To eliminate the miss roll produced by cutting of material (21–4 N and 21–43)	To reduce the cost of disassembly od repeater
Problem	There is too much breakdown and bearing consumption in discharge roller table (bearing no. 22212)	There is breakage of chains in the ejector that is carried ingot/billets from furnace to mill	Hot material was coming out of the flying shear machine causing unsafe condition	Miss roll generation	The driving belt fail unnoticed causing breakdown of hot saw machine and miss roll	Miss roll generation on hot shear machine	Disassembly time was high during changing of setup of repeater
Team size	9	8	6	7	4	11	6
Idea	Old Bearing must be replaced with more heat resistant one	Wire rope is to provide to reduce the mechanical breakdown of ejector	To install closed MS pipe	To install pinch roller instead of manual operation	To provide a visual inspection by operator in the side of belt guard towards the operator	To use abrasive cutting machine to cut ends of the bars	To make efficient design
Counter measure	Bearing no. 22312 was provided in place of 22212	Wire rope is provided to reduce the mechanical breakdown due of breakage of chain of ejector	A 6″ Dia- pipe is provided	Operation is done automatic	The belt guard has been modified: the side wall of the belt guard towards the operator has been fab. by using steel wire mesh to facilitate visual inspection	Efficient machine is provided with higher stroke rate	To provide MS plate

(continued)

(continued)

	Kaizen 1	Kaizen 2	Kaizen 3	Kaizen 4	Kaizen 5	Kaizen 6	Kaizen 7
Benefits	1. Reduction in breakdown and consumption of bearing 2. 5 s and safety (4)	1. Reduction in breakdown 2. 5 s and safety 3. Cost saving in spare parts of chain (4)	1. Unsafe condition elimination 2. Reduction in miss roll (4)	1. Productivity increased 2. Reduction in miss roll material 3. Reduction in cost (4)	1. Inspection time reduced. 2. Easy monitoring 3. Breakdown prevention 4. Timely maintenance (4)	1. Miss roll reduction 2. Increase in productivity 3. Safety improvement (4)	1. Setting time will reduce that will increase productivity 2. Cost saving (4)

(continued)

(continued)

	Kaizen 1	Kaizen 2	Kaizen 3	Kaizen 4	Kaizen 5	Kaizen 6	Kaizen 7
Why-Why Analysis	Q1—Why there is too much bearing consumption and breakdown in the roller table? A1—Due to high temperature bearing is underrated Q2—Why was high temperature bearing is underrated? A2—There is high operation temperature at first roll	Q1—There is too much breakdown occurred in the ejector? A1—Due to breakage of chain of the ejector Q2—Why did the chain of the ejector broke? A2—Due to fatigue occur in the chain	Q1—Why was unsafe condition created? A1—Hot material sometimes came of the mill in the air Q2—Why was hot material coming out in open condition? A2—And open MS channel was used to transfer the material Q3—Why open MS channel is used? A3—Due to poor design from the manufacture	Q1—Why there was miss roll? A1—Because material cool down during processing Q2—Why was material cool down? A2—because time of processing was higher Q3—Why the time was higher? A3—Because the process was done manually	Q1—Why there is breakdown due to belt failure? A1—The belt wear and tear is un noticed to the operator Q2—Why the belt condition unnoticed to the operator? A2—The belt gaud has no visual inspection Q3—Why there is no visual inspection? A3—The belt guard that is installed is made up of solid MS sheet	Q1—Why was miss rolls were generated on hot shear m/c? A1—Due to material cool down Q2—why was material cool down? A2—Due to less strokes of machine delay in cutting time Q3—Why was delay in cutting time? A3—Due to machine old design	Q1—Why disassembly time and welding rod consumption was high? A1—Because repeater was bolted and welder to main frame of the platform Q2—Why it was bolted and welded? A2—To stabilize the repeater these setting were done Q3—Why we have to change the setup again and again A3—Due to old design of mill and different grades are used

References

1. Abdulmouti, H.: Benefits of Kaizen to business excellence: evidence from a case study. Indus. Eng. Manage. **7**(2). https://doi.org/10.4172/2169-0316.1000251 (2018)
2. Ahmad, K.I., Shrivastav, R., Pervez, S., Khan, N.P.: Analysing quality and productivity improvement in steel rolling industry in central India. IOSR J. Mechan. Civil Eng. (IOSR-JMCE) 6–11 (2014)
3. Ai Moi, W., Sing, S.H.: The implementation of Kaizen and 5S concept for overall improvement of an agricultural organisation. Int. J. Sci. Res. Sci. Eng. Technol. 23–37 (2020). https://doi.org/10.32628/ijsrset196656
4. Antony, J., Caine, P., Escamilla, J.: Lean sigma [production and supply chain management]. Manuf. Eng. **82**(2), 40–42 (2003). https://doi.org/10.1049/me:20030203
5. Ataka, M.: Rolling technology and theory for the last 100 years: the contribution of theory to innovation in strip rolling technology. ISIJ Int. **55**(1), 89–102 (2015). https://doi.org/10.2355/isijinternational.55.89
6. Desta, A., Mezgebe, T., Asgedom, H., Gerezgiher, A.: Kaizen as a strategic choice for enhancing the capabilities of manufacturing companies in Ethiopia. Int. J. Bus. Strategy **16**(1), 55–72 (2016). https://doi.org/10.18374/ijbs-16-1.6
7. Gera, G., Saini, G., Kumar, R., Gupta, S.K.: Improvement in Operational Efficiency of equipment through TPM: a case study. Int. J. Indus. Eng. Res. Dev. **03**(01), 67–73 (2012)
8. Hasegawa, A.: Harmonious improvement through Kaizen teian. Kaizen Teian **2**, 181–188 (2017). https://doi.org/10.1201/9780203749739-21
9. Chandra Shashidhar, S.R., Verma, D.S.: Human aspects in implementation of total productive maintenance. Int. J. Trend Sci. Res. Dev. **2**(2), 326–333 (2018). https://doi.org/10.31142/ijtsrd9396
10. Kumar, R., Kumar, V., Singh, S., Gupta, S.K.: Office efficiency enhancement through TPM: an empirical study. In: Proceeding of national conference on trend and advancement in mechanical engineering (TAME-2012), YMCA University of Science and Technology, Faridabad (Hr.), 19–20 Oct 2012, pp. 711–717 (2012)
11. Kumar, R., Kumar, V., Singh, S.: Effect of lean principles on organizational efficiency. Appl. Mech. Mater. **592–594**, 2613–2618 (2014). https://doi.org/10.4028/www.scientific.net/amm.592-594.2613
12. Kumar, R., Kumar, V., Singh, S.: Role of lean manufacturing and supply chain characteristics in accessing the manufacturing performance. Uncertain Supply Chain Manage. **2**(4), 219–228 (2014). https://doi.org/10.5267/j.uscm.2014.7.007
13. Kumar, R., Kumar, V., Singh, S.: Relationship establishment between lean manufacturing and supply chain characteristics to study the impact on organizational performance using SEM approach. Int. J. Value Chain Manage. **7**(4), 352 (2016). https://doi.org/10.1504/ijvcm.2016.080435
14. Kumar, K., Dhillon, V.S., Singh, P.L., Sindhwani, R.: Modeling and analysis for barriers in healthcare services by ISM and MICMAC analysis. In: Advances in Interdisciplinary Engineering, pp. 501–510. Springer, Singapore (2019)
15. Mittal, V.K., Sindhwani, R., Singh, P.L., Kalsariya, V., Salroo, F.: Evaluating significance of green manufacturing enablers using MOORA method for Indian manufacturing sector. In: Proceedings of the International Conference on Modern Research in Aerospace Engineering, pp. 303–314. Springer, Singapore (2018)
16. Mittal, V.K., Sindhwani, R., Shekhar, H., Singh, P.L.: Fuzzy AHP model for challenges to thermal power plant establishment in India. Int. J. Oper. Res. **34**(4), 562–581 (2019)
17. Mundhada, N., Wankhade, A., Bohra, B.: Detail investigation, analysis and implementation for improving quality/productivity in Rolling Mill Unit. Int. J. Eng. Innov. Technol. (IJEIT), 5–13 (2013)

18. Murugabhoopathy, K., Satish, R., Prakash, R.S.: Study on improving the rolling and its allied practices to achieve high productivity, quality, improved techno-economic factors and equipment reliability in hot rolling mill of Salem steel plant. Int. Conf. Mater. Manuf. Mach. **2128**(01), 302–317 (2019). https://doi.org/10.1063/1.5117960
19. Patel, V.: Review on implementation of Kaizen technique for productivity improvement in manufacturing organization. Int. J. Res. Appl. Sci. Eng. Technol. **V**(X), 1520–1525 (2017). https://doi.org/10.22214/ijraset.2017.10219
20. Sahu, S.K., Gangber, P., Mishra, S.K., Sahu, S.K.: Total productive maintenance (TPM) implementation: a review. Int. J. Sci. Res. Dev. **4**(7), 175–179 (2016)
21. Sahu, A.K., Sahu, A.K., Sahu, N.K.: A review on the research growth of Industry 4.0. Int. J. Bus. Anal. **7**(1), 77–97 (2020)
22. Schonberger, R.: Waste elimination, Kaizen, and continuous improvement: misdefined, misunderstood. In: Best Practices in Lean Six Sigma Process Improvement. Wiley Publication, pp. 47–55 (2015). https://doi.org/10.1002/9781119196761.ch5
23. Sethia, C.S., Shende, P.N., Dange, S.S.: A case study on total productive maintenance in rolling mill. Int. J. Emerg. Technol. Innov. Res. **1**(5), 283–289 (2016). http://www.jetir.org/papers/JETIR1405007.pdf
24. Sharma, K., Thakar, G.D.: Productivity enhancement at an Indian iron and steel re-rolling mill. Perform. Improv. **56**(7), 25–34 (2017). https://doi.org/10.1002/pfi.21715
25. Sharma, K., Gera, G., Kumar, R., Chaudhary, H.K., Gupta, S.K.: An empirical study approach on TPM implementation in manufacturing industry. Int. J. Emerg. Technol. **3**(1), 18–23 (2012)
26. Sindhwani, R., Singh, P.L., Iqbal, A., Prajapati, D.K., Mittal, V.K.: Modeling and analysis of factors influencing agility in healthcare organizations: an ISM approach. In: Advances in Industrial and Production Engineering, pp. 683–696. Springer, Singapore (2019)
27. Sindhwani, R., Singh, P.L., Chopra, R., Sharma, K., Basu, A., Prajapati, D.K., Malhotra, V.: Agility evaluation in the rolling industry: a case study. In: Advances in Industrial and Production Engineering, pp. 753–770. Springer, Singapore (2019)
28. Sindhwani, R., Mittal, V.K., Singh, P.L., Kalsariya, V., Salroo, F.: Modelling and analysis of energy efficiency drivers by fuzzy ISM and fuzzy MICMAC approach. Int. J. Product. Qual. Manage. **25**(2), 225–244 (2018)
29. Singh, H., Gupta, N.K.: Kaizen Improvement in a Process Organization. Lambert Academic Publishing (2010)
30. Singh, J., Singh, H., Singh, G.: Productivity improvement using lean manufacturing in manufacturing industry of northern India. Int. J. Prod. Perform. Manage. **67**(8), 1394–1415 (2018). https://doi.org/10.1108/ijppm-02-2017-0037
31. Singh, P.L., Sindhwani, R., Dua, N.K., Jamwal, A., Aggarwal, A., Iqbal, A., Gautam, N.: Evaluation of common barriers to the combined lean-green-agile manufacturing system by two-way assessment method. In: Advances in Industrial and Production Engineering, pp. 653–672. Springer, Singapore (2019)

Identification of Factors for Lean and Agile Manufacturing Systems in Rolling Industry

Rahul Sindhwani, Rahul Dev Gupta, Punj Lata Singh, Vipin Kaushik, Sumit Sharma, Rakesh Kumar Phanden, and Rajender Kumar

Abstract The rolling industries have significant contribution to produce the sheet metal-based components. To obtain better outcome and enhanced performance, the implementation of integrated lean and agile manufacturing concept is highly important for such industries. In the present paper, the issues related to the influence of applying of lean and agile system have been recognized at the initial stage. In addition, ordinary issues (factors) were also explored at the later stage. The paper will be helpful for the authors and managers in identifying as well as developing the basis of LM and AM simultaneously and their impact on rolling industries.

Keywords Lean manufacturing · Agile manufacturing · Rolling industry · Factors

1 Introduction

The rolling process is a very simple and a common category of production methods in which irregular form of sheets of metals is converted in a consistent structure having a regular thickness. The present way of functioning of the rolling manufacturing firm is through either of two from agile thinking approach or lean manufacturing methodology. It is important to understand that the individual methods have various limitations corresponding to the advantages of both approaches. Thus, in the present

R. Sindhwani (✉) · V. Kaushik · S. Sharma · R. K. Phanden
Department of Mechanical Engineering, Amity School of Engineering and Technology, Amity University, Noida 201313, UP, India
e-mail: rsindhwani@amity.edu

R. D. Gupta
Department of Mechanical Engineering, MM Engineering College, MM University Mullana (Ambala), Ambala, India

P. L. Singh
Department of Civil Engineering, Amity School of Engineering and Technology, Amity University, Noida 201313, UP, India

R. Kumar
Mechanical Engineering Department, FET, MRIIRS, Faridabad, Haryana, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_33

work, the efforts have been made to assimilate the issue of both approaches. This attempt is made to explore the developments in production performance based on the quantitative and qualitative way of calculation the effective factors.

Fahmi and Hollingworth [21] illustrated that factors pertaining to LAMS system are interconnected and found to be supportive of each other. Maintaining the use of techniques like waste elimination, error proofing, root cause analysis and visualization (Visual plant), the facts pertaining to lean manufacturing are implemented. In this regard, as per Sharifi and Zhang [58], the term agility is said to be inclusive of two visions. First, it entails the complete integration of multiple business components and secondly, mandates a flexible relationship between manufacturing, organization, and people. As stated by Gunasekaran et al. [27], and Adeleye and Yusuf [5], the term agility is: Responsibility-Based Manufacturing (RBM) is responsible for making swift and continuous modifications in processes, which are older and in terms of product variety in such a way that earlier reconfigurations are not necessarily required to create any further customization. Gunasekaran et al. [27] depicted that agility dictates the changes in foundational principles of primitive operations and eliminates orthodox methods which are no longer found suitable. Yusuf et al. [80] and Vazquez-Bustelo et al. [77] state that in order to produce the products and services which are customer driven, the expertise plays the deciding role in an enterprise. These products and services are produced after thorough analysis of various competitive measures (speed, flexibility, and innovation, quality) and further integration with resources which are reconfigurable. In the light of above understanding, modeling, and analysis of implementation strategies, LM and AM in rolling industry are offered by the present study. As a foremost step, the literature review and study are conducted and consequently factors of LAMS were identified. Further, tabulation of the common factor was done. Thus, all such factors, which enhance the efficacy of leanness and agility with regard to rolling industries, need to be identified. In the present paper, the various sections are structured as follows: Sect. 2 entails the discussion with respect to literature review along with identifying various factors and consequently compiling the common factors related to LAMS. Further, the discussions pertaining to managerial implications are dealt with in Sect. 3.

2 Literature Review

2.1 Lean Manufacturing

Lean Manufacturing (LM) may understood to be an approach, which is based upon on reducing the wastage while utilizing minimum input without compromising with the quality of the product and productivity. In 1950, the concepts of LM were implemented in TOYOTA and popularly referred to as total productive maintenance [2]. The main emphasis in LM lies on the quality rather than on the quantity of the produced goods. It is pertinent to mention that though the goods produced using LM are in the equal quantity as that happens in the traditional methods of mass production but is accomplished by utilizing low capital investment, lesser raw material and tooling, reduced time with lesser floor space requirements.

LM may be regarded as amalgamation of multiple methodologies and techniques. Therefore, it is not prudent to apply the same methodology with respect to every sphere of production [57, 79]. LM found to be successful in those industries, which involve discrete manufacturing processes, e.g., in a process industry an automobile is pretty much difficult to replicate because of its incessant nature [2, 37]. The tools like TPM, Kaizen and TQM are utilized for products with low varieties while Kanban, JIT, and standardization are employed for the products having high variety [3]. With an ever-increasing competition between the local and foreign establishments on account of globalization, the role of LM is considered to be of more significance with regard to steel and rolling industrial sectors [4]. The integration of LM in rolling industry has been subjected to hinderance on account of multiple factors like inefficient top-level management, investment matters, ill-addressed worker grievances, outdated skill, inefficient training, poor quality controls, obsolete technologies and replete with complete apathy to planning at floor level which affected the competitiveness of factories [15, 17, 74]. Hence, there developed a need for incorporation of a wide range of factors that establish modern principles of management along with newer methods of quality control, etc. in a structured manner of consolidation [57]. After several rounds of deliberations and discussion with experts from diverse industries, researchers and academia, 10 significant lean manufacturing factors that should be integrated with rolling industry are hereby represented along with brief explanation in Table 1.

2.2 Agile Manufacturing

Agile manufacturing may be recognized as a novel manufacturing strategy with an ultimate aim to increase the competitiveness of an industry by creating high-quality products with minimal cost [28, 30]. The concept thus developed is actually an outcome of environmental change and includes following four dimensions: Offering value to demands of customers, generating a virtual platform that consolidates and encompasses core competencies of the involved firm, an acknowledgment of human skills and knowledge and lastly, the ability to respond and adapt to changes [28]. A wide variety of tools are utilized by AM which enables it to reconfigure and counter the challenges posed by market automation, TQM, mass customization, concurrent engineering, outsourcing, etc. [77]. It may also be regarded as an evolution of orthodox techniques of manufacturing e.g. mass production, lean and flexible types of manufacturing [23, 34]. It becomes necessary to mention here that for AM to succeed, the onus lies on management which can guide the firm through the path of competition by incorporating several novel strategies and understand the market trajectories along with continuous upgradation of technical expertise. In this backdrop, good IT practices should be enabled, which allows an organization to mould

Table 1 Factors considered and its description in rolling industries for lean manufacturing method

Factors	Description	References
Quality	Measurement errors, incorrect shape, cracks, tears and holes, bad quality of surface lead to rejection of parts and produce waste	[1, 4, 6, 17, 37, 46, 70]
Customer-focused product	Products should be designed to customer specification to avoid rejection and thus reduce waste from the supply chain. Customer choice can be known by market survey and inputs from the customer	[1, 4, 15, 17, 46, 57, 73]
Skills and expertise	A skilled staff can operate in diverse environment, accepts changes in role easily and take more responsibility helps to increase the leanness of a firm	[1, 15, 46, 69, 72, 76]
Financial capabilities	A healthy finance is needed to invest in training and development, consultancy, modernization, increasing efficiency and improving plant layout and simplifying the supply stream	[4, 15, 46, 68]
Leadership and management	A strong leadership is required to execute project management style to enable flexible organizational structure. It allows fostering skill and enhancing knowledge among the workforce	[1, 15, 18, 22, 37, 46]
Continuous flow	Identify the input/supplies properly so that unnecessary waste is not produced due to not fulfilling product parameters. Processes are adjusted in such a manner so that material undergoes uniform treatment to eliminate variation in the product after every stage	[1, 17, 33]
Streamlining supply	Procuring supply from a small number of reliable sources and integrating them to supply chain reduces lead time of the product	[15, 17, 20, 76, 78]
Competition	With the backdrop of globalization, there is increasing competition among producers. To stay competitive a producer has to implement lean manufacturing to bring down prices and reduce expenditure due to waste creation	[4, 15, 71]
Automatic information flow	Issuing orders and sending information through communication systems reduce lead time of the product. Plants are informed about new orders electronically. It empowers employees and improves production planning on the shop floor	[1, 2, 37]

(continued)

Table 1 (continued)

Factors	Description	References
Continuous improvement	Improvement must be made in measurement and control to provide better tolerance in products. Operating techniques and practices are continuously updated to integrate new manufacturing technologies. Process equipment is upgraded or purchased to improve efficiency, material handling and reduce fuel consumption	[1, 7, 15, 32, 46]

according to the changes with integration of multiple functions of business, labor and technical expertise [10]. As per the studies conducted by Gunasekaran [26, 27], short product life-cycle is regarded as one of the important factor after agility and is mainly occurred with the continuous advent of innovative technologies. Thus, AM may not be having a single most definition which is universally accepted. In this regard, various definitions are provided which are classified here into following three types [80]. These are put under one group on the basis of results (speed, response, flexibility etc.), operational practices (technology implementation, collaboration, incorporation etc.) and lastly the amalgamation of two classifications which will ultimately render the novel idea into a feasible concept.

It is further stated that duplication and application of several methodologies, which are being implemented in one firm cannot be done in a simple manner with respect to another firm. Therefore, there is a need to strategically analyze the strengths and shortcomings of an industry with regard to its present and future scope [39, 61]. In order to achieve the best possible results, the environment (economic, politics, technical etc.), resources (workforce, technical expertise, business, etc.) and capabilities (innovation, efficiency, quality etc.) need to be explored so as to complete the formulations for an industry. Moreover, the implementation of these formulations needs to be just and proper as an Industry's success will be dependent upon them [62]. It is pertinent to mention the eco-friendly feature of AM as they are inclusive of several environmental guidelines. Thus, after conducting a detailed review of the literature and taking into account, the observations of several researchers, Table 2 introduces 11 crucial factors for implementing AM in rolling industry.

2.3 Integrated Lean and Agile Manufacturing

In the absence of a conventional framework, the integration of LM and AM techniques is found to be problematic [38]. The environment that is conducive to Stability of demand allows for flourishing of LM while AM is more conducive to an environment having unstable features of demand. The penchant of a firm toward becoming lean or agile depends largely upon the reduction of lead times or reduced costs or quality

Table 2 Factors and its description in rolling industry for agile manufacturing

Factors	Description	References
Competitive environment	The firm can only survive if it provides customer-designed components and assistance in a highly unpredictable competitive climate by using its skill and competency	[13, 18, 25, 36, 56]
Customer requirements	Agile manufacturing enables a firm to use its capacities (technical base, human resource, information, quality) to meet customer requirements (new technology, competition, delivery time)	[19, 27, 54, 55, 80]
Swift response	Agility enables the firm to have strategies to give a swift response to changes (entry of new players in the market, new technology, government policies) which are permanent in nature	[25, 59, 77, 78]
Flexibility	Attention is given to flexibility of firm to respond to unique demand while maintaining its leanness	[8, 20, 30, 80]
Continuous change	A firm can become agiler by cooperating with other firms, which let each partner focus on their core strengths and them to prosper among continuous change	[5, 16, 26, 27, 30, 36, 40, 43, 78]
Continuous adjustment	Responsibility Based Manufacturing (RBM) is used to make rapid and continuous adjustments in older processes and product variety so that prior reconfigurations are not always required to make any customization	[5, 10, 24, 27, 30, 31, 49]
Product lifetime	Product lifetime is decreasing due to obsolete technology, design or customer needs. A firm needs to continuously improve and use the latest technology in its product to stay competitive and survive	[1, 5, 10, 15, 19, 25, 27, 31, 44, 48–50, 65]

(continued)

Table 2 (continued)

Factors	Description	References
Integrate developed technology	The use of technology like CAD/CAM/FMS/Automated Storage and Retrieval System (AS/RS)/Electronic Data Interchange(EDI)/Communication system & methods like partnerships/outsourcing increases the agility of firms	[1, 13, 17, 20, 28, 37, 46, 58, 60, 80]
Customer-driven product	The expertise of an enterprise is used to produce customer-driven product and services by analyzing competitive bases (speed, flexibility, innovation, quality) and integrating them with reconfigurable resources	[15, 16, 26, 40, 64, 77, 80]
Visibility	The implementation of quality and safety protocols along with post design development lends an insight to the firm's manufacturing strength and helps it become agiler	[15, 27, 52, 53, 57, 80]
Restructuring	A firm is always moving in the process of restructuring its management, business functions and technical base to become agile in changing market	[9, 31, 78]

of service. In this regard, positioning of the point of decoupling on supply chain determines a firm's degree towards becoming lean and agile [45]. The positioning of the point of decoupling can be obtained by taking into account the aspects of present demand and future predictions with further locating the order and assembly of the product in supply chain [31]. Moreover, the concentration should be placed in obtaining the parameter, which deals with who is acting as the receiver of the material from supply chain and whether there exists any end-user [45]. With regard to rolling industry, it can be stated that final goods are being obtained from the products that are supplied mainly to the manufacturing plant. The representation of seven common factors between LM and AM along with references is provided in Table 3.

2.4 Research Gaps and Highlights

A plethora of literature from the past of history exists on integrated lean-agile manufacturing eventually such considerate studies are focused at discrete manufacturing industries or concentrating just on the enactment of lean manufacturing in the rolled industry. Though an enormous literature review flourished with the concept on lean

Table 3 Mutual factors for implementation of lean and agile manufacturing in rolling industry

Sr. No.	Common factors	References
1	Customer prospective requirement	[4, 17, 27, 41, 46, 51]
2	Strategies and supervision of management	[1, 37, 42, 46, 77]
3	Expertise and services	[1, 13, 15, 25, 46, 54, 56]
4	Agility and alterations	[1, 5, 17, 24, 55, 67]
5	Consumer-focused production	[4, 9, 15, 31, 63, 75]
6	Value aided sustainability	[4, 66, 77]
7	Acceptance of recent trends in technologies	[1, 7, 32, 46]

manufacturing and agile manufacturing is not being executed and implemented in the rolling industries. Thus this research work is reinforced to discover the factors of manufacturing associated with integrated lean-agile for the existing rolling industries and fill the gap. However, the highlighted features of this research work are to discover the factors of integrated lean and agile manufacturing.

3 Result and Discussion

This research work emphasizes and stimulates on the common factors affecting manufacturing of rolling industries. The basic requirement to facilitate the application is to understand the importance and its inter-rapport of the Lean Manufacturing and Agile Manufacturing. The research outcome of this paper will be effectively advantageous to the authors and managers in identifying and developing as well the origin of Lean Manufacturing and Agile Manufacturing simultaneously and their bearing impact on rolling industries. The future scope work can be associated with depiction of more factors entirely examined for further analysis. This paper is focused especially on rolling industries established in India.

References

1. Abdullah, F.M.: Lean Manufacturing Tools and Techniques in the Process Industry with a Focus on Steel, Diss. The University of Pittsburgh (2003)
2. Abdulmalek, F.A., Rajgopal, J.: Analyzing the benefits of lean manufacturing and value stream mapping via simulation: a process sector case study. Int. J. Prod. Econ. **107**(1), 223–236 (2007)
3. Abdulmalek, F.A., Rajgopal, J., Needy, K.L.: A classification scheme for the process industry to guide the implementation of lean. Eng. Manage. J. **18**(2), 15–25 (2006)
4. Ahmad, K.I., Shrivastav, R.L., Pervez, S., Khan, N.P.: Analysing quality and productivity improvement in steel rolling industry in central India. IOSR J. Mechan. Civil Eng. (IOSR-JMCE) 6–11 (2014)
5. Adeleye, E.O., Yusuf, Y.Y.: Towards agile manufacturing: models of competition and performance outcomes. Int. J. Agile Syst. Manage. **1**(1), 93–110 (2006)

6. Belekoukias, I., Garza-Reyes, J.A., Kumar, V.: The impact of lean methods and tools on the operational performance of manufacturing organizations. Int. J. Prod. Res. **52**(18), 5346–5366 (2014)
7. Bessant, J., Caffyn, S.: High-involvement innovation through continuous improvement. Int. J. Technol. Manage. **14**(1), 7–28 (1997)
8. Booth, R.: Agile manufacturing. Eng. Manage. J. **6**(2), 105–112 (1996)
9. Bullinger, H.J.: Turbulent times require creative thinking: new European concepts in production management. Int. J. Prod. Econ. **60**, 9–27 (1999)
10. Burgess, T.F.: Making the leap to agility: defining and achieving agile manufacturing through business process redesign and business network redesign. Int. J. Oper. Prod. Manage. **14**(11), 23–34 (1994)
11. Chand, M., Raj, T., Shankar, R.: Weighted-ISM technique for analyzing the competitiveness of uncertainty and risk measures in the supply chain. Int. J. Logist. Syst. Manage. **21**(2), 181–198 (2015)
12. Chand, M., Raj, T., Shankar, R.: Analysing the operational risks in the supply chain by using weighted interpretive structure modelling technique. Int. J. Serv. Oper. Manage. **18**(4), 378–403 (2014)
13. Cho, H., Jung, M., Kim, M.: Enabling technologies of agile manufacturing and its related activities in Korea. Comput. Ind. Eng. **30**(3), 323–334 (1996)
14. Cleveland, J.N., Murphy, K.R., Williams, R.E.: Multiple uses of performance appraisal: prevalence and correlates. J. Appl. Psychol. **74**(1), 130–135 (1989)
15. Crute, V., Ward, Y., Brown, S., Graves, A.: Implementing Lean in aerospace—challenging the assumptions and understanding the challenges. Technovation **23**(12), 917–928 (2003)
16. Devor, R., Graves, R., Mills, J.J.: Agile manufacturing research: accomplishments and opportunities. IIE Trans. **29**(10), 813–823 (1997)
17. Dhandapani, V., Potter, A., Naim, M.: Applying lean thinking: a case study of an Indian steel plant. Int. J. Logist. Res. Appl. **7**(3), 239–250 (2004)
18. Dutta, G., Kumar, R., Sindhwani, R., Singh, R.K.: Digital transformation priorities of India's discrete manufacturing SMEs—a conceptual study in perspective of Industry 4.0. Compet. Rev. Int. Bus. J. (2020)
19. Elkins, D.A., Huang, N., Alden, J.M.: Agile manufacturing systems in the automotive industry. Int. J. Prod. Econ. **91**(3), 201–214 (2004)
20. Elmoselhy, S.A.: Hybrid lean–agile manufacturing system technical facet, in the automotive sector. J. Manuf. Syst. **32**(4), 598–619 (2013)
21. Fahmi, S.M., Hollingworth, D.G.: Revisiting the roots of JIT and LEAN manufacturing. J. Supply Chain Oper. Manage. **10**(2), 29 (2012)
22. Fullerton, R.R., Kennedy, F.A., Widener, S.K.: Management accounting and control practices in a lean manufacturing environment. Acc. Organ. Soc. **38**(1), 50–71 (2013)
23. Goldman, S.L., Nagel, R.N.: Management, technology and agility: the emergence of a new era in manufacturing. Int. J. Technol. Manage. **8**(1–2), 18–38 (1993)
24. Gould, P.: What is agility? Manuf. Eng. **76**(1), 28–31 (1997)
25. Gopalakrishnan, K., Yusuf, Y.Y., Musa, A., Abubakar, T., Ambursa, H.M.: Sustainable supply chain management: a case study of British Aerospace (BAe) Systems. Int. J. Prod. Econ. **140**(1), 193–203 (2012)
26. Gunasekaran, A., Yusuf, Y.Y.: Agile manufacturing: a taxonomy of strategic and technological imperatives. Int. J. Prod. Res. **40**(6), 1357–1385 (2002)
27. Gunasekaran, A., Tirtiroglu, E., Wolstencroft, V.: An investigation into the application of agile manufacturing in an aerospace company. Technovation **22**(7), 405–415 (2002)
28. Gunasekaran, A.: Agile manufacturing: enablers and an implementation framework. Int. J. Prod. Res. **36**(5), 1223–1247 (1998)
29. Gunasekaran, A., Lai, K.H., Cheng, T.E.: Responsive supply chain: a competitive strategy in a networked economy. Omega **36**(4), 549–564 (2008)
30. Gunasekaran, A.: Agile manufacturing: a framework for research and development. Int. J. Prod. Econ. **62**(1), 87–105 (1999)

31. Helo, P.: Managing agility and productivity in the electronics industry. Ind. Manage. Data Syst. **104**(7), 567–577 (2004)
32. Kano, M., Nakagawa, Y.: Data-based process monitoring, process control, and quality improvement: recent developments and applications in the steel industry. Comput. Chem. Eng. **32**(1), 12–24 (2008)
33. Karim, A., Arif-Uz-Zaman, K.: A methodology for effective implementation of lean strategies and its performance evaluation in manufacturing organizations. Bus. Process Manage. J. **19**(1), 169–196 (2013)
34. Kidd, P.T.: Agile Manufacturing: Forging New Frontier. Addison-Wesley Longman Publishing Co., Inc. (1995)
35. Kumar, K., Dhillon, V.S., Singh, P.L., Sindhwani, R.: Modeling and Analysis for Barriers in Healthcare Services by ISM and MICMAC Analysis. In: Advances in Interdisciplinary Engineering, pp. 501–510 (2019)
36. Leite, M., Braz, V.: Agile manufacturing practices for new product development: industrial case studies. J. Manuf. Technol. Manage. **27**(4), 560–576 (2016)
37. Mahapatra, S.S., Mohanty, S.R.: Lean manufacturing in continuous process industry: an empirical study. J. Sci. Ind. Res. **66**(1), 19–27 (2007)
38. Mason-Jones, R., Naylor, B., Towill, D.R.: Engineering the agile supply chain. Int. J. Agile Manage. Syst. **2**(1), 54–61 (2000)
39. McCarthy, I.: Manufacturing classification: lessons from organizational systematics and biological taxonomy. Integr. Manuf. Syst. **6**(6), 37–48 (1995)
40. Meade, L.M., Sarkis, J.: Analyzing organizational project alternatives for agile manufacturing processes: an analytical network approach. Int. J. Prod. Res. **37**(2), 241–261 (1999)
41. Mittal, V.K., Sindhwani, R., Kapur, P.K.: Two-way assessment of barriers to lean-green manufacturing system: insights from India. Int. J. Syst. Assur. Eng. Manage. **7**(4), 400–407 (2016)
42. Mittal V.K., Sindhwani R., Kalasariya V., Salroo F., Sangwan K.S., Singh P.L.: Adoption of integrated lean-green-agile strategies for modern manufacturing systems. Procedia CIRP **61**(1), 463–468 (2017)
43. Mittal, V.K., Sindhwani, R., Shekhar, H., Singh, P.L.: Fuzzy AHP model for challenges to thermal power plant establishment in India. Int. J. Oper. Res. **34**(4), 562–581 (2019)
44. Mittal, V.K., Sindhwani, R., Singh, P.L., Kalsariya, V., Salroo, F.: Evaluating significance of green manufacturing enablers using MOORA method for indian manufacturing sector. In: Singh, S., Raj, P., Tambe, S. (Eds.) Proceedings of the International Conference on Modern Research in Aerospace Engineering. Lecture Notes in Mechanical Engineering. Springer, Singapore. pp. 303–314 (2018)
45. Naylor, J.B., Naim, M.M., Berry, D.: Leagility: integrating the lean and agile manufacturing paradigms in the total supply chain. Int. J. Prod. Econ. **62**(1–2), 107–118 (1999)
46. Nordin, N., Deros, B.M., Wahab, D.A.: A survey on lean manufacturing implementation in Malaysian automotive industry. Int. J. Innov. Manage. Technol. **1**(4), 374 (2010)
47. Phanden, R.K., Sindhwani, R., Kalsariya, V., Salroo, F.: Selection of material for electric arc spraying by using hierarchical Entropy- TOPSIS approach. Int. J. Prod. Qual. Manage. **26**(3), 276–289 (2019)
48. Potdar, P.K., Routroy, S.: Performance analysis of agile manufacturing: a case study on Indian auto component manufacturer. Measur. Bus. Excellence **21**(2) (2017)
49. Power, D.: Supply chain management integration and implementation: a literature review. Suppl. Chain Manage. Int. J. **10**(4), 252–263 (2005)
50. Phanden, R.K., Jain, A.: Assessing the impact of changing available multiple process plans of a job type on mean tardiness in job shop scheduling. Int. J. Adv. Manuf. Technol. **80**(9–12), 1521–1545 (2015)
51. Phanden, R.K.: Multi agents approach for job shop scheduling problem using genetic algorithm and variable neighborhood search method. In: Proceedings of the 20th world multi-conference on systemics, cybernetics, and informatics (2016)

52. Phanden, R.K., Demir, H.I., Gupta, R.D.: Application of genetic algorithm and variable neighborhood search to solve the facility layout planning problem in job shop production system. In: 2018 7th International Conference on Industrial Technology and Management (ICITM). IEEE (2018a)
53. Phanden, R.K., Saharan, L.K., Erkoyuncu, J.A.: Simulation based cuckoo search optimization algorithm for flexible job shop scheduling problem. In: Proceedings of the International Conference on Intelligent Science and Technology (2018b)
54. Phanden, R.K. Ferreira, J.C.E.: Biogeographical and variable neighborhood search algorithm for optimization of flexible job shop scheduling. In: Advances in Industrial and Production Engineering. Springer, Singapore, pp. 489–503 (2019a)
55. Phanden, R.K., Palková, Z., Sindhwani, R.: A framework for flexible job shop scheduling problem using simulation-based cuckoo search optimization. In: Advances in Industrial and Production Engineering. Springer, Singapore, pp. 247–262 (2019b)
56. Sanchez, L.M., Nagi, R.: A review of agile manufacturing systems. Int. J. Prod. Res. **39**(16), 3561–3600 (2001)
57. Shah, R., Ward, P.T.: Lean manufacturing: context, practice bundles, and performance. J. Oper. Manage. **21**(2), 129–149 (2003)
58. Sharifi, H., Zhang, Z.: Agile manufacturing in practice-application of a methodology. Int. J. Oper. Prod. Manage. **21**(5/6), 772–794 (2001)
59. Sindhwani, R., Malhotra, V.: Overview and drivers of agile manufacturing system: a review. Int. J. Market. Technol. **3**(12), 144–154 (2013)
60. Sindhwani, R., Malhotra, V.: Lean and agile manufacturing system barriers. Int. J. Adv. Res. Innov. **3**(1), 110–112 (2015)
61. Sindhwani, R., Malhotra, V.: Barriers evaluation for agile manufacturing system with fuzzy performance importance index approach. Int. J. Agile Syst. Manage. **9**(5), 292–301 (2016a)
62. Sindhwani, R., Malhotra, V.: Modelling the attributes affecting design and implementation of agile manufacturing system. Int. J. Process Manage. Benchmarking **6**(2), 216–234 (2016b)
63. Sindhwani, R., Mittal, V.K., Singh, P.L., Kalsariya, V., Tewari, A.: A hybrid approach for selection of most sustainable cooking fuel (MSCF) in Indian context. Int. J. Knowl. Manage. Tourism Hosp. **1**(2), 226–240 (2017)
64. Sindhwani, R., Malhotra, V.: A framework to enhance agile manufacturing system: a total interpretive structural modelling (TISM) approach. Benchmarking: Int. J. **24**(2), 467–487 (2017a)
65. Sindhwani, R., Malhotra, V.: Modelling and analysis of agile manufacturing system by ISM and MICMAC analysis. Int. J. Syst. Assur. Eng. Manage. **8**(2), 253–263 (2017)
66. Sindhwani, R., Malhotra, V.: An integrated approach for implementation of agile manufacturing system in an indian manufacturing industry. Benchmarking: Int. J. **25**(4), 1106–1120 (2018)
67. Sindhwani, R., Mittal, V.K., Singh, P.L., Kalsariya, V., Salroo, F.: Modelling and analysis of energy efficiency drivers by Fuzzy ISM and Fuzzy MICMAC approach. Int. J. Prod. Qual. Manage. **25**(2), 225–244 (2018)
68. Sindhwani, R., Mittal, V.K., Singh, P.L., Aggarwal, A., Gautam, A.: Modelling and analysis of barriers affecting the implementation of lean green agile manufacturing system (LGAMS). Benchmarking: Int. J. **26**(2), 498–529 (2019a)
69. Sindhwani, R., Singh, P.L., Chopra, R., Sharma, K., Basu, A., Prajapati, D.K., Malhotra, V.: Agility evaluation in the rolling industry: a case study. in advances in industrial and production engineering. In: Lecture Notes in Mechanical Engineering, pp. 753–770 (2019b)
70. Sindhwani, R., Singh, P.L., Prajapati, D.K., Iqbal, A., Phanden, R.K., Malhotra, V.: Agile system in health care: literature review. In: Advances in Industrial and Production Engineering, Lecture Notes in Mechanical Engineering, pp. 643–652 (2019c)
71. Sindhwani, R., Singh, P.L., Iqbal, A., Prajapati, D.K., Mittal, V.K.: Modeling and analysis of factors influencing agility in healthcare organizations: an ISM approach. In: Advances in Industrial and Production Engineering, Lecture Notes in Mechanical Engineering, pp. 683–696 (2019d)

72. Sindhwani, R., Singh, P.L., Kaushik, V., Sharma, S., Phanden, R.K.: Analysis of barriers to lean–green manufacturing system (LGMS): a multi-criteria decision-making approach. In: Advances in Intelligent Manufacturing, pp. 181–188. Springer, Singapore (2020a)
73. Sindhwani, R., Singh, P.L., Kaushik, V., Sharma, S., Phanden, R.K., Prajapati, D.K.: Ranking of factors for integrated lean, green and agile manufacturing for indian manufacturing SMEs. In: Advances in Intelligent Manufacturing (pp. 203–219). Springer, Singapore (2020b)
74. Singh, B., Garg, S.K., Sharma, S.K., Grewal, C.: Lean implementation and its benefits to production industry. Int. J. Lean Six Sigma **1**(2), 157–168 (2010)
75. Singh, P.L., Sindhwani, R., Dua, N.K., Jamwal, A., Aggarwal, A., Iqbal, A., Gautam, N.: Evaluation of common barriers to the combined lean-green-agile manufacturing system by two-way assessment method. In: Advances in Industrial and Production Engineering, Lecture Notes in Mechanical Engineering, pp. 653–672 (2019)
76. Thanki, S.J., Thakkar, J.: Status of lean manufacturing practices in Indian industries and government initiatives: a pilot study. J. Manuf. Technol. Manage. **25**(5), 655–675 (2014)
77. Vazquez-Bustelo, D., Avella, L., Fernández, E.: Agility drivers, enablers and outcomes: an empirical test of an integrated agile manufacturing model. Int. J. Oper. Prod. Manage. **27**(12), 1303–1332 (2007)
78. Vinodh, S., Devadasan, S.R., Vimal, K.E.K., Kumar, D.: Design of agile supply chain assessment model and its case study in an Indian automotive components manufacturing organization. J. Manuf. Syst. **32**(4), 620–631 (2013)
79. Womack, J.P., Jones, D.T.: Lean thinking: banish waste and create wealth in your corporation. Simon and Schuster (2010)
80. Yusuf, Y.Y., Sarhadi, M., Gunasekaran, A.: Agile manufacturing: the drivers, concepts, and attributes. Int. J. Prod. Econ. **62**(1), 33–43 (1999)

Development of an Industry 4.0-Enabled Biogas Plant for Sustainable Development

B. Rajesh Reddy, Sumit Gupta, and Rakesh Kumar Phanden

Abstract In India, apart from having huge population, it has limited skilled workers. The handling of organic waste requires a lot of care since it may lead to unwanted diseases if not properly handled. This research study employs a modern approach of Industry 4.0 in order to eliminate human intervention in the process of production using advanced concepts and IoT devices. It is proposed to use the old technique of producing biogas from organic waste and combines it with modern techniques to make an efficient and reliable process and supporting the nation's most crucial requirement of energy. It can be concluded that the proposed work may help the nation's sanitation and sustainable development initiative.

Keywords Industry 4.0 · Biogas · Cyber physical system · Sustainable development

1 Introduction

India is a nation that struggles to meet its energy needs as the population of India is very high and fossil reserves are very less. India being the second-most populous country in the world produces a significant amount of waste, which is disposed of in a very inefficient way leading to the unhygienic environment to eradicate this, all the organic waste produced can be converted to useful biomethane and the digested slurry acts as a great fertilizer for agriculture [1]. Organic waste comprises about 51% of the total waste produced, amounting to about 81 billion tons per year, this is waste usually left to decompose in the open or disposed into the sea [2]. This way of disposal leads to environmental pollution in different ways. The discarded waste decomposes in the open producing methane, which is a greenhouse gas; this gas settles on the topmost layer of the atmosphere and acts as a blanket, which restricts the heat radiation from leaving the planet's atmosphere causing global warming. Industry 4.0 is a modern approach to eliminate human intervention in the process of

B. Rajesh Reddy · S. Gupta (✉) · R. K. Phanden
Department of Mechanical Engineering, ASET, Amity University Noida, Noida 201313, UP, India
e-mail: sumitgupta2007@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_34

production of biomethane. This research focuses to develop a model based on the existing models, which are more efficient and optimize the most factors associated with the production facility for sustainable development.

2 Literature Review

Industry 4.0 is dependent mostly on data analytics and real-time systems, which monitor the process and act accordingly. By employing Industry 4.0, a lot of human work can be reduced, which is very crucial in today's world as there is a lack of skilled labor available and also prevent an unforeseen thing happening due to unethical use of labor to meet the demands of the market.

Biomethane, when compared with conventional fossil fuels, is eco-friendlier and abundant in nature and also comparing it to the present day batteries, which employ rare earth metals to hold the energy, it is very eco-friendly and also has very high energy density making it a great alternative for both [3]. Dahunsi and Oranusi [1] focus the study on the ever-increasing cost of fossil fuels and its attendant pollution menace and have provided the pedigree to consider alternative sources of energy. Bouallagui et al. [3] suggest that anaerobic digestion represents a commercially viable process to convert FVW to methane gas, a useful energy source. Arthur et al. [4] focus the study on the associated harmful environmental, health and social effects with the use of traditional biomass and fossil fuel has enhanced the growing interest in the search for an alternate cleaner source of energy globally. The main drawback in the production of biomethane is the barriers associated with it as there stands a social stigma when it comes to waste handling and usage [5, 6]. There has not been any significant development of biomethane facilities in terms of engineering, they are mostly focused on biological terms as there is a gap between two fields and this research focuses on building this bridge between these two fields by using the research developments to date in both biological and engineering fields [7, 8].

3 Methodology

The problem formulation was made using the current problems of the society, which are majorly environmental and sanitation which go hand in hand mostly, the problem had been identified and then the problem was defined and objectives had been set, model was build using CAD and had been collaborated by the existing design and modifications, the data were collected using the literature available from international conferences and journals, which were used in formulating the algorithm and the architecture of the system. The model has been conceptualized using the following systemic process. Figure 1 shows the concept of the adopted model.

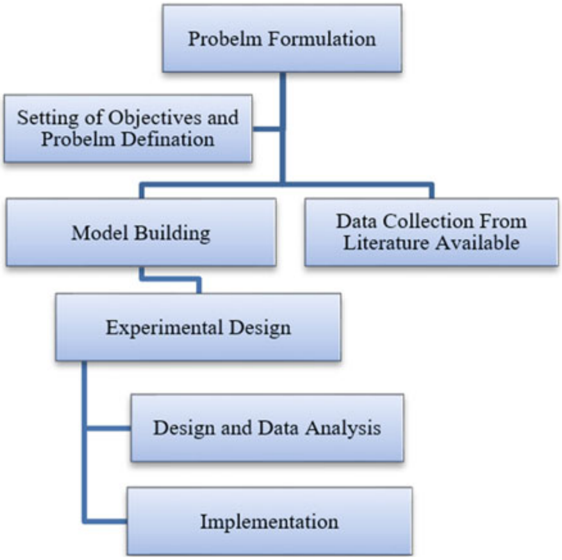


Fig. 1 Model conceptualization

3.1 Fabrication of Biogas Plant

In traditional biogas plant, inlet and outlet have not closed with a valve. So, the efficiency of methane was less. So, to increase the efficiency of biogas, the new fabrication model has been closed with a knife-edge valve with pneumatic actuator and the outlet valve position has been changed. The gas outlet has changed with a solenoid valve. Because in the old model, they use ball-operated valve that to have open and close manually. In the traditional model, the digester is fully closed so the temperature, pressure, gas, P_H cannot be measure and we have to calculate manually for gas production. So, in the new model, every parameter is monitored online by using a sensor that is implemented inside the digester. By the sensor value, the actuator is actuated according to condition requirements for the bioplant. In the new model, water scrubber has added for purifying CO_2 and H_2S that increase the efficiency of methane gas.

3.2 Digester Modifications and Specifications

Table 1 presents the comparison of the traditional model and the newly proposed model for the biogas plant. In the modified design, the process has been changed from an uncontrolled process to a controlled process, the slurry entering the digester does not go out until it is completely digested making it an efficient fertilizer producer. The controlled process also ensures that the slurry does not go out until the complete gas has been produced from the organic matter making it efficient gas producer for

Table 1 Comparison of two biogas plants

Specification of traditional model (Deenbandhu biogas plant)	Specification of the newly proposed model
Inlet pipe diameter—8 inch	Inlet pipe diameter—3 inch
Outlet pipe diameter—10 Inch	Outlet pipe diameter—3 inch
Digester length—11 ft	Digester length—11 ft
Dome above field—3 ft	Dome above field—3 ft
Outlet gas pipe diameter—1 inch	Outlet gas pipe diameter—1/2 inch
Outlet tank length—2 m	Outlet tank length—2 m
Outlet tank height–2 m	Outlet tank height—2 m
Digester inner diameter—2 m	Digester inner diameter—4 m
Digester outer diameter—2.5 m	Digester outer diameter—5 m
Digester volume—80%	Digester volume—80%
Gas storage volume—20%	Gas storage volume—20%

a long time compared with the traditional method, which requires everyday input of slurry. The digester also has a moisture controller that controls the moisture of the slurry maintaining it between 55 and 45%. The digester does not require time to time refilling of slurry as it takes slurry if required only and reduces human effort and work hours and performing more efficiently.

3.3 Water Scrubbing

The system purifies the produced gas to pure methane by a technique called water scrubbing the water scrubbing is mostly used in industries to purify carbon dioxide from the emissions, the same process is used to remove carbon dioxide in the biogas produced in the system, the water is atomized and sprayed in a counter direction of the gas flow reacting with the gas, the carbon dioxide and other impurities are dissolved in the water, as methane does not react with water it passes through the water resulting in pure methane gas. The water droplets moving with the methane are removed by a demystifier and only pure methane enters the process of compression (refer Figs. 2 and 3).

The water scrubber has been manufactured in a very economical way by the use of HDPE pipes and end cups, which have been coupled with ½ inch pipe for the flow of gas and water according to the process. Figure 2 explains the purification process, it is a pictographic cross-section representation of the process. Figure 3 shows the real image of the prototype manufactured.

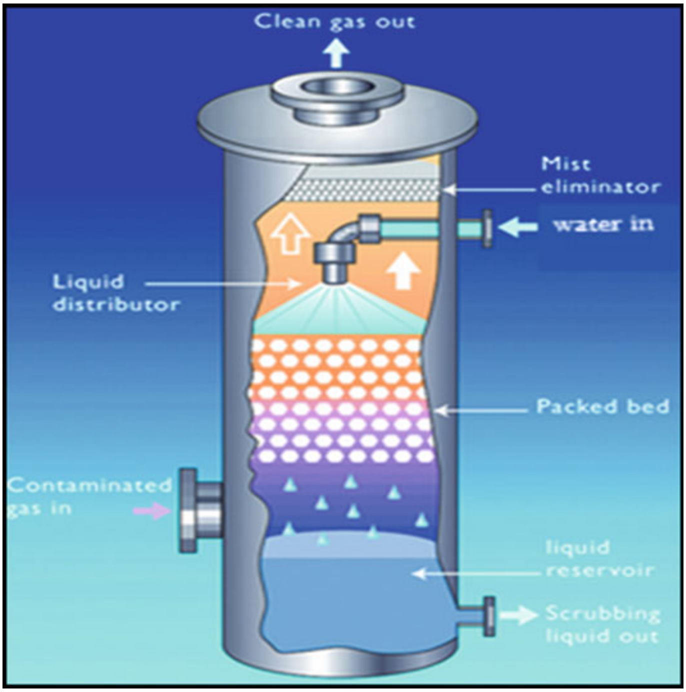


Fig. 2 Water scrubbing process

Fig. 3 The prototype of water scrubber

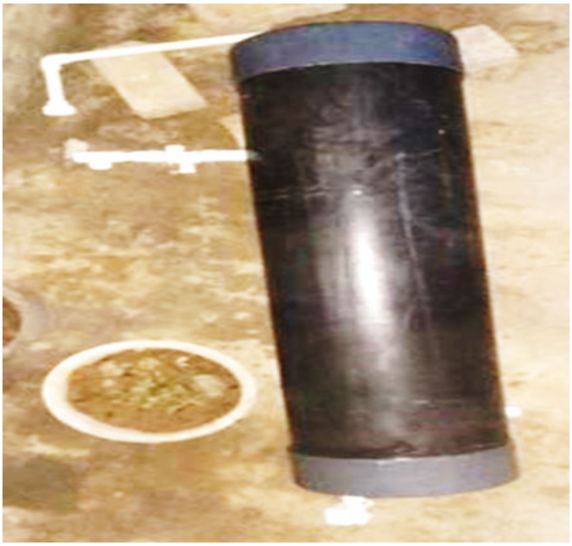


Fig. 4 Pneumatic actuated Knife valve

3.4 Pneumatic Actuated Knife Valve

The pneumatic actuated knife valve has been used to regulate the slurry flow inside the digester and also to hold the slurry in place until it is completely digested. The valve structure is made of cast iron and is coupled with a pneumatic cylinder made of stainless steel and aluminum as shown in Fig. 4.

3.5 Gas Storage Tank

The system has a gas storage capability that stores the gas in a cylinder after compression this compression is attained by the help of a gas compressor. The compressor compresses the gas and stores the gas in the gas tank, the gas tank also features a nonreturn valve and gas level indicator, which indicates the amount of gas stored in the gas.

3.6 Process of Production

The biomethane is produced by going through different processes as shown in Fig. 5, the digester produces biogas that is transferred to water scrubber by the pressure in the digester, the water scrubber removes the impurities present in the biogas and makes it pure methane, this methane is compressed and stored in the storage tank.

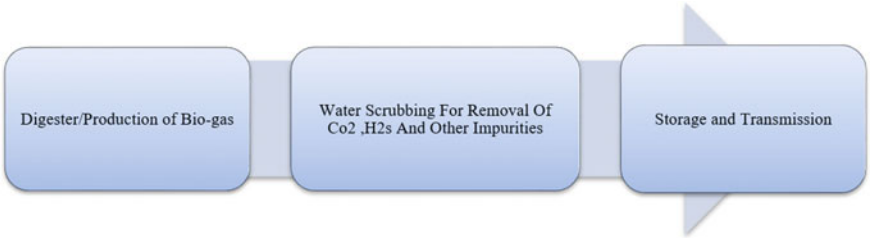


Fig. 5 Production process

Table 2 List of electronic components used

S. No.	Component	Purpose
1	DHT11	Sensing temperature and humidity of the digester
2	RC-A-353	pH sensing of the slurry
3	MQ5	The gas concentration of the digester
4	BMP280	Pressure sensing inside the digester
5	Arduino Nano	To sense from the sensor and control the actuators
6	NodeMCU	Receive the values from Arduino and transmit it to the Internet via IOT TWEET
7	½ Inch Solenoid valve	To control the flow of gas and water in the system
8	8 Channel relay modules	To control the actuators according to the input provided by the controller
9	Moisture sensor	To sense the moisture of the slurry

3.7 Implementation of Cyber-Physical System (CPS) in the Plant

The plant has been connected to sensors, controllers and actuators, which control the process of production, this system is also connected to the internet and the production facility can be viewed from any corner of the world. This is made possible by the use of electronic systems in the digester, scrubber, and storage facility. Table 2 shows the list of electronics components that are used in the production facility.

3.8 System Architecture and Working

Figure 6 shows the flowchart of system architecture and its working.

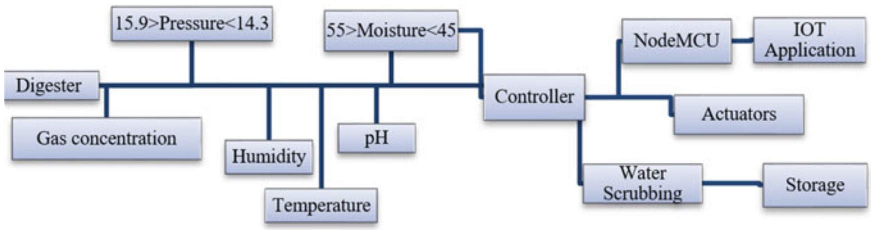


Fig. 6 Flowchart of system architecture and its working

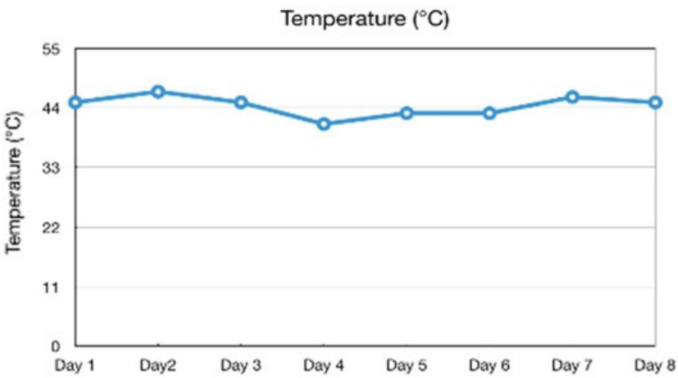


Fig. 7 Temperature variation in time

4 Data collection and Analysis

Data have been collected for 8 days with different time of a day (in morning, afternoon and night). The following data have been collected using the sensors deployed inside the digester and data have been transmitted to the IoT application. The data have been collected on a real-time system. Figures 7, 8, 9, 10, 11 and 12 show the temperature variation in time, humidity variation in time, moisture variation in time, pH variation in time, gas variation in time and pressure variation in time, respectively.

5 Results, Discussion and Comparison

The efficiency of different factors affecting the yield of biogas has been considered.

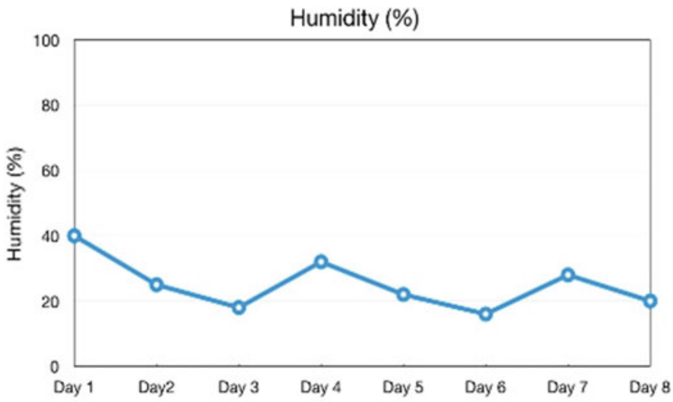


Fig. 8 Humidity variation in time

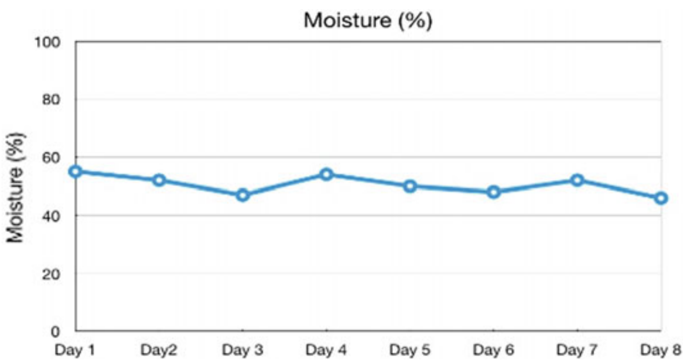


Fig. 9 Moisture variation in time

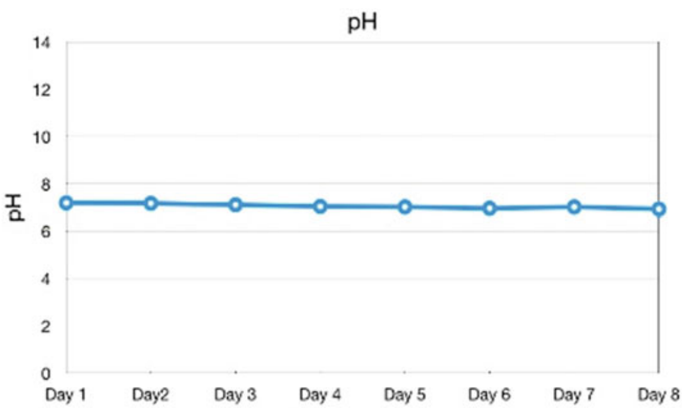


Fig. 10 pH variation in time

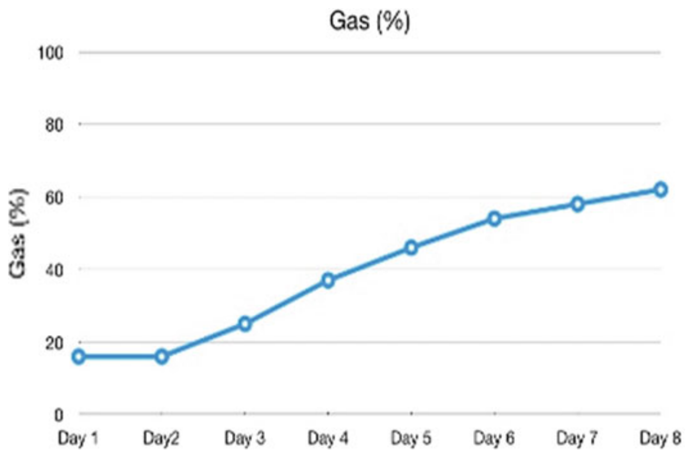


Fig. 11 Gas variation in time

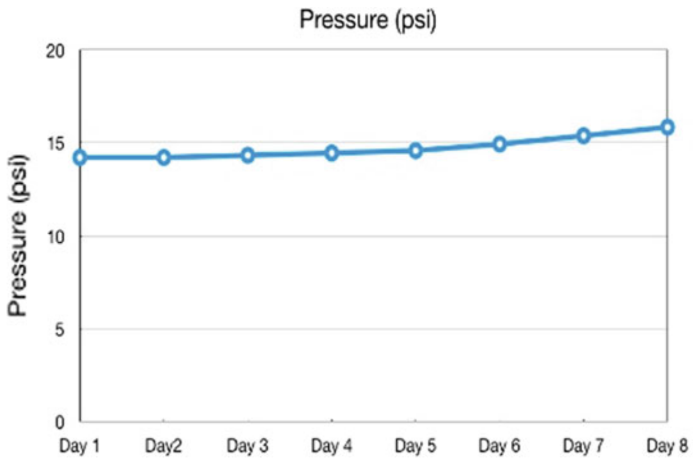


Fig. 12 Pressure variation in time

5.1 Heat Efficiency

The model is very heat efficient as the temperature of the system is between 41 and 47 °C, as per the literature the most optimum temperature for a biogas plant is between 37 and 55 °C, at this temperature the maximum yield is obtained and this can also be observed with the rise in pressure and gas concentration inside the digester in a period of time. Comparing it to similar conventional model, the temperature inside the digester is very high and efficient, the temperature of the conventional model is at a maximum of 35 °C, however, the new design holds at the minimum of 41 °C and a maximum of 47 °C. There is the constant input of slurry and output of undigested slurry, the temperature decreases as the heat is lost through the outgoing slurry and also in the process of heating the newly taken slurry, it can be verified that the new system is more heat-efficient as it is a controlled process.

5.2 Humidity

The humidity is observed to be varying with time. The humidity is mostly observed to be falling as the gas concentration and pressure increases, this indicates the humidity or the water particles in the gas produced is very low which is a good indication that the gas produced has a higher calorific value. There is a significant drop in the humidity of gas as the days' increases and it can also be observed that the humidity rises on the introduction of water to maintain the moisture of the slurry, as water is introduced into the slurry the temperature of the slurry also drops a little, the humidity on other hand increases as there are unsettled water particles in the gas, the humidity is observed to fall significantly the next day as the water particles have settled and the temperature also increases.

5.3 Moisture and pH

The moisture is observed to be in the prespecified range as the moisture of the slurry is controlled by the controller, as soon as the moisture drops below 45% water is added to increase the moisture to 55%, As per the literature, the maximum yield is when the moisture is above 45 and 60%, and the result of the system is observed to be efficiently maintaining the required moisture for the maximum yield. When compared with the conventional model, the system is highly efficient in maintaining the moisture as in the conventional model, the moisture reduces due to seepage of water into concrete and also due to the reaction with slurry to produce methane, as the water content in the slurry is maintained this in turn also help maintain the pH of the system between 6.8 and 7.2, which is the most optimum desired pH for the maximum yield.

5.4 Pressure and Gas concentration

The pressure and gas concentration of the system rise as the system produces gas, the gas concentration attained is about 62%, which explains the composition of biogas to have about 62% of methane and 38% impurities such as carbon dioxide, hydrogen sulfide and a negligible amount of water particles, which in turn will be purified by the water scrubber and the dehumidifier which have been installed for purification. The purity of the gas is about 95–99% after purification. By applying the real gas

Table 3 Comparison between conventional plant and Industry 4.0 enabled plant

Factors	Conventional plant [5]	Industry 4.0 enabled plant
Slurry input M^3	4 + Daily input of about 0.3 M^3	4
Biogas output IN KG calculated for 8 days	3.52	7.08
Biogas output IN M^3	2.74	5.94
Methane output IN M^3	1.72	3.72
Methane output	1.14 kg	2.5 kg

equation, $PV = nRT$ we can calculate the amount of biogas produced by the digester. Where P is the pressure, V is the volume, n is the number of moles, R is the real gas constant and T is the temperature.

1 mole = 24 l of gas.

From the data collected, we have, $P = 15.83$ PSI, $T = 45$ °C, $V = 6$ M^3.

By applying the Ideal gas equation, the total number of moles of gas produced is 247.56 mol. $n = 247.56$.

Volume of gas produced = 247.56 × 24 = 5941.44 l.

Gas concentration obtained is 62% hence the total pure methane produced = 5941.44 × 0.62 = 3683.69 l.

- The density of biogas is 1.18 kg/M^3.
- The density of methane 16.043 g/mole.
- The total weight of gas produced = 6 × 1.18 = 7.08 kg.
- The total amount of pure methane produced is about 2.5 kg for the input of 4 M^3 of cow dung.
- The total methane produced in 8 days is about 2.5 kg or 3.7 M^3.

The new plant seems to be harvesting the biogas at a much faster rate than the traditional model as shown in Table 3 and Fig. 13 because the factors affecting the have been controlled and are acting favorably to the bacteria to consume the slurry at a faster rate accelerating the rate of harvest.

6 Conclusion

After examining the data that have been attained, it can be concluded that the system's heat efficiency, moisture control and gas yield have been significantly improved compared with the conventional model. The process involves human skill to gain efficiency and timely monitoring, which increases the cost of maintenance. However,

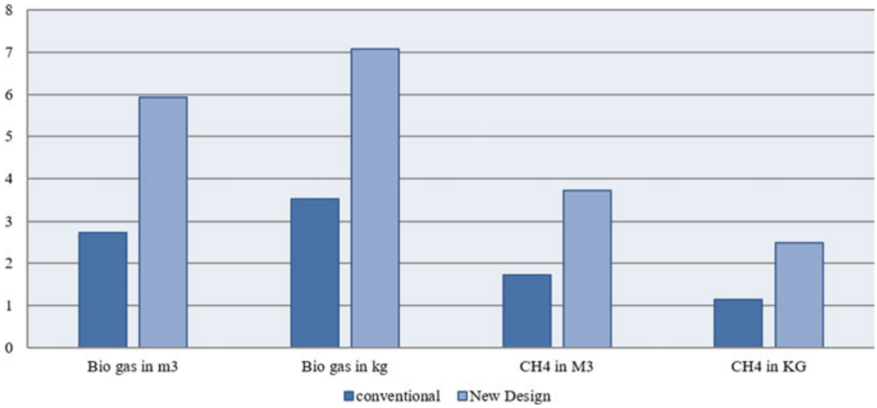


Fig. 13 Graphical comparison of conventional and new design

in the automated plant, human work is minimum and obtaining the maximum possible output. The potential threat of methane gas to the environment is reduced if this is employed in large scale and this system can also be used in municipal waste treatment plants to produce biomethane with human excreta making it a very efficient way of handling waste. The system is tested with cow dung as a biofuel, there is a lot of scope for this system to be used in urban areas where there is a huge population to handle wastewater, the system does not require any physical modifications to be employed. Although, the controller has to be configured for the biofuel being used and tested for results and efficiency. This system could be employed in rural areas where there is a lot of social stigmas associated with handling waste as this system does not require much human intervention.

References

1. Dahunsi, S.O., Oranusi, U.S.: Co-digestion of food waste and human excreta for biogas production. Biotechnol. J. Int. 485–499 (2013)
2. Narayana, T.: Municipal solid waste management in India: From waste disposal to recovery of resources? . Waste Manage. **29**(3), 1163–1166 (2009)
3. Bouallagui, H., Touhami, Y., Hanafi, N., Ghariani, A., Hamdi, M.: Performances comparison between three technologies for continuous ethanol production from molasses. Biomass Bioenerg. **48**, 25–32 (2013)
4. Arthur, R., Baidoo, M.F., Antwi, E.: Biogas as a potential renewable energy source: a Ghanaian case study. Renew. Energy **36**(5), 1510–1516 (2011)
5. Boysan, F., Özer, Ç., Has, M., Murat, M.: Project on solid waste recycling plant in Sakarya University Campus. Procedia Earth Planet. Sci. **15**, 590–595 (2015)
6. Singh, M., Arora, R., Ojha, A., Sharma, D., Gupta, S.: Solid waste management through plasma arc gasification in Delhi: a step towards Swachh Bharat. In: Advances in Industrial and Production Engineering, pp. 431–440. Springer, Singapore (2019)

7. Ling, L.: China's manufacturing locus in 2025: with a comparison of "Made-in-China 2025" and "Industry 4.0". Technol. Forecast. Soc. Change **135**, 66–74 (2018)
8. Theorin, A. et al.: An event-driven manufacturing information system architecture for Industry 4.0. Int. J. Prod. Res. **55**(5), 1297–1311 (2017)

Sustainable Supplier Selection in Automobile Sector Using GRA–TOP Model

Sanatan Ratna, Mohit Bhat, Nirbhay Pratap Singh, Mitansh Saxena, Sheelam Misra, Prem Narayan Vishwakarma, and B. Kumar

Abstract In automobile sector, supply chain management plays a very important role we can consider it as a spinal code of manufacturing system. Major part of automobile sector is transportation, storage facility, retailers and even the customers who are going to be benefitted the most that are the user. Supply chain can be distributed into two parts or we can say factors physical distribution and supply chain management system. The issues faced by the supply chains in the current scenario are environment based. There is an immediate need to select the suppliers based on factors, which are important for sustainability. The criteria for supplier selection are shortlisted using Grey Relational Analysis (GRA). Finally, the best supplier is selected using TOPSIS that is based on calculating the Euclidean distances from the ideal best and the ideal worst. We can learn deeply and vastly about this concept to make our process more efficient, that is, by using green supply chain management. Selecting best supplier is very important in this competitive world that can be done using supply chain management.

Keywords Grey relational model · TOPSIS · Multicriteria decision decision-making · Green supply chain management

1 Introduction

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a multicriteria decision analysis method, which was originally developed by Ching-Lai Hwang and Yoon in 1981 with further developments by Yoon in 1987, and Hwang, Lai and Liu in 1993 TOPSIS is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution (PIS) and the longest geometric distance from the negative ideal solution (NIS).

S. Ratna (✉) · M. Bhat · N. P. Singh · M. Saxena · S. Misra · P. N. Vishwakarma
Amity University Noida, Sector 125, Noida 201313, UP, India
e-mail: sratna@amity.edu

B. Kumar
Sunrise University, Alwar, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_35

Selecting best supplier is the most important part of supply chain management for improving the supply chain management. The aim is to select the factors that are responsible for selecting the best supplier that facilitates the process in the context of Indian automobile industry. TOPSIS is used make ranking of the best supplier approach that is dependent on the principle of inductive, the methodology of research data collected from the vendor is well known. The result of the process gives the best one vendor or supplier in the market this is the best possible solution for automobile industry. To achieve more in the global market as there are many manufacturers around the globe so as to maintain the global competition position in the world market we need to follow the strategies that lead to shorter lead time reduce the overall cost and bring the best quality. Thus we can say that suppliers are very important for achieving the competitiveness in the market as they are the one who is going to help in achieving the above objective thus the suppliers are the key component of the process thus suppliers are the best strategy maker. There are various conflicting criteria that are quantitative and qualitative some of them are such which conflict each other. Decrease in global demand less per capita income around the globe, which makes company to make itself more efficient so that it can match up with the market there are various government regulations, which have come into existence which force the manufacturing unit to opt for green supply chain management so that safeguard of the global environment can be done and not only government but nowadays common public is also concerned more about the environment as common public is the one who is most affected due to poor environment condition . The supply chain management has been used for last two decades and can be defined as the integration of various aspects like procurement of material their transformation so as to supply in the market according to the need and the efficient way of delivery. Coordination between the supplier and manufacturer is also the important aspect and this is the important and difficult link of supply management. Once a relation has been established, it will last long for the better efficient supply chain management this relation will have the long-lasting effect on the supply chain management. Supplier selection is the most difficult aspect of supply chain management. Besides selection of supplier, various other criteria are also took into consideration to take decision research have found that supplier selection method is the best method out there, which will directly affect the performance and output of the organization [1–5]. The organizations are more and more dependent on their suppliers and if the decision that is made is poor will directly affect the organization thus suppliers play a vital role in the performance of an organization which is quiet critical. This decision is mostly complicated and is not properly structured. There are also various trades of problems, which are qualitative and quantitative in nature and mostly conflict each other. In this project, we have worked on the various methods, which work on the various criteria, which lead to proper supplier selection. With the help of TOPSIS, we have waited various different criteria and according to that criteria, we have selected the best supplier. Ranking them that is suppliers through GREY method. As TOPSIS includes various formulas and criteria, which include multiple steps, which have qualitative and quantitative factors example sending product from one place to another, quality, various government criteria. TOPSIS thus plays a vital role in ranking and valuing the most important criteria, which means it prioritizes one vendor over the another.

2 Literature Review

Sun et al. (2010) [1] used TOPSIS method as it is based on the concept that the chosen alternative should have the shortest distance from the positive-ideal solution (i.e., achieving the minimal gaps in each criterion) and the longest distance from the negative-ideal solution (i.e., achieving the maximal levels in each criterion). Torfi et al. [2] stated that the TOPSIS method is based on choosing the best alternative, which has the shortest distance from the positive-ideal solution and the longest distance from the negative-ideal solution. Tavana et al. [3] used TOPSIS for addressing the rank reversal issue, which is the change in the ranking of alternatives when a non-optimal alternative is introduced. Chen and Hwang [4] used TOPSIS to identify solutions from a finite set of alternatives. Buyukozkan et al. [5] used TOPSIS for supplier selection in a manufacturing enterprise.

3 Methodology Used

The current research work aims at selecting the best supplier in automobile industry, which fits the bill for sustainability. Sustainability is important in any industry as it fulfills the needs of the current generation without hampering the requirements of future customers. So, a total of 10 factors affecting green supply chain are selected using literature review. Next the five most important factors are selected using GRA. For this purpose, a survey is taken on the scale of 5 from 13 industry experts for judging the importance of the respective criteria in the selection process of the supplier. The 10 criteria under consideration are reuse of the component (C1), handling and storage of nonrecyclable material (C2), recycle of waste (C3), emission ISD 14,000:certifications (C4), reusable package (C5), domestic policy of government (C6), cost implications (C7), lack of public consciousness (C8), lack of corporate social responsibility (C9) and poor human resource quality (C10). A survey is taken on the scale of 5 from 13 industry experts for selecting the five most important criteria (Table 1).

In the next step, the results from the questionnaire responses are listed and calculate the difference between the sequence and the reference sequence (Table 2).

The grey relational coefficients, i.e., GRG (1) for all the 10 criteria are calculated.

$$\xi i(K) = \frac{(\Delta \min + p\Delta \max)}{(\Delta Xi(K) + p\Delta \max)} \tag{1}$$

Table 1 Survey values from 13 industry experts

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
E1	3	2	5	3	4	3	5	2	3	3
E2	4	3	4	3	3	2	4	3	4	2
E3	4	4	5	5	5	4	4	5	4	4
E4	4	4	5	5	5	4	4	5	4	4
E5	4	4	5	5	5	4	4	5	4	4
E6	1	5	5	5	4	5	5	3	3	3
E7	1	5	4	5	4	5	5	4	3	3
E8	3	5	5	4	5	5	4	3	3	3
E9	3	5	5	5	4	5	5	3	3	4
E10	2	4	5	5	4	5	5	3	4	2
E11	2	5	4	5	4	2	5	3	5	3
E12	1	5	4	4	5	3	4	4	3	2
E13	1	5	4	5	3	5	5	3	4	3

Table 2 The difference between the sequence and the reference sequence

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
E1	2	3	0	2	1	2	0	3	2	2
E2	1	2	1	2	2	3	1	2	1	3
E3	1	1	0	0	0	1	1	0	1	1
E4	1	1	0	0	0	1	1	0	1	1
E5	1	1	0	0	0	1	1	0	1	1
E6	4	0	0	0	1	0	0	2	2	2
E7	4	0	1	0	1	0	0	1	2	2
E8	2	0	0	1	0	0	1	2	2	2
E9	2	0	0	0	1	0	0	2	2	1
E10	3	1	0	0	1	0	0	2	1	3
E11	3	0	1	0	1	3	0	2	0	2
E12	4	0	1	1	0	2	1	1	2	3
E13	4	0	1	0	2	0	0	2	1	2

Here, p is the distinguishing factor taken as 0.5. The GRG is calculated and shown in Table 3.

It is clearly indicated that the factors C1, C2, C3, C4 and C10 are the five most important criteria for sustainability as have the highest grey relational coefficients. The supplier selection in the next step is done by evaluating the five suppliers based on these five shortlisted criteria.

Table 3 Calculated grey relational coefficients

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
E1	0.75	0.33333333	1	0.33333333	0.5	0.42857143	1	0.33333333	0.33333333	0.71428571
E2	1	0.42857143	0.33333333	0.33333333	0.33333333	0.33333333	0.333333	0.42857143	0.5	0.55555556
E3	1	0.6	1	1	1	0.6	0.333333	1	0.5	1
E4	1	0.6	1	1	1	0.6	0.333333	1	0.5	1
E5	1	0.6	1	1	1	0.6	0.333333	1	0.5	1
E6	0.5	1	1	1	0.5	1	1	0.42857143	0.33333333	0.71428571
E7	0.5	1	0.33333333	1	0.5	1	1	0.6	0.33333333	0.71428571
E8	0.75	1	1	0.5	1	1	0.333333	0.42857143	0.33333333	0.71428571
E9	0.75	1	1	1	0.5	1	1	0.42857143	0.33333333	1
E10	0.6	0.6	1	1	0.5	1	1	0.42857143	0.5	0.55555556
E11	0.6	1	0.33333333	1	0.5	0.33333333	1	0.42857143	1	0.71428571
E12	0.5	1	0.33333333	0.5	1	0.42857143	0.333333	0.6	0.33333333	0.55555556
E13	0.5	1	0.33333333	1	0.33333333	1	1	0.42857143	0.5	0.71428571
Sum	9.45	10.1619048	9.66666667	10.6666667	8.66666667	9.32380952	9	7.53333333	6	9.95238095
GRG	0.72692308	0.78168498	0.74358974	0.82051282	0.66666667	0.71721612	0.692308	0.57948718	0.46153846	0.76556777

Table 4 Decision matrix

Criteria	Supplier 1	Supplier 2	Supplier3	Supplier 4	Supplier 5
Reuse of the component (C1)	5	5	3	5	3
Handling and storage of nonrecyclable material (C2)	4	4	4	3	3
Recycle of waste (C3)	5	5	4	3	3
Emission ISD 14,000:Certification (C4)	5	4	4	3	3
Poor human resource quality (C5)	3	4	3	3	3

Table 5 Normalized decision matrix

Criteria	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
C1	0.518475	0.518475	0.311085	0.518475	0.311085
C2	0.492366	0.492366	0.492366	0.369274	0.369274
C3	0.577350	0.461880	0.461880	0.346410	0.346410
C4	0.54554	0.545544	0.436435	0.327326	0.327326
C10	0.4160251	0.554700	0.4160251	0.4160251	0.4160251

The decision matrix obtained from a survey conducted in an automobile industry located in Delhi-NCR is shown below (Table 4).

The normalized decision matrix is shown in Table 5.

Next, the Ideal best (Vj+) and Ideal worst (Vj−) are calculated as shown in Table 6. The value of Ideal best and Ideal worst depends on the criteria for which we are calculated. If it is a positive criterion, then for ideal best we will choose the maximum value among all the supplier and for ideal worst, choose the minimum value among all the supplier. If it is a negative criterion, then for ideal best choose minimum value among all the supplier and for ideal worst we will choose the minimum value among all the supplier.

Next, the Euclidean distance from the ideal best to the ideal worst using Eqs. 2 and 3.

$$S_i^+ = \left[\sum_{j=1}^{m}\left(V_{ij} - V_j^+\right)^2\right]^{0.5} \tag{2}$$

Table 6 Ideal best and ideal worst solution table

	C1	C2	C3	C4	C10
Vj+	0.518475	0.492366	0.577350	0.545544	0.4160251
Vj−	0.311085	0.369274	0.346410	0.327326	0.554700

Table 7 Ranking of the suppliers

Suppliers	Si+	Si−	Si+ + Si−	Pi	Rank
S1	0	0.42166	0.42166	1	1
S2	0.178	0.5423	0.7203	0.7528	2
S3	0.2533	0.2509	0.5042	0.4976	3
S4	0.3438	0.2441	0.5879	0.4152	4
S5	0.3977	0.14	0.5377	0.2603	5

$$S_i^- = \left[\sum_{j=1}^{m}\left(V_{ij} - V_j^-\right)^2\right]^{0.5} \tag{3}$$

At the end the performance index is calculated for all the five suppliers using Eq. 4.

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \tag{4}$$

The Euclidean distances and the performance index of all the five suppliers are listed in Table 7.

4 Conclusion

It is evident that the supplier S1 has the highest performance index and hence, is selected as the best supplier followed by the supplier S2. The current research work aimed at selecting the best supplier in a green supply chain in automobile sector for sustainability. To begin with, a total of 10 criteria for supplier selection were taken using literature review. Five selection criteria were then shortlisted using grey relational analysis. These five shortlisted criteria were then used for final supplier selection for increased sustainability using TOPSIS method, which is based on calculating the Euclidean distances from the ideal best and ideal worst. The scope of the work can be extended to other industries as well for implementing sustainability.

References

1. Sun, C.C.: A performance evaluation model by integrating fuzzy AHP and fuzzy TOPSIS methods. Expert Syst. Appl. **37**, 7745–7754 (2010)
2. Torfi, F., Reza, Z.F., Rezapour, S.: Fuzzy AHP to determine the relative weights of evaluation criteria and Fuzzy TOPSIS to rank the alternatives. Appl. Soft Comput. **10**, 520–528 (2010).

https://doi.org/10.1016/j.asoc.2009.08.021https://doi.org/10.1016/j.asoc.2009.08.021
3. Kuo, T.: A modified TOPSIS with a different ranking index. Eur. J. Oper. Res. **260**, 152–160 (2016). https://doi.org/10.1016/j.ejor.2016.11.052https://doi.org/10.1016/j.ejor.2016.11.052
4. Jahanshahloo, G.R., et al.: Extension of TOPSIS for decision making problems with interval data: Interval efficiency. Math. Comput. Model. **49**, 1137–1142 (2009)
5. Arabzad, S.M., Mazaher, G., Razmi, J., Shirouyehzad, H.: Employing fuzzy TOPSIS and SWOT for supplier selection and order allocation problem. Int. J. Adv. Manuf. Technol. (2015). https://doi.org/10.1007/s00170-014-6288-3https://doi.org/10.1007/s00170-014-6288-3

Human Empowerment by Industry 5.0 in Digital Era: Analysis of Enablers

Ravinder Kumar, Piyush Gupta, Sahil Singh, and Dishank Jain

Abstract In modern digital era, technology has dominated in all sectors of society. In manufacturing sectors, technology development has been divided into different time zones (Industry 1.0–4.0). These industrial upheavals have highly focused on technology applications. But modern challenges of customization, personalization and technology upgrading can only be done by human involvement. These modern challenges have led to new industrial revolution called "Industry 5.0," which emphasizes on technology advancement with human empowerment. In this research paper, authors have studied the enablers, which help in execution of Industry 5.0 in Indian manufacturing sector. Eight enablers have been distinguished by literature review and specialist's supposition. By using total interpretative structural modeling (TISM) technique, authors have studied the relationship between these enablers. Authors have developed a diagraph to show structural relationship between different enablers influencing implementation of Industry 5.0 in Indian manufacturing sector.

Keywords Industry 5.0 · Human empowerment · Enablers · TISM

1 Introduction

The term "Industry 5.0" was initially coined by Michael Rada in 2015 in his article "From Virtual to Physical." Industry 5.0 emphasis on empowering the human being specially the customers through fulfilling their personalizing and customized needs [19]. This technology stresses on automation with co-existence of human [4]. Chronologically, Industry 5.0 has followed Industry 4.0, all technologies of later will be an asset for I5.0 (Table 1). After going through four revolutions over a period of more than two centuries, these revolutions made a significant technical development (Fig. 1). Latest running industrial revolution, "Industry 4.0" incorporates various technologies such as "Big data analytics," "autonomous robotics," "the industrial

R. Kumar (✉) · P. Gupta · S. Singh · D. Jain
Amity University Noida, Sector 125, Noida 201313, UP, India
e-mail: rkumar19@amity.edu

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_36

Table 1 Chronology of industrial revolutions

Industrial revolutions	Description
Industry 1.0	The methodology of industry 5.0 evolved from the late eighteenth century when water and steam-powered machines were made for mass production of goods thereby removing the barrier of serving limited number of customers and lead to the expansion of business and was referred as the era of industry 1.0
Industry 2.0	The starting of the twentieth century gave rise to the next industrial upheaval, which came into limelight because of the production of machines running on electricity. These machines not only reduced the human effort but they were also easy to operate and were better than machines operated on steam and water as they were not resource hungry
Industry 3.0	With the more advancements in the electronic industry, automation in production and manufacturing sector promoted to a new level as many new electrical devices came into existence such as transistors, PLC's and integrated circuits automated the machines which substantially reduced human labor, increased pace, improved accuracy and in fact full substitution of human body. This level of automation was referred to as Industry 3.0
Industry 4.0	The blast in the web and media transmission industry in the late 1990s took the automation to a new level when the connection and exchange of information were done in totally different ways as compared with earlier ones. Cyber Physical System was one property that enabled us to merge the physical world with the virtual one where machines became smarter enough to communicate with each other without any physical or geographical barrier and is known as Industry 4.0
Industry 5.0	This era of industrial upheaval attempts to take the Industry 4.0 to a new milestone by integrating humans and machines in the smart factory. It will also enable the implementation of critical factors such as mass customization and personalization. It will also enhance the skills of the workers and improve their knowledge about the manufacturing processes

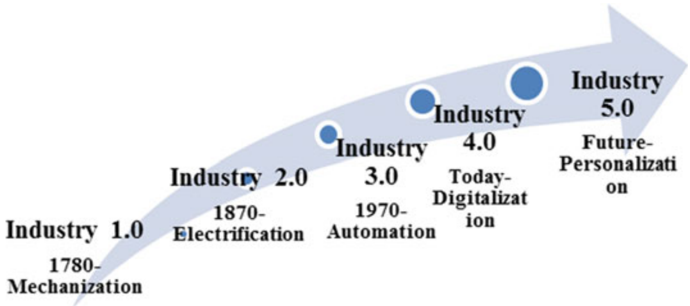


Fig. 1 Industrial development phases (Industry 1.0–Industry 5.0)

internet of things," "simulation," "system integration," "cyber security," "cyber physical system," "the cloud," "additive manufacturing" and "augmented reality" [11, 12]. But there are many issues with these technologies like loss of job, issues of autonomy and investment scarcity. Industry 5.0 works with all these technologies with human involvement. Industry 5.0 allows staying competitive in global market because it can provide higher efficiency, cost reduction, mass individualization, and safe factories with more human empowerment. Section 2 discusses the related literature. Section 3 discusses the research methodology and its discussion. Section 4 is Discussion and conclusion.

2 Literature Review

Industry 4.0 implementation investment with different other challenges push it to a slow implementation [5]. Industry 5.0 is the totality of the circles of economy wherein the completely programmed creation process depends on the counterfeit keenness and the web make new machines without the human support [1]. Sanders et al. [22] stated that Industry 5.0 essentially impacts the creation condition with radical changes in the execution of tasks. Industry 5.0 empowers ongoing arranging of creation plans, alongside unique self-enhancement. Demir et al. [4] discussed the issues of human–robot coworking from organizational and human perspective. There are various issues in coworking of human and robots like legal, regulatory, psychological, social, and ethical. Various enablers of Industry 5.0 have been summarized with related references in Table 2.

3 Research Methodology and Application

Total Interpretative structural Modeling Technique (TISM) is the procedure that changes indistinct and ineffectively verbalized models of system, which is into unmistakable, very much characterized models, which is helpful for some research purposes. Khurana et al. [9] used TISM for analyzing the critical factors of sustainable-oriented innovation for Indian manufacturing MSMEs. TISM is an interactive management technique, which helps look into research groups as well as research scholars in dealing with complex issues. It is also used for distinguishing and condensing relationship among explicit factors, which characterize a problem or an issue. Research methodology has been graphically summarized in Fig. 2. The application of TISM has been discussed from Tables 3, 4, 5, 6, 7, 8, 9 and 10.

"A": Connection from section i to section j but not segment j to segment i

"V": Connection from section j to section i but not segment i to segment j

Table 2 Enablers of Industry 5.0

Enablers of Industry 5.0	Description	References
Exoskeleton	These are the devices and equipment human can wear on body to overcome fatigue and exhaust. Some exoskeletons may be driven by motor and actuators to reduce human efforts	[18, 24–26]
Block chain-enabled Fog computing	Blockchain technology provides extreme security feature. Information saves in blocks and blocks are connected to each other by unique id number (UID)	[16, 17, 21]
IOT Data Interoperability	From Industry 4.0 we found that big data analysis helps in data analysis received from various IoT devices to achieve the mass customization faster	[11, 12, 14, 15, 23]
Intelligent autonomation	Robots that can directly interact to human by using safety features assured by human in them	[2, 28, 29]
Personalized delivery system	Drones are devices used in sudden inspection. These devices can also be used to transfer low weight material from one palace to another palace	[3, 6, 7]
Manufacturing traceability	Shop floor trackers are devices used to track the real-time production. They help to link the sales and production department along with buffer with efficient use of resources and reduced wastage	[13, 27]
Mixed reality	Mixed reality is the outcome that is received when we integrate the physical world with the digital world. It is the evolution that will involve the role of human, environment and computer interaction	[8, 10, 20]

"X": Connection between both direction, section i to section j and section j to section i

"0" (zero): No connection in both direction.

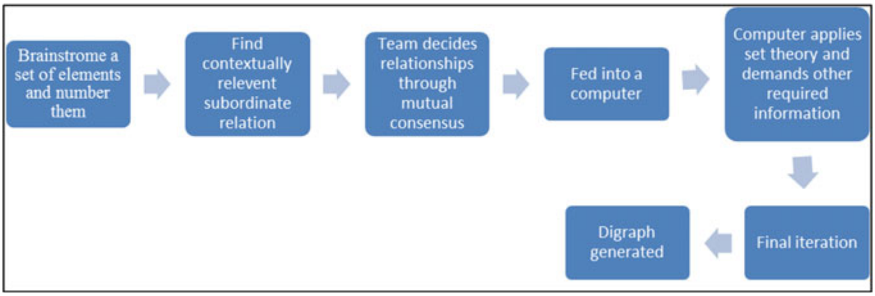


Fig. 2 The steps of research methodology of TISM

Table 3 Symbols and assigned values

Symbol	‘V’	‘A’	‘X’	‘O’
For (*i*, *j*) cell	1	0	1	0
For (*j*, *i*) cell	0	1	1	0

Table 4 Structural self-interaction matrix (SSIM) of critical factors

Variable	EL.8	EL.7	EL.6	EL.5	EL.4	EL.3	EL.2	EL.1
EL.1	V	V	X	V	V	V	X	X
EL.2	V	0	A	X	A	0	X	
EL.3	0	0	0	0	X	X		
EL.4	X	V	A	V	X			
EL.5	A	V	A	X				
EL.6	V	V	X					
EL.7	A	X						
EL.8	X							

EL.1—Virtual training, **EL.2**—Exoskeleton, **EL.3**—Block chain enabled Fog computing, **EL.4**—IOT Data Interoperability, **EL.5**—Intelligent autonomation, **EL.6**—Mixed reality technologies, **EL.7**—Personalized delivery system, **EL.8**—Manufacturing traceability, **EL.**—Enabler

Table 5 Initial reachability matrix

Enablers code	EL.8	EL.7	EL.6	EL.5	EL.4	EL.3	EL.2	EL.1
EL.1	1	1	1	1	1	1	1	1
EL.2	1	1	0	0	1	0	0	1
EL.3	0	0	1	1	0	0	0	0
EL.4	0	1	1	1	1	0	1	1
EL.5	0	1	0	0	1	0	1	0
EL.6	1	1	0	1	1	1	1	1
EL.7	0	0	0	0	0	0	1	0
EL.8	0	0	0	1	1	0	1	1

Table 6 Final reachability matrix

Enablers code	EL.8	EL.7	EL.6	EL.5	EL.4	EL.3	EL.2	EL.1
EL.1	1	1	1	1	1	1	1	1
EL.2	1	1	1*	1*	1	1*	1*	1
EL.3	0	1*	1	1	1*	0	1*	1*
EL.4	1*	1	1	1	1	0	1	1
EL.5	1*	1	0	0	1	0	1	1*
EL.6	1	1	1*	1	1	1	1	1
EL.7	0	0	0	0	0	0	1	0
EL.8	0	1*	1*	1	1	0	1	1

*To develop the final reachability matrix, transitivity check is applied on the initial reachability matrix following the transitivity rule as mentioned in methodology. In this final reachability matrix dependence power and driving power are obtained for each challenge represented by row and column respectively

Table 7 Level partitioning level 1

S. No.	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 3, 4, 5, 6, 7, 8	1, 2, 4, 5, 6	1, 2, 4, 5, 6	
2	1, 2, 3, 4, 5, 6, 7, 8	1, 2, 3, 4, 5, 6, 8	1, 2, 3, 4, 5, 6, 8	
3	2, 3, 4, 5, 7, 8	1, 2, 3, 4, 6, 8	2, 3, 4, 8	
4	1, 2, 3, 4, 5, 7, 8	1, 2, 3, 4, 6, 8	1, 2, 3, 4, 8	
5	1, 2, 5, 7, 8	1, 2, 3, 4, 5, 6, 8	1, 2, 5, 8	
6	1, 2, 3, 4, 5, 6, 7, 8	1, 2, 6	1, 2, 6	
7	7	1, 2, 3, 4, 5, 6, 7, 8	7	One
8	2, 3, 4, 5, 7, 8	1, 2, 3, 4, 5, 6, 8	2, 3, 4, 5, 8	

Table 8 Level partitioning level 2

S. No.	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 3, 4, 5, 6, 8	1, 2, 4, 5, 6	1, 2, 4, 5, 6	
2	1, 2, 3, 4, 5, 6, 8	1, 2, 3, 4, 5, 6, 8	1, 2, 3, 4, 5, 6, 8	Second
3	2, 3, 4, 5, 8	1, 2, 3, 4, 6, 8	2, 3, 4, 8	
4	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 6, 8	1, 2, 3, 4, 8	
5	1, 2, 5, 8	1, 2, 3, 4, 5, 6, 8	1, 2, 5, 8	Second
6	1, 2, 3, 4, 5, 6, 8	1, 2, 6	1, 2, 6	
8	2, 3, 4, 5, 8	1, 2, 3, 4, 5, 6, 8	2, 3, 4, 5, 8	Second

Table 9 Level partitioning level 3

S. No.	Reachability set	Antecedent set	Intersection set	Level
1	1, 3, 4, 6	1, 4, 6	1, 4, 6	
3	3, 4	1, 3, 4, 6	3, 4	Third
4	1, 3, 4	1, 3, 4, 6	1, 3, 4	Third
6	1, 3, 4, 6	1, 6	1, 6	

Table 10 Level partitioning level 4

S. No.	Reachability set	Antecedent set	Intersection set	Level
1	1, 6	1, 6	1, 6	Fourth
6	1, 6	1, 6	1, 6	Fourth

4 Discussion and Conclusion

In the current research paper, authors have identified eight enablers, which help in implementing Industry 5.0 in the manufacturing sector, from literature review and expert opinions. Further authors have used TISM technique for establishing the structural relationship between these enablers. From the TISM analysis, authors observed the interrelationship between the enablers of Industry 5.0. Virtual training (EL1) and mixed reality technologies (EL6) train the manpower and helps to improve the efficiency of block chain enabled fog computing (EL3) and IOT data interoperability (EL4). By Block chain-enabled Fog computing (EL3), the data gathered by different IOT devices can be analyzed and stored more securely. These enablers further connect and enable exoskeleton (EL2), intelligent autonomation (EL5) and manufacturing traceability (EL8). These enablers ultimately help in meeting modern challenge of personalized product development and customized delivery system (EL7) (Fig. 3). This will empower future manufacturing organizations in improving delivery, logistic, individualization, customization and human involvement.

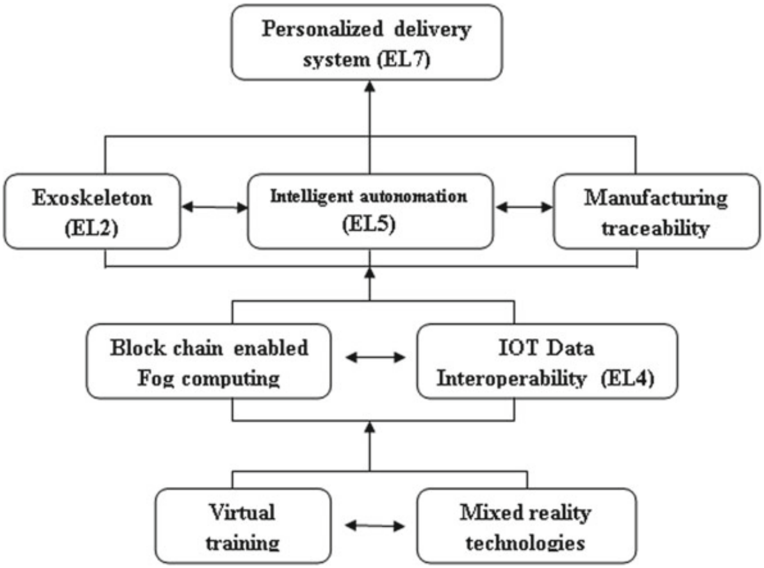


Fig. 3 TISM diagraph

References

1. Alekseev, A.N., Buraeva, E.V., Kletskova, E.V., Rykhtikova, N.A.: Stages of formation of Industry 4.0 and the key indicators of its development. In: Industry 4.0: Industrial Revolution of the 21st Century, pp. 93–100. Springer, Cham (2019)
2. Al-Tahat, M.D., Jalham, I.S.: A structural equation model and a statistical investigation of lean-based quality and productivity improvement. J. Intell. Manuf. **26**(3), 571–583 (2015)
3. Coelho, J.F., Ferreira, P.C., Alves, P., Cordeiro, R., Fonseca, A.C., Góis, J.R., Gil, M.H.: Drug delivery systems: advanced technologies potentially applicable in personalized treatments. EPMA J. **1**(1), 164–209 (2010)
4. Demir, K.A., Doven, G., Sezen, B. Industry 5.0 and human-robots co-working. Procedia Comput. Sci. **158**, 688–695 (2019)
5. Dutta, G., Kumar, R., Sindhwani, R., Singh, R.: Digital transformation priorities of India's discrete manufacturing SMEs—a conceptual study in perspective of Industry 4.0. Compet. Rev. Int. Bus. J. (2020). https://doi.org/10.1108/CR-03-2019-0031
6. Garfield, S.: Advancing access to personalized medicine: a comparative assessment of European reimbursement systems. Personalized Medicine Coalition (2011)
7. Goole, J., Amighi, K.: 3D printing in pharmaceutics: a new tool for designing customized drug delivery systems. Int. J. Pharm. **499**(1–2), 376–394 (2016)
8. Kamal, M., Nadiah, N., Mohd Adnan, A.H., Yusof, A.A., Ahmad, M.K., Kamal, M., Anwar, M.: Immersive interactive educational experiences–adopting Education 5.0, Industry 4.0 learning technologies for Malaysian Universities. In: Proceedings of the International Invention, Innovative & Creative (InIIC) Conference, Series, pp. 190–196. (2019, January)
9. Khurana, S., Mannan, B., Haleem, A.: Total interpretive structural modelling of critical factors of sustainable-oriented innovation for indian manufacturing MSMEs. In: Kumar, H., Jain, P.K. (eds) Recent Advances in Mechanical Engineering, Lecture Notes in Mechanical Engineering. Springer Nature Singapore Pte Ltd. (2020)

10. Kotranza, A., Lok, B., Deladisma, A., Pugh, C.M., Lind, D.S.: Mixed reality humans: evaluating behavior, usability, and acceptability. IEEE Trans. Vis. Comput. Gr. **15**(3), 369–382 (2009)
11. Kumar, R.: Sustainable supply chain management in the era of digitalization: issues and challenges. In: Idemudia, E.C. (Ed.) Handbook of Research on Social and Organizational Dynamics in the Digital Era. IGI Global, 2020, pp. 446–460. Web. 1 Aug. 2019. https://doi.org/10.4018/978-1-5225-8933-4.ch021. Publisher & ISSN/ISBN No. 290319-062455. Arkansas Tech University, USA (2020a)
12. Kumar, R.: Espousal of Industry 4.0 in Indian manufacturing organizations: analysis of enablers. In: Gaur, L. et al. (Eds.) Handbook of Research on Engineering Innovations and Technology Management in Organizations, IGI Global, ISBN13: 9781799827726|ISBN10: 1799827720|EISBN13: 9781799827733|. https://doi.org/10.4018/978-1-7998-2772-6 (2020b)
13. Massaro, A., Contuzzi, N., Galiano, A.: Intelligent processes in automated production involving Industry 4.0 technologies and artificial intelligence. In: Advanced Robotics and Intelligent Automation in Manufacturing IGI Global. pp. 97–122 (2020)
14. Nahavandi, S.: Industry 5.0—a human-centric solution. Sustainability **11**(16), 4371 (2019)
15. Paschek, D., Mocan, A., Draghici, A.: Industry 5.0–the expected impact of next industrial revolution. In: Thriving on Future Education, Industry, Business and Society; Proceedings of the MakeLearn and TIIM International Conference 2019, pp. 125–132. ToKnowPress (2019)
16. Pramanik, P.K.D., Mukherjee, B., Pal, S., Upadhyaya, B.K., Dutta, S.: Ubiquitous manufacturing in the age of Industry 4.0: a state-of-the-art primer. In: A Roadmap to Industry 4.0: Smart Production, Sharp Business and Sustainable Development, pp. 73–112. Springer, Cham (2020)
17. Puthal, D., Malik, N., Mohanty, S.P., Kougianos, E., Das, G.: Everything you wanted to know about the blockchain: its promise, components, processes, and problems. IEEE Consum. Electron. Mag. **7**(4), 6–14 (2018)
18. Puvvada, Y.S., Vankayalapati, S., Sukhavasi, S.: Extraction of chitin from chitosan from exoskeleton of shrimp for application in the pharmaceutical industry. Int. Curr. Pharm. J. **1**(9), 258–263 (2012)
19. Rada, M.: From virtual to physical. https://medium.com/@michael.rada/industry-5-0-definition-6a2f9922dc48 (2015). Accessed on 03 May 2020
20. Sachsenmeier, P.: Industry 5.0—the relevance and implications of bionics and synthetic biology. Engineering **2**(2), 225–229 (2016)
21. Samaniego, M., Deters, R.: Virtual resources & blockchain for configuration management in IoT. J. Ubiquitous Syst. Pervasive Netw. **9**(2), 1–13 (2017)
22. Sanders, A., Elangeswaran, C., Wulfsberg, J.P.: Industry 4.0 implies lean manufacturing: research activities in industry 4.0 function as enablers for lean manufacturing. J. Indus. Eng. Manage. (JIEM) **9**(3), 811–833 (2016)
23. Skobelev, P.O., Borovik, S.Y.: On the way from Industry 4.0 to Industry 5.0: from digital manufacturing to digital society. Industry 4.0 **2**(6), 307–311 (2017)
24. Spada, S., Ghibaudo, L., Gilotta, S., Gastaldi, L., Cavatorta, M.P.: Analysis of exoskeleton introduction in industrial reality: main issues and EAWS risk assessment. In: International Conference on Applied Human Factors and Ergonomics, pp. 236–244. Springer, Cham (2017, July)
25. Sung, T.K.: Industry 4.0: a Korea perspective. Technol. Forecast. Soc. Change **132**, 40–45 (2018)
26. Sylla, N., Bonnet, V., Colledani, F., Fraisse, P.: Ergonomic contribution of ABLE exoskeleton in automotive industry. Int. J. Ind. Ergon. **44**(4), 475–481 (2014)
27. Thakur, M., Wang, L., Hurburgh, C.R.: A lot aggregation optimization model for minimizing food traceability effort. In: 2009 Reno, Nevada, June 21–June 24, 2009, p. 1. American Society of Agricultural and Biological Engineers (2009)
28. Villalba-Diez, J., Schmidt, D., Gevers, R., Ordieres-Meré, J., Buchwitz, M., Wellbrock, W.: Deep learning for industrial computer vision quality control in the printing Industry 4.0. Sensors **19**(18), 3987 (2019)

29. Yang, C.C., Yeh, T.M., Yang, K.J.: The implementation of technical practices and human factors of the Toyota production system in different industries. Hum. Fact. Ergon. Manuf. Serv. Industr. **22**(6), 541–555 (2012)

Analyzing the Role of Six Big Losses in OEE to Enhance the Performance: Literature Review and Directions

Sandeep Singh, Jaimal Singh Khamba, and Davinder Singh

Abstract The engineering sectors have a considerable contribution toward a nation's economy. These industries are amid the principle-focused industries around the globe. Hence, appropriate utilization of available resources as well as equipment is a high priority in task list of every industry. Since many of these industries are dealing with hurdles to keep all the activities, operations, and synchronized use of equipment with a considerable reduction of time losses. These time losses (so called Six Big Losses) have a set of analyzing factors, which affect the overall performance. Six Big Losses (SBL) are now becoming the real cause of focus to attain world class manufacturing standards in association with strategic tool such as OEE (Overall Equipment Effectiveness). To cover the wide-ranging and dynamic time loss analysis, the corrective measure is OEE. The aim of implementation of OEE is to enhance and acquire the equipment's effectiveness by removing all the potential losses of the industry. This paper discloses the importance of the extensive literature for analysis of these losses systematically. This study also covers a powerful organized strategy, i.e., OEE and the actual time losses in the industries to bring transformation in the attitude of management, managers and workers. This paper tunes up the literature related to SBL to find the potential errors through optimized approach to improve decision-making.

Keywords Overall equipment effectiveness (OEE) · Performance measurement · Six big losses (SBL)

1 Introduction

Six Big Losses (SBL) support the entire perspective of effectiveness during the implementation of OEE. These identified six significant losses are associated with production equipment, diminishing which is beneficial to execute real execution in any discrete industry. In the contemporary era, the competitive process industries

S. Singh (✉) · J. S. Khamba · D. Singh
Department of Mechanical Engineering, Punjabi University, Patiala, Punjab, India
e-mail: er.sunny@yahoo.co.in

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_37

subsume different structured maintenance strategies such as Lean Manufacturing (LM), Total Quality Management (TQM), Total Productive Maintenance (TPM) and 5S tool where OEE is a common tool among these approaches [6]. The desire to improve OEE not only includes performance-enhancement but also encircles six big losses associated with OEE, which could be synchronized throughout the units to increase productivity [11]. The identification of losses in OEE also finds the hidden capacity of miscellaneous equipment. According to Ahmed et al. [2], the rapid and ever-changing manufacturing methods in industrial culture and technology do not ensure the prolonged productivity and profitability; hence endurance of such industries may become endangered. The enterprises must acquire and sustain the right pace toward improvement of reliable maintenance strategies such as OEE.

The established concepts define “maintenance” as “restoration or overhauling of the equipment,” but this concept covers very limited dimensions. This notion of maintenance relates the repair strategies only as a function of preventive, predictive and corrective maintenance. The current era demands the revision of maintenance tactics. Nevertheless, process industries are learning finely tuned maintenance strategies [43]. This study relates the execution of effective maintenance strategy, i.e., the ability of OEE and eliminating significant losses associated with it. These losses help to predict possible errors, henceforth achieve accuracy. In fact, it has seen the different facets of OEE implementation in terms of severe changes in the industrial culture during the recent decades. Gits (1992) submitted a different view of maintenance strategy in his findings that the consideration of random errors was not taken critically and the demand for maintenance was initiated purely after the breakdown of equipment. However, the introduction of multifaceted tools has amended the maintenance control system, which is now being referred as a very crucial measure.

Overall Equipment Effectiveness is the result of cutting-edge technology, which has given a new direction to the industrial sector. The concept of OEE was coined by Nakajima, with detailed directions through the implementation of Total Productive Maintenance (TPM). OEE, an effective Japanese tool, is amid those practical tools that meet the required objectives by analyzing and refining the production process. It rectifies the effective functioning of equipment, labor, substantial errors and the ability to satisfy the customer in terms of efficacy [45].

Murray et al. [33] described that the role of an effective maintenance tool must be capable of enhancing each phase of technical systems such as acquisition of the equipment, scheduling, operation, routine evaluation of performance, improvement, waste and re-work. The production strategies have transformed enormously due to the implementation of different progressive engineering tools. Though, the paybacks from these programs have some limitations and restrictions to manage the time losses of the equipment [54]. The maintenance departments are often the largest, comprising about 30% of staff. Hence, to keep them synchronized, effective strategy is mandatory [15].

2 Literature Review: OEE as a Metric Tool

OEE metric is the most suitable tool for micro, small, medium and large-scale industries. In this section, a study to understand the implementation of the OEE and six big losses would be carried out. Baluch et al. [9] accomplished that OEE splits the term "Performance" of manufacturing apparatus into three quantifiable modules: Availability rate, Performance rate, and Quality rate.

While calculating OEE, the factors that are affecting it can be considered as barriers and performance improvement measures can augment the process. OEE is calculated in percentage, where Availability (A) can be defined as the real total of the shift time when the machine is running, i.e., (Operating time minus Downtime) to the Total Operating Time.

Performance can be defined as the total products produced to the production rate of the equipment which can be obtained by total output divided by potential output. Quality can be defined as the high-quality products out of the total products produced, which is acceptable in terms of customer satisfaction and general standards [35].

Ghafoorpoor et al. [19] suggested that OEE and losses associated with this metric are valuable for any discrete work station and can be established to the level of department or industry. It is essential to measure the improvements through OEE to have a direct positive effect on the bottom line. Times losses are actually vital to know before the actual implementation of OEE tool.

The attention has been shifted to increase competency of effectiveness and internal specialization to meet developed industrial conditions. Similarly, Huang et al. [24] concluded that OEE is the product of three factors stated below.

$$\begin{aligned}&\text{Overall Equipment Effectiveness (OEE)}\\&\quad = \text{Availability}(A) \times \text{Performance (Performance)} \times \text{Quality } (Q)\end{aligned}$$

3 Six Big Losses: Explanation and Calculations

In the concept of OEE, integration of three components is calibrated, i.e., equipment effectiveness, individual maintenance activities and peer maintenance strategies [35]. Dal [14] concluded that there are numerous losses associated with machinery, which are crucial for efficient working. These losses are originated from performance, quality and availability rate of the machinery. These are helpful to locate faults and rectify mistakes of the production line.

I. Downtime losses: are referred as equipment failures.
II. Quantity losses: are referred to faulty products, which create wastage.
III. Setup losses: are referred to downtime and time lost in re-adjustment of the equipment.
IV. Speed losses: are referred to Idling and minor stoppages.

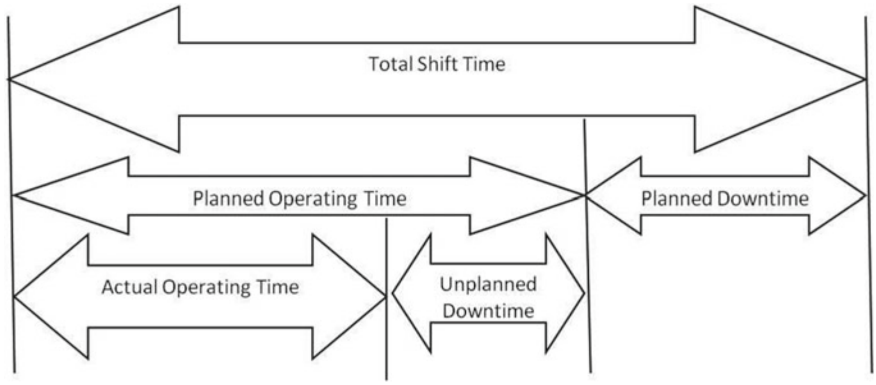


Fig. 1 Time distribution in production line

V. Quality losses: are considered as "rework" damages.
VI. Yield losses: are referred to slow starting of machine till it reaches the level of its actual production efficiency (Fig. 1).

By controlling the OEE and six big losses variables, this study can predict the performance of effective operation. According to Ahmed et al. [2], OEE, single-handedly, cannot solve all the organizational needs but assistance of significant losses on the real-time workstation may contribute to industrial operational requirements. Nord et al. [37] also combined OEE with TQM and TPM to achieve desired equipment performance for improved process. OEE is the most suitable metric tool to optimize the efficacy even in the dense volume-based production houses where utilization of available resources is at a high priority [13].

The influence of OEE in "Process Improvement" is the result of the quest for economic efficiency, maintenance prevention, improving sustainability and total participation of all employees [3]. OEE is a collective strategy to stages of enhanced precision through people but not technology [56]. The enhanced automation in the industry provides the reason to acquire and analyze manufacturing data automatically. The industries are devoting their efforts on maintenance strategies and OEE, being a fundamental part, has become an essential reason for the execution. However, the validity and usefulness of OEE procedures are extremely reliant on the data collection as stated by Saenz de Ugarte et al. [45].

4 Practical Implications

According to Vijayakumar and Gajendran [55], a company must give preference on the small and continuous changes to boost performance by plummeting waste and cost, enhanced productivity, quality, and customer gratification. OEE, a successor tool

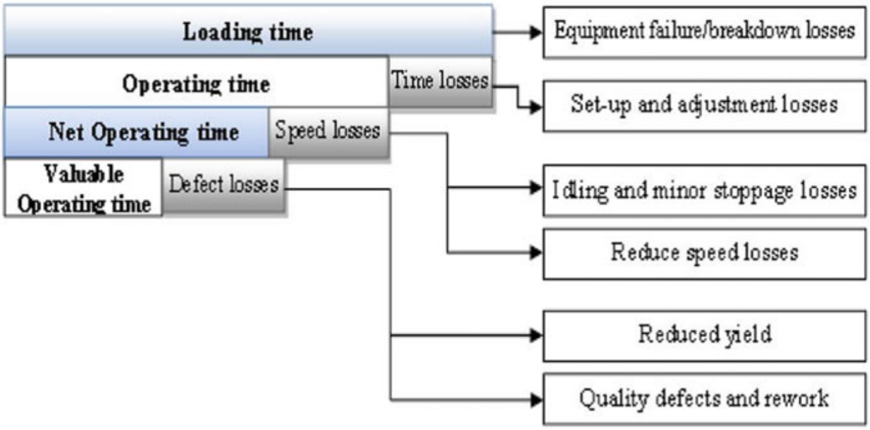


Fig. 2 Relationship between equipment timing and six major losses [20]

of total productive maintenance (TPM) and its six big losses are further optimized and specific factors to attain the results.

Gholizadeh [20] found that OEE is a metric tool that can consistently remove the root causes of speed and breakdown losses. It can also be used in the mechanized sector and other process industry manufacturers to improve the procedure of the processes. The OEE metric is reflected as the most suitable gizmo semiautomatic and automatic manufacturing process where time losses are the keys to unlock the success as stated by De Ron and Rooda [42]. Saenz de Ugarte et al. [45] coined that facts can be acquired in an analyzing tool through simplified time loss variables and time lag. The organized descriptions of loss times grouped into eight classifications such as scheduled downtime, setup time, adjustment of the tool or machine, equipment failure, idling and slight stoppages, downtime losses, redrafting of design, unsystematic losses (Fig. 2).

Concerning the literature review associated with OEE and Six Big Losses, it has become compulsory to understand that OEE alone is not capable of solving complex problems at macro level unless it is calculated at micro level, i.e., at the level of Six Big Losses.

The benchmarking values obtained from OEE factors can be measured as Quality—99% or above and Performance—95, Availability—90% or above, respectively, but these values are dynamics and may vary as per industrial requirements and conditions. The scope to improve and sustain OEE implementation, with world-class acceptable values, is always high for domestic units but these values must not be lie below 70% [6, 7, 26, 27, 36]. The literature reveals that OEE covers a wide range of its applications in various industrial sectors, but there are no standardized factors to calculate time losses.

Pomorski [38] described that the calculation of OEE and monitoring of the associated time losses can be applied to any discrete manufacturing organization. Although OEE and Six Big Losses have been developed from the principle of Total Productive

Maintenance (TPM) but this does mean that an organization requires the implementing of TPM to gain OEE's benefits of reducing losses from the machines [5].

The discrepancies with calculations of OEE recommend that different strategies such as six striking losses can be followed to compute the availability, performance efficiency and quality factors along with simulation, a technique to evaluate the alternative changes in the strategies [1].

Hedman et al. [22] stated that a complete study on various losses across various industries due to the influence of the Operators had been accomplished in a stratified way to trigger suitable action for overall equipment effectiveness hence improving production.

The decision-making plays a noteworthy and vital issue in the organizations. Hence, they pay adequate attention to the framework development to utilize the available resource to the maximum with discrete metric tools. A precise strategic tool can bring enhancement in the life cycle of all industrial equipment to save wealth, environment, and society by reducing losses and wastages [27]. Hence, a proper maintenance tool is the fundamental metric to augment the overall performance by providing hike to the life cycle of equipment. Moseichuk et al. [31] concluded that the equipment's life cycle extension is based on the utilization of convenient methods/strategies with least possible harm to the environment. This increment in life span of equipment will facilitate to trim down consumer expenditure, energy consumption, wastages and most importantly time losses until its usage.

The trends of various losses of OEE are shown to justify these factors as most useful to monitor the losses and improve the performance of the multiple types of industries. The quantity of operator influenced loss time was determined by systematically classifying each of the loss categories, based on their explanation in the data file, as either "operator influenced loss time," "maybe operator influenced loss time," or not operator influenced loss time, which was recorded in the form a questionnaire.

Consequently, the part of unclassified losses, which comprises of lack of description to do correctly, had to be revoked for apparent reasons. Operator influence on loss times does not confirm that operators cause the losses but submissions to the fact that the operators are significant elements in influencing the duration of the lost time.

Likewise, Herry et al. [23] have also unleashed the accomplishment of Overall Equipment Effectiveness by first calculating the Availability, Performance Rate and Rate of Quality, then identifying the Six Big Losses that occur during the real implementation at ground level. They found that the average value of OEE on given machine could be acceptable at 70% effectiveness in moderate circumstances but the standard OEE value of 85% could be adequate as world-class value for a company. While the factors of SBL hold the chief influence on the low effectiveness of the equipment and may affect positively. They calculated the reduced speed loss with total loss for a year at 53% of all losses, which may be accountable for enriched performance [29, 30, 41].

Sutoni et al. [52, 53] depicted that measurement of the effectiveness of the machine by using the OEE is self-optimized. They conducted a study of OEE execution, which covered a span of 1 year. Where, they observed the data processing of the SBL's factors in which the setup and adjustment factors, reduced speed losses and breakdown losses are the principal focused losses of the OEE that affect the appropriate usefulness of the machines [39, 51].

5 Literature Summary

In the summing up, it has been observed that OEE may assist the execution of different strategic tools, which are universally used for performance enhancing such as Lean Maintenance (LM), decision-making models, TQM, TPM, 5S and other diversified conventional maintenance strategies. Karaulova and Bashkite [27] foresaw that finding appropriate SBL's factors during implementation of OEE and rectifying these losses must be considered as vital issue in every industry. They found the positive upshots on the decision-making structure after the reduction of these losses.

Dogra et al. [16] portrayed the elevated expansion of strategies that companies must have provision to several technical changes in the process, operations and activities aided by automation of the industries, which need a massive amount of manual efforts to uphold the engineering and management structures. The approach of maintaining the utilization of equipment is essential for the performance of the processing industry, in terms of motivated workers, enhancement in overall equipment effectiveness (OEE) along with decrement in hazardous work stations and time losses in the production process.

Munoz-Villamizar et al. [32] gave a picture of methodology for assessing the effectiveness of urban freight transportation systems using the OEE (Overall Equipment Effectiveness) metric, associated with the Lean Manufacturing framework. The appropriate utilization along with the extended life cycle of equipment covers a critical notion to use the equipment with the least possible damage. It can assist industrialists in controlling and scrutinizing consumer's expenses, effective utilization of available resources and reduced material wastage. En-Nhaili et al. [17] followed the four parts, which involved the maintenance actions by mapping the OEE indicator in which productivity parameters were linked to commanding OEE tool and its backing in improved activities to diminish the time losses in their case study.

The performance of the equipment may also be obtained by the running time (Operating time minus stop time) instead of operating time (Planned production time minus unplanned downtime) thus accounting for the suitable duration for which the equipment must be used [1]. On the other hand, Jeong and Phillips [25] encouraged "time loss" assessment work must be done on the basis of low availability along with other factors affecting performance efficiency. As an extension of the OEE, a strategy was supported to evaluate the earning capacity of machine by keeping a check on time losses. Similarly, Da Costa and de Lima [12] observed that there are many difficulties that hinder the proper implementation, acquiring proper data and using in the calculations of OEE alone. A badly chosen definition of OEEs factors may lead to a misrepresentation of the estimates and a misread of those standard values act as a trap to unaware authorities.

6 Research Gaps

The swiftly changing requirements of contemporary businesses have underlined the re-examination of maintenance strategies [40]. The entrepreneurs are locating maintenance strategies under the spotlight to adapt new advancements and benefits of these strategic tools [18]. OEE and associated losses have provided thrust to adapt this efficient maintenance tool over the traditional maintenance approaches [46]. However, the effect of government policies can also be considered as a barrier to technical development [47]. Limited literature associated with OEE and time losses have hindered the ability of the policymakers to take the right and timely decision to enhance performance.

The basic fundamentals during the selection and hunt for the research papers were the keywords such as "Overall Equipment Effectiveness," "Time Losses," "Six Big Losses" and "Performance." When the searched papers contained fewer necessary elements as per criteria, those papers were selected as possible candidates in the study. The sites used for the papers were Google, Google Scholar, Research-gate and Sc-hub etcetera.

7 Conclusions

The study highlights that the SBL are the most valuable, considerable and strategically organized factors during the implementation of the OEE metric, which can potentially assist the industries in terms of reliable information on time losses and processes inefficiencies [43, 44, 52, 53]. The results are, totally, based on the orientation of the employees, questionnaire making and data collection techniques to avoid unrealistic and wrong results calculations. The findings of this literature can contribute to both positive and negative sense radically. This review has been conducted for manufacturing and processing industries both and focused on whether decision-makers can use one or more maintenance tools/strategies/factors to get optimum results and enhanced performance [10, 49, 50].

As described by Anvari and Edwards [4], the importance of the maintenance tool to calculate the time losses and its active monitoring in a manufacturing plant has become extremely vital. OEE and time losses associated during the real execution of this concept give managers of manufacturing and process industries, a whole perspective on effectiveness. Singh et al. [48] concluded that small enterprises contribute on a large scale to manufacturing and processing sectors of under-developed countries. The industries in these countries have limited resources and revenues to apply, which force them to use a strategic metric to encompass the proper utilization of available resources and apparatus However, the technical factors such as SBL of OEE can reveal the effective use of equipment, which are utmost important for each industry to create a continuous learning and progressing environment. Singh et al. [49, 50] concluded that improvement in OEE holds the optimistic approach toward enhancement in the performance of any industries by reducing and monitoring the time losses. SBL in the production line not only serves the barriers but reduces the capacity of the equipment. The study covers progressive improvements in trade excellence performance parameters of OEE through six significant losses and its rectification, thereby demonstrating strong potential of OEE implementation to maintain business quality within limited expenditure and time periods.

References

1. Aghaie, A., Popplewell, K.: Simulation for TQM-the unused tool? TQM Mag. **9**(2), 111–116 (1997)
2. Ahmed, S., Hj. Hassan, M., Taha, Z.: TPM can go beyond maintenance: excerpt from a case implementation. J. Qual. Maint. Eng. **11**(1), 19–42 (2005)
3. Ahuja, I.P.S., Khamba, J.S.: Total productive maintenance: literature review and directions. Int. J. Qual. Reliab. Manage. **25**(7), 709–756 (2008)
4. Anvari, F., Edwards, R.: Performance measurement based on a total quality approach. Int. J. Prod. Perform. Manage. **60**(5), 512–528 (2011)
5. Arturo Garza-Reyes, J., Eldridge, S., Barber, K.D., Soriano-Meier, H.: Overall equipment effectiveness (OEE) and process capability (PC) measures: a relationship analysis. Int. J. Qual. Reliab. Manage. **27**(1), 48–62 (2010)
6. Badiger, A.S., Gandhinathan, R.: A proposal: evaluation of OEE and impact of six big losses on equipment earning capacity. Int. J. Process Manage. Benchmarking **2**(3), 234–248 (2008)
7. Badiger, A.S., Gandhinathan, R., Gaitonde, V.N.: A methodology to enhance equipment performance using the OEE measure. Eur. J. Indus. Eng. **2**(3), 356–376 (2008)
8. Badiger, A.S., Gandhinathan, R., Gaitonde, V.N., Jangaler, R.S.: Implementation of Kaizen and Poka-yoke to enhance overall equipment performance—a case study. Manuf. Eng. Vyrobne Inzinierstvo **6**(1), 24–29 (2007)
9. Baluch, N.H., Abdullah, C.S., Mohtar, S.: TPM and lean maintenance—a critical review. Interdiscipl. J. Contemp. Res. Bus. (IJCRB) (2012)
10. Burhan, N., Sari, D.A.: Analysis of overall equipment effectiveness in fanuc line 1 machines by minimizing six big losses. J. Sustain. Eng. Proc. Ser. **1**(2), 164–73 (2019)
11. Chand, G., Shirvani, B.: Implementation of TPM in cellular manufacture. J. Mater. Process. Technol. **103**(1), 149–154 (2000)
12. da Costa, S.G., de Lima, E.P.: Uses and misuses of the overall equipment effectiveness' for production management. In: IEEE International Engineering Management Conference, Vol. 2, pp. 816–820. IEEE (2002)
13. Dal, B., Tugwell, P., Greatbanks, R.: Overall equipment effectiveness as a measure of operational improvement–a practical analysis. Int. J. Oper. Prod. Manage. **20**(12), 1488–1502 (2000)
14. Dal, B.: Audit and review of manufacturing performance measures at Airbags International Limited. Doctoral dissertation (1999)
15. Dekker, R.: Applications of maintenance optimization models: a review and analysis. Reliab. Eng. Syst. Saf. **51**(3), 229–240 (1996)
16. Dogra, M., Sharma, V.S., Sachdeva, A., Dureja, J.S.: TPM–a key strategy for productivity improvement in process industry. J. Eng. Sci. Technol. **6**(1), 1–16 (2011)

17. En-Nhaili, A., Meddaoui, A., Bouami, D.: Effectiveness improvement approach basing on OEE and lean maintenance tools. Int. J. Process Manage. Benchmarking **6**(2), 147–169 (2016)
18. Garg, A., Deshmukh, S.G.: Maintenance management: literature review and directions. J. Qual. Maint. Eng. **12**(3), 205–238 (2006)
19. Ghafoorpoor Yazdi, P., Azizi, A., Hashemipour, M.: An empirical investigation of the relationship between overall equipment efficiency (OEE) and manufacturing sustainability in industry 4.0 with time study approach. Sustainability **10**(9), 3031 (2018)
20. Gholizadeh, S.: Evaluation of overall equipment effectiveness in developing country in crankshaft manufacturing. In: Proceedings of Academics World International Conference, Johannesburg, South Africa, 25–26 May 2019 (2019)
21. Gits, C.W.: Design of maintenance concepts. Int. J. Prod. Econ. **24**(3), 217–226 (1992)
22. Hedman, R., Subramaniyan, M., Almström, P.: Analysis of critical factors for automatic measurement of OEE. Procedia CIRP **57**, 128–133 (2016)
23. Herry, A.P., Farida, F., Lutfia, N.I.: November. Performance analysis of TPM implementation through Overall Equipment Effectiveness (OEE) and Six Big Losses. In: IOP Conference Series: Materials Science and Engineering, Vol. 453, No. 1, p. 012061. IOP Publishing (2018)
24. Huang, W., Xiong, Y., Wang, X., Miao, F., Wu, C., Gong, X., Lu, Q.: Fine-grained refinement on tpm-based protocol applications. IEEE Trans. Inf. Forensics Secur. **8**(6), 1013–1026 (2013)
25. Jeong, K.Y., Phillips, D.T.: Operational efficiency and effectiveness measurement. Int. J. Oper. Prod. Manage. **21**(11), 1404–1416 (2001)
26. Jonsson, P., Lesshammar, M.: Evaluation and improvement of manufacturing performance measurement systems-the role of OEE. Int. J. Oper. Prod. Manage. **19**(1), 55–78 (1999)
27. Karaulova, T., Bashkite, V.: Decision-making framework for used industrial equipment. Inzinerine Ekonomika-Engineering Economics **27**(1), 23–31 (2016)
28. Mahmood, K., Otto, T., Shevtshenko, E., Karaulova, T. (2016). Performance evaluation by using overall equipment effectiveness (OEE): an analyzing tool
29. Martomo, Z.I., Laksono, P.W.: Analysis of total productive maintenance (TPM) implementation using overall equipment effectiveness (OEE) and six big losses: A case study. In: AIP Conference Proceedings, Vol. 1931, No. 1, p. 030026. AIP Publishing LLC (2018)
30. Mathur, A., Dangayach, G.S., Mittal, M.L., Sharma, M.K. (2011). Performance measurement in automated manufacturing. Measuring business excellence
31. Moseichuk, V., Bashkite, V., Karaulova, T.: Lifecycle extension for industrial equipment. In: Proceedings of 7th International Conference of DAAAM Baltic Industrial Engineering, pp. 364–369 (2010)
32. Munoz-Villamizar, A., Santos, J., Montoya-Torres, J.R., Jaca, C.: Using OEE to evaluate the effectiveness of urban freight transportation systems: a case study. Int. J. Prod. Econ. **197**, 232–242 (2018)
33. Murray, V., Tassie, B.: Evaluating the effectiveness of nonprofit organizations. Jossey-Bass Handb. Nonprofit Leadersh. Manage. **14**, 303-324 (1994)
34. Nachiappan, R.M., Anantharaman, N.: Evaluation of overall line effectiveness (OLE) in a continuous product line manufacturing system. J. Manuf. Technol. Manage. **17**(7), 987–1008 (2006)
35. Nakajima, S.: Introduction to TPM: total productive maintenance. (Translation). Productivity Press, Inc., 1988:129 (1988)
36. Nakajima, S.: TPM development program: implementing total productive maintenance. Productivity press (1989)
37. Nord, C., Petterson, B., Johansson, B.: TPM: Total Productive Maintenance. Idrottens Grafiska, Goteborg (1997)
38. Pomorski, T.R.: Total productive maintenance (TPM) concepts and literature review. Brooks Automation, pp. 1–110 (2004)
39. Rajput, H.S., Jayaswal P.: A total productive maintenance (TPM) approach to improve overall equipment efficiency. Int. J Mod. Eng. Res. **2**(6), 4383–4386 (2012)
40. Riis, J.O., Luxhoj, J.T., Thorsteinsson, U.: A situational maintenance model. Int. J. Qual. Reliab. Manage. **14**(4), 349–366 (1997)

41. Rimawan, E., Mardono, U., Purba, H., Univercity, M.B.: Mathematical Modeling with Sem–PLS in elimination of six big losses to reduce production cost of steel factories (2018)
42. De Ron, A.J., Rooda, J.E.: Equipment effectiveness: OEE revisited. IEEE Trans. Semicond. Manuf. **18**(1), 190–196 (2005)
43. Rozak, A., Shadrina, A., Rimawan, E.: Kaizen in world class automotive company with reduction of six big losses in cylinder block machining line in Indonesia. Int. J. Innov. Sci. Res. Technol. **4**(7), 339–344 (2019)
44. Rusman, M., Parenreng, S.M., Setiawan, I., Asmal, S., Wahid, I.: The overall equipment effectiveness (OEE) analysis in minimizing the Six Big Losses: an effort to green manufacturing in a wood processing company. In: IOP Conference Series: Earth and Environmental Science, Vol. 343, No. 1, p. 012010. IOP Publishing (2019)
45. Saenz de Ugarte, B., Artiba, A., Pellerin, R.: Manufacturing execution system–a literature review. Prod. Plan. Control **20**(6), 525–539 (2009)
46. Sharma, R.K., Kumar, D., Kumar, P.: FLM to select suitable maintenance strategy in process industries using MISO model. J. Qual. Maint. Eng. **11**(4), 359–374 (2005)
47. Singh, D., Khamba, J.S., Nanda, T.: Factors contributing towards technology development in small firms. World Acad. Sci. Eng. Technol. Int. J. Mech. Indus. Sci. Eng. **8**(1), 235–243 (2014)
48. Singh, D., Khamba, J.S., Nanda, T.: Justification of technology innovation implementation in Indian MSMEs using AHP. Int. J. Serv. Oper. Manage. **32**(4), 522–538 (2019)
49. Singh, S., Singh, K., Mahajan, V., Singh, G.: Justification of overall equipment effectiveness (OEE) in Indian sugar mill industry for attaining core excellence. Int. J. **8**(1), 34–36 (2020)
50. Singh, S., Khamba, J.S., Singh, D.: Analysis and directions of OEE and its integration with different strategic tools. J. Proces. Mech. Eng. (2020). Accepted: May 2020
51. Sowmya, K., Chetan, N.: A review on effective utilization of resources using overall equipment effectiveness by reducing six big losses. Int. J. Sci. Res. Sci. Eng. Technol. **2**(1), 2394–4099 (2016)
52. Sutoni, A., Setyawan, W., Munandar, T.: Total productive maintenance (TPM) analysis on lathe machines using the overall equipment effectiveness method and six big losses. In Journal of Physics: Conference Series, Vol. 1179, No. 1, p. 012089. IOP Publishing (2019)
53. Sutoni, A., Setyawan, W., Munandar, T.: Total productive maintenance (TPM) analysis on lathe machines using the overall equipment effectiveness method and six big losses. In: Journal of Physics: Conference Series, Vol. 1179, No. 1, p. 012089. IOP Publishing (2019)
54. Tajiri, M., Gotoh, F.: Autonomous maintenance in seven steps: implementing TPM on the shop floor. Productivity (1999)
55. Vijayakumar, S.R., Gajendran, S.: Improvement of overall equipment effectiveness (OEE) in injection moulding process industry. IOSR J. Mech. Civil Eng. **2**(10), 47–60 (2014)
56. Willmott, H.: Business process re-engineering and human resource management. Personnel Rev. **23**(3), 34–46 (1994)

Optimization of Inventory Decisions Using Fuzzy Cognitive Mapping in an Automobile Component Manufacturing SME

Sanatan Ratna, Absar Ahmad, Deepak Kumar Sonu, Kushank Gupta, and B. Kumar

Abstract Inventory optimization is a serious challenge to industries around the globe. It poses a challenge to the decision-makers as poor judgment or decision can be catastrophic to any enterprise's fortunes regardless of its size and sector. The complexity arises due to the dynamic movement behavior of various inventories in the supply chain. The main aim of the current research work is to identify the most central and important concepts affecting inventory optimization in an automobile component manufacturing SME located in Delhi-NCR. The variables considered for inventory optimization are identified through a thorough literature review. The variables affecting inventory optimization are capital available, usage level, cost of procurement, credit time and material availability. The current research work makes use of Fuzzy cognitive mapping (FCM) for inventory optimization by identifying the interrelations between the various factors and the most central concept. Also, the paper aims at identifying the positive and negative associations among the various variables under study, which affect the inventory optimization decisions. The importance of the various variables is measured by making a note of the incoming and outgoing arcs for each variable in the directed graph. It is found that the most central concept is the cost of procurement.

Keywords Inventory optimization · Supply chain · Fuzzy cognitive mapping · Directed graph

1 Introduction

Inventory optimization is a matter of great concern for all the industries as it plays a very vital role in determining the profitability and smooth operation of the enterprise. It is very important to identify the most central concepts in inventory optimization

S. Ratna (✉) · A. Ahmad · D. K. Sonu · K. Gupta
Amity University Noida, Sector 125, Noida 201313, UP, India
e-mail: sratna@amity.edu

B. Kumar
Sun Rise University, Alwar 301026, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_38

as well as to study the interrelations between the various variables involved in inventory optimization. The current research work studies the inventory optimization in an automobile component manufacturing SME based in Delhi-NCR using fuzzy cognitive mapping (FCM). Axelrod, who was a political scientist, introduced the use of cognitive maps for studying and analyzing the sociological problems in the 1970s. later, with the advent of fuzzy logic, the limitations of the cognitive maps were removed and, fuzzy cognitive maps (FCM), was introduced by B. Kosko in the late 1980s. Since then, fuzzy cognitive maps have found a wide range of applications in various fields ranging from, robotics, learning management systems, reliability engineering, risk analysis in IT sector, modeling and control in engineering projects, etc. The directed graphs that are the heart and soul of the FCM are prepared based on the expert's opinion. Hence, the reliability of the FCM model is directly dependent on the expertise of the expert involved in decision-making. The FCM can be prepared using either systemic encoding of documents or by the questionnaire method by the help of domain experts. In the current research work, the author has made use of the questionnaire method wherein the expert opinion is taken for constructing the directed graphs. Using the fuzzy cognitive map obtained by expert opinion, the research work aims to find the most central concept affecting the inventory optimization decision.

2 Literature Review

John et al. [1] used Fuzzy Cognitive Mapping for studying the impact of stress among workers in renewable energy windfarm. A total of 15 attributes were taken into consideration for preparing the questionnaire. It was found that off-road traveling and issues between the locals and the employees were the main factors behind the worker's stress. Martin et al. [2] made use of FCM for analyzing the advantages of biotreatment over mechanical processing used in leather industry. The six factors considered for the study are listed as, cost-effectiveness, environment friendly, no secondary pollution, reduction in toxicity level, remedial to environmental regulation and reliability enhancement. Using FCM, it was quite evident that the concepts environment friendly and no secondary pollution were the most central ones. Jahangoshai Rezaee et al. [3] studied the prioritization of risks based on a hybrid approach by combining failure analysis and fuzzy cognitive mapping in automotive component manufacturing industry. The author carried the prioritization if the failures by considering three criteria namely detection, severity and occurrence. Sujatha et al. [4] used fuzzy cognitive mapping and induced fuzzy cognitive mapping for controlling the traffic menace in the city of Chennai. They used signal waiting time at the traffic at different time slots. The outcomes of the techniques used clearly indicated the relationship between traffic volume, signal waiting time and time intervals. Papakostas et al. [5] used fuzzy cognitive maps for pattern recognition. The researchers introduced the use of a highly flexible FCM by making use of nodes that could adapt with adjusted activation functions. This flexibility introduced to the FCM led to an increase in the degrees of freedom so that the model could store more information and could learn more, which is a necessity in pattern recognition applications. Azadeh et al. [6] carried out the leanness assessment in packaging industry in Iran using fuzzy cognitive mapping and multivariate analysis. The approach used could be used to measure the degree of effect of leanness attribute to each other. It was concluded that the major factor that had most impact on the leanness in the packaging industry stood out to be the production procedure. Sona et al. [7] made use of fuzzy cognitive mapping for analyzing the factors in production management. The factors that are considered vital for affection production management are listed as, machine availability, material availability, sustainability, environmental difficulties, dynamic market conditions, labor availability, market competition and technological improvement. It was deduced that, as the environmental difficulties increase and the technological developments decrease, then the production process improvements can be brought about by keeping the factors labor availability, machine availability, material availability (between positively strong and very strong). Balaji and Lokeswara Choudary [8] used fuzzy cognitive mapping for inventory functions optimization in the automobile component manufacturing industry. On the basis of previous work done, the researchers identified 15 key variables affecting the inventory optimization decisions in the automobile component manufacturing industry. Using static analysis, it was determined the key central concept affecting the optimization decision was the purchase cost of the components. It was also concluded that the purchasing cost had a positive relation with carrying cost and transportation cost. Azhdari [9] integrated Bayesian network learning along with fuzzy cognitive mapping for supply chain causal modeling. A total of 20 variables were taken into account for preparing the directed graph. It was quite evident from the outcomes that the technology used for interorganizational communication had direct relation with information sharing. It was also concluded that supply chain integration was directly linked to logistics performance. Rajkumar et al. [10] used combined overlap block fuzzy cognitive mapping for finding a solution for effective teaching. The researcher made use questionnaire to take into account, a total of 11 concepts affecting effective teaching. It was concluded that for effective teaching that the educational institutes needed to focus on the student‘s social and personal competence to tackle the complex real-life challenges.

3 Attributes of the Study

Using the literature review, the main factors affecting the inventory optimization decisions are selected and listed below.

S1—Capital Available; S2—Usage Level; S3—Cost of Procurement; S4—Credit Time and S5—Material Availability

Using expert opinion, the adjacency graph is obtained, showing the interrelations between the various factors as shown in Fig. 1.

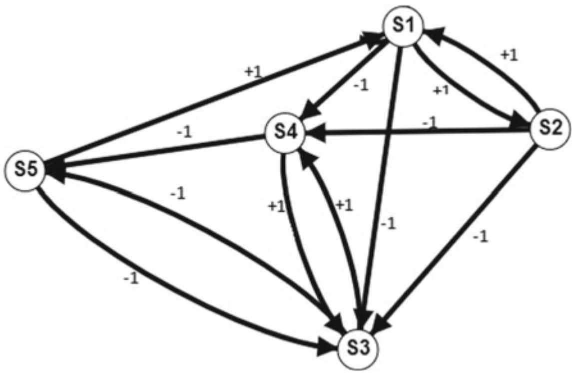


Fig. 1 Directed graph showing interrelationships between nodes

Table 1 FCM matrix for inventory

	S1	S2	S3	S4	S5
S1	0	1	−1	−1	0
S2	1	0	−1	−1	0
S3	0	0	0	1	−1
S4	0	0	1	0	−1
S5	1	0	−1	0	0

The FCM matrix thus obtained for the inventories is shown in Table 1.

The adjacency matrix E can be denoted as,

$$E = \begin{bmatrix} 0 & 1 & -1 & -1 & 0 \\ 1 & 0 & -1 & -1 & 0 \\ 0 & 0 & 0 & 1 & -1 \\ 0 & 0 & 1 & 0 & -1 \\ 1 & 0 & -1 & 0 & 0 \end{bmatrix}$$

If there is no relationship (null) between two variables, it is represented by Zero (0); if there is a positive relation between two variables, it is represented by One (1); a negative relation between variables is represented by -1. Also, in the adjacency graph forward and reverse direction, arrows are used for representing positive and negative relationships.

4 Static Analysis

The static analysis is carried out by studying the adjacency graph obtained as per the expert opinion. It basically represents the FCM model, using the graph theory technique. The first step to examine the model statically is to calculate the density "d of the model, which is given by Eq. 1.

$$d = \frac{m}{n(n-1)} \quad (1)$$

Here, "m" is the number of arcs in the model while, "n" is the number of nodes/variables involved in the adjacency graph. The product "$n(n - 1)$" represents the maximum number of arcs that the graph can possibly have. The density thus obtained indicates the complexity of the problem. In this case, the density "d" is obtained as $d = 12/5(5 - 1) = 0.60$, which is quite high.

The graph theory also provides the importance of the nodes used in the directed graph used in FCM model. The importance of a node in the adjacency graph is measured as Imp. (i) = In (i) + Out (i).

Where, In (i) = number of incoming arcs for the nodes.

Out (i) = number of outgoing arcs for the nodes.

The incoming and outgoing arcs for each node are listed in Table 2.

It is found that the most important concept is S3 followed by S1 and S4. Table 3 below classifies the various factors based on the total scores obtained by each factor.

Based on the scores obtained by the various factors, the five factors under consideration have been classified into, most critical, moderately critical and least critical factors.

Table 2 Critical node of inventory optimization

	S1	S2	S3	S4	S5
In	2	1	4	3	2
Out	3	3	2	2	2
Total	5	4	6	5	4

Table 3 Factor classification based on scores obtained

	Factor	Score	Nature of factors
S3	Cost of procurement	6	Most critical
S1	Capital available	5	Moderately critical
S4	Credit time	5	Moderately critical
S2	Usage level	4	Least critical
S5	Material availability	4	Least critical

5 Dynamic Analysis

S1—Capital available

If the Capital available is considered as a decision parameter and all other variables are not considered for decision purpose, the dynamic behavior observed by the variable from the below-mentioned matrix is as follows.

The behavior observed in the matrix multiplication is, when S1 is on

$$\begin{aligned} &\mathrm{A1} = [1, 0, 0, 0, 0] \\ &\mathrm{A2} = \mathrm{A1} * E = [01 - 1 - 10] = \mathrm{A2} = [\,1\,1\,0\,0\,0] \\ &\mathrm{A3} = \mathrm{A2} * E = [\,1\,1\ -2\ -2\,0\,] = \mathrm{A3} = [\,1\,1\,0\,0\,0] \end{aligned}$$

The matrix remultiplication is ceased here, due to convergence happened in the outcome results by observing similar results. It is quite clear, that the key decision variables are S2 while, S3, S4 and S5 are negative. Hence, if S1 is on, then the factors S1 and S2 are on and S3, S4 and S5 become negative. Therefore, if S1 is on then, S2, S3, S4, S7, S8, S10, S13, S14 are on and S5, S15 becomes negative. This means that the factor S1 (capital available) has got a positive association with the factor S2 (usage level).

S2—Usage level

The behavior observed in the matrix multiplication is, when S2 is on

$$\begin{aligned} \mathrm{B1} &= [0\,1\,0\,0\,0] \\ \mathrm{B2} = \mathrm{B1} * E\ = [1\,0\ -1\ -1\,0] = \mathrm{B2} &= [1\,1\,0\,0\,0] \\ \mathrm{B3} = \mathrm{B2} * E\ = [1\,1\ -2\ -2\,0] = \mathrm{B3} &= [1\,1\,0\,0\,0] \end{aligned}$$

The matrix remultiplication is ceased here, due to convergence happened in the outcome results by observing the similar results.

S3—Cost of Procurement

The behavior observed in the matrix multiplication is, when S3 is on

$$\begin{aligned} &\mathrm{C1} = [0\,0\,1\,0\,0] \\ &\mathrm{C2} = \mathrm{C1} * E = [0\,0\,0\,1\ -1] = \mathrm{C2} = [0\,0\,1\,1\,0] \\ &\mathrm{C3} = \mathrm{C2} * E = [0\,0\,1\,1\ -2] = \mathrm{C3} = [0\,0\,1\,1\,0] \end{aligned}$$

The matrix remultiplication is ceased here, due to convergence happened in the outcome results by observing the similar results.

S4—Credit Time

The behavior observed in the matrix multiplication is, when S4 is on

$$\mathrm{D1} = [0\,0\,0\,1\,0]$$

$$\text{D2} = \text{D1} * E = [0\,0\,1\,0\ -1] = \text{D2} = [0\,0\,1\,1\,0]$$
$$\text{D3} = \text{D2} * E = [0\,0\,1\,1\ -2] = \text{D3} = [0\,0\,1\,1\,0]$$

The matrix remultiplication is ceased here, due to convergence happened in the outcome results by observing similar results.

S5—Material Availability

The behavior observed in the matrix multiplication is, when S5 is on

$$\text{E1} = [0\,0\,0\,0\,1]$$
$$\text{E2} = \text{E1} * E = [1\,0\ -1\,0\,0] = \text{E2} = [1\,0\,0\,0\,1]$$
$$\text{E3} = \text{E2} * E = [1\,1\ -2\ -1\,0] = \text{E3} = [1\,1\,0\,0\,0]$$
$$\text{E4} = \text{E3} * E = [1\,1\ -2\ -2\,0] = \text{E4} = [1\,1\,0\,0\,0]$$

The matrix remultiplication is ceased here, due to convergence happened in the outcome results by observing the similar results.

6 Conclusion

Minimization of inventory costs is a challenge faced by the industries worldwide. There can be a number of approaches used to solve this problem. The current research work makes use of fuzzy cognitive mapping for addressing the issue of inventory optimization in an automobile component manufacturing SME. FCMs are used for controlling and modeling complex systems. It is found through static analysis that the inventory cost is mostly influenced by the variable S3 (Cost of Procurement), followed by S1 (Capital Available) & S4 (Credit Time). Also, it is observed that, if S1 is on, then the factors S1 and S2 are on and S3, S4 and S5 become negative. This means that the factor S1 (capital available) has got a positive association with the factor S2 (usage level). Similarly, the positive and negative associations between the various factors are calculated for different conditions. In the future, more factors can be taken into account for making inventory optimization decisions, which will lead to robustness of the system.

References

1. John, A. et al.: A study on impact of stress among workmen in a renewable energy windfarm. Int. J. Manage. Appl. Sci. **3**(3),48–52 (2017)
2. Martin, N et al.: An analysis of the influential advantage of bio treatment over mechanical processing in conversion of Cr (VI) To Cr (III) in leather industry using fuzzy cognitive maps. Int. J. Adv. Eng. Manage. Sci. **2**(7), 1037–1040 (2016)

3. Jahangoshaye Rezaei, M., Youssefi, S., Bagheri, M.: A hybrid approach to risk prioritization based on failure analysis and fuzzy cognitive map: a case study of the automotive parts industry. Adv. Indus. Eng. **52**(2), 193–205 (2018)
4. Sujatha, R., Kuppuswami, G.: Fuzzy cognitive maps and induced fuzzy cognitive maps approach to traffic flow. J. Phys.: Conf. Ser. **1377**, 012012 (2019)
5. Papakostas, G.A., Boutalis, Y.S., Koulouriotis, D.E., Mertzios, B.G.: Fuzzy cognitive maps for pattern recognition applications. Int. J. Pattern Recognit Artif. Intell. **22**(08), 1461–1486 (2008)
6. Azadeh, A., Zarrin, M., Abdollahi, M., Noury, S., Farahmand, S.: Leanness assessment and optimization by fuzzy cognitive map and multivariate analysis. Expert Syst. Appl. **42**(15), 6050–6064 (2015)
7. Sona, P., Johnson, T., Vijayalakshmi, C.: Analyzing factors in production management using fuzzy cognitive mapping. Int. J. Pure Appl. Math. **118**(23), 517–524 (2018)
8. Balaji, N., Lokeswara Choudary, Y.: An application of fuzzy cognitive mapping in optimization of inventory function among auto component manufacturing units in SME sector. Int. J. Manage. **3**(2), 13–24 (2012)
9. Azhdari, B. (2018). Integrating fuzzy cognitive mapping and bayesian network learning for supply chain causal modeling. In: Proceedings of the 7th International Conference on Operations Research and Enterprise Systems, pp. 59–70 (ICORES 2018)
10. Rajkumar, A., Parveena, J., Jayalatha, C., Praveen Prakash, A. (2012). A solution for effective teaching methods for teachers by fuzzy cognitive maps (COBFCMS). Int. J. Sci. Eng. Res. **3**(3), March-2012. ISSN 2229-5518

A Preliminary Study on Six Sigma to Reduce the Waiting Time of the Patients in Hospitals

S. Anjana and O. S. Deepa

Abstract This paper is based on a preliminary study of six sigma methodology for reducing the waiting time thereby increasing the patient satisfaction and to minimize the cost in a hospital. An optimization model is developed with regard to minimize waiting time and minimize cost. Various factors like time taken by the doctors to examine the patient, time taken to administer the medicines, number of skilled persons, total time taken to shift to the ward or to the scanning center were considered for testing the hypothesis. A nonparametric approach is used to test the significant difference between certain factors also collected data were tested to determine the need for the waiting time in the anesthetic lab. DMAIC technique is used for continuous improvement on quality and for achieving operational superiority. By identifying the key factors as the root cause and thereby deriving solutions is the main aim of this paper, which ultimately leads to success of the hospitals and hence offers the potentiality to implement the suggestions on every small and medium hospitals for gaining patient satisfaction.

Keywords Six sigma · DMAIC technique · Nonparametric test · Patients · Hospitals · Scanning labs

1 Introduction

SS is an efficient data-driven procedure with the intention dropping down the process variation. Process variation naturally reduces energy consumption, reduce cost, reduce defect, reduce workflow variability, and reduce scrap which in turn leads to eco-friendly environment. Six sigma has been a powerful management strategy across all services. It also focuses on rapid and robust improvements. Six sigma concentrates on the performance of the process and process flow improvement. There is much increasing pressure on health care industry due to competitive priorities and

S. Anjana · O. S. Deepa (✉)
Department of Mathematics, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, India
e-mail: os_deepa@cb.amrita.edu

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_39

resource constraints, which has made researchers to focus on continuous improvement practices throughout the globe. In recent days, patients think about quality requirement in all health care services as an important aspect. Patients look out for quality as a requirement choosing a healthcare service. Also based on experiences, patients acquire satisfaction level for future decisions. Hence six sigma plays an important role in both waiting time and cost by reducing the likelihood in the occurrence of errors. Only few documented research were done integrating optimization and six sigma in health care and hence this paper tries to fill in the gaps by providing a case study thereby increasing patient satisfaction and overall improvement in health care performance. This paper identifies the key performance measures like efficacy in public health service, expanding public health challenges and optimizing resources utilization including the waiting time, length of stay, increased capacity, increased staff morale, patient satisfaction, patient-centric service levels, medical quality and cost reduction. Leading private hospitals are acknowledged as world-class hospitals and are considered as one of the competitors and are expected to increase their performance by the usage of six sigma with the combination of optimization and probabilistic models together. A great sum of hospitals in India are facing difficulties in meeting the demands of the customers while handling the minimum expenses and waiting time of each customers. Controlling health care costs while providing the best possible health outcomes has become a serious issue [1–4]. Control charts are used to check whether the system is in control or not. Data mining application of Chinese students' physical health test was studied in detail [5–7]. Lean Six Sigma as a panacea to improve service quality in medical tourism was explained [8, 9]. Chronic conditions and barriers to care in Indiana and studies in Cyprus was also made [10–12]. Application of Lean Six Sigma approach in Indian hospitals to improve patient care control charts has been extensively used in attribute sampling plan and variable sampling plan and is the most commonly used in industries to monitor the production process [5, 6, 13, 14].

2 Implementation of Six Sigma

This paper deals with the implementation of six sigma methodology for reducing the waiting time in hospital which leads to increase in patient satisfaction. Our study was conducted at a hospital consisting of 150 bed multispecialty hospital with 24/7 emergency, clinical laboratory, radiology and scanning services. Scanning services include CT scan, ultrasound and ECHO cardiography. The hospital though specifically catering to Pediatrics, Neonatology, Obstetrics and Gynecology, infertility clinic with assisted reproductive treatment also has broad and super specialties including Medicine, Cardiology, Pulmonology, Endocrinology, Surgery, Orthopaedics, Urology, ENT, Ophthalmology, Anesthesiology and intensive care and Dentistry. The hospital caters to approximately 800 outpatients (all departments) and around 90–100 inpatients per day. Around 300–350 surgeries including major, minor and emergency procedures are performed per month.

2.1 Define Phase

Under the define phase, four major tasks are undertaken, i.e., a project team should be formed, customer requirements should be documented, a project charter should be developed, and a project map should be formed.

Our six sigma team includes specialists, chief nurse, practice nurse, secretary and purchase manager. The main objective of the project is to minimize cost of setting up a hospital and to minimize the waiting time of the patients without degrading the quality of service. In this study, we are mainly focusing on scanning centers and analyzing laboratories. Therefore, at the beginning of the study, the difference in the output of a particular equipment from different companies was recorded. The summary of the work to be done is noted for implementation.

1. To create an optimization model for reducing the cost and waiting time
2. To incorporate fishbone diagram based on quality scanning service.
3. Analyzing the patient waiting time in laboratory by a schematic diagram.
4. To check whether the type of anesthesia affects the patients' health factors.
5. To test the association between expert's opinion and type of anesthesia.
6. Rank correlation for the patient waiting time.
7. Details of time taken to administer medicines and time taken to shift toward by hypothesis testing.

2.2 Measure Phase

With the quality of scanning service and other factors, minimizing the waiting time and cost was developed with objective functions and constraints.

(i) Minimize the waiting time

Index:

n—index of patients
s—index of services
m—index of machines
a—index of analyzers.

Parameters:

R_s—fixed service time for each customer at registration desk
Mt_m—fixed total time taken by the machine m to provide results
At_a—fixed total time taken by the analyzers a to provide results
A_n—average number of customers
T_s—average service time for each customer
T—total time till horizon.

Variables:

D_s^n—consulting time for each patient n.
P_q—number of patients waiting in the queue.
M_s^n—time taken to prescribe medicine to each patient n.

$$\min\left\{\left[\sum_{s\in S}\sum_{n\in N} D_s^n P_q\right] + \left[\sum_{s\in S}\sum_{n\in N} M_s^n P_q\right] + \left[\sum_{s\in S} R_s P_q\right] + \left[\sum_{m\in M} M t_m\right] + \left[\sum_{a\in A} A t_a\right]\right\}$$

Subject to constraints:

$A_n.\, t_s \le T$

(i) Minimum Cost

Index:

i—index of locations of specialized hospitals
s—index of types of specialized services

Parameters:

h_i—fixed cost of opening specialized hospital at location i.
d_s—coefficient of specialized doctors required for the specialized services.
dm_s—maximum number of available specialized doctors in the system.
d_n—maximum number of available nurses in the system.
q_s—coefficient of the required nurse.
Cy_{is}—maximum capacity of specialized hospital at location i for specialized service s.
Coy_{is}—cost of setting up services s in specialized hospital at i location.
πa—the cost of unit storage for service s.

Machines and laboratories' parameters:

MC_m^s—fixed cost of machines m for service types.
EW_m—electricity and water resources consumed annually.
HR_m—cost of human resources.
A_a^{ld}—fixed cost of analyzers for setting labs l in hospital for service s.

Variables:

y_i—1, if specialized hospital is opened at location i; 0 other.

ey_i^s—number of beds for specialized service types.
ny_i^s—number of required specialized doctors for service types.
nq_i^s—number of required nurses for service types.
ay_i—flow of patients to specialized hospitals at *i*.
O_l—cost of other consumables in laboratories' l.
AMC_m—annual maintenance cost of machines m.

$$\min\left\{\left[\sum_{i\in I} h_i y_i\right]+\left[\sum_{i\in I}\sum_{s\in S}\mathrm{Coy}_{is} ey_i^s\right]+\left[\sum_{m\in M}\sum_{s\in S}\mathrm{MC}_m^s\mathrm{AMC}_m\right]\right.$$
$$\left.+\left[\sum_{l\in L} O_l\right]+\left[\sum_{l\in L}\sum_{a\in A} A_a^l\right]+\left[\sum_{i\in I}\sum_{s\in S}\pi a * \max[cy_{is} - ay_i]\right]\right\}$$

Subject to constraints:

(i) $\sum ny_i^s \le dm_s$
(ii) $\sum nq_i^s \le dn$
(iii) $\sum d_s.\ ey_i^s \le ny_i^s$.

Considering the above mentioned two objective functions and its constraints (i) minimize the waiting time and (ii) minimize cost and, it was found that minimize the waiting time has to be concentrated more. This decision was reached in discussion with the authorities of the hospital.

2.3 Analyze Phase

A fishbone diagram has been implemented based on quality scanning service and is shown in Fig. 1.

A survey was conducted to analyze the waiting time of patients and the representation is given in Fig. 2.

2.4 Measure Phase

Since ultrasound, CT scan and X-ray are used in this study, it is decided to check whether the type of anesthesia affects the patients' health factors. Few questions were discussed with the experts of the lab:

1. Does the patient experience pain?
2. Is the patient sedated?
3. Does the patient have nausea and vomiting?

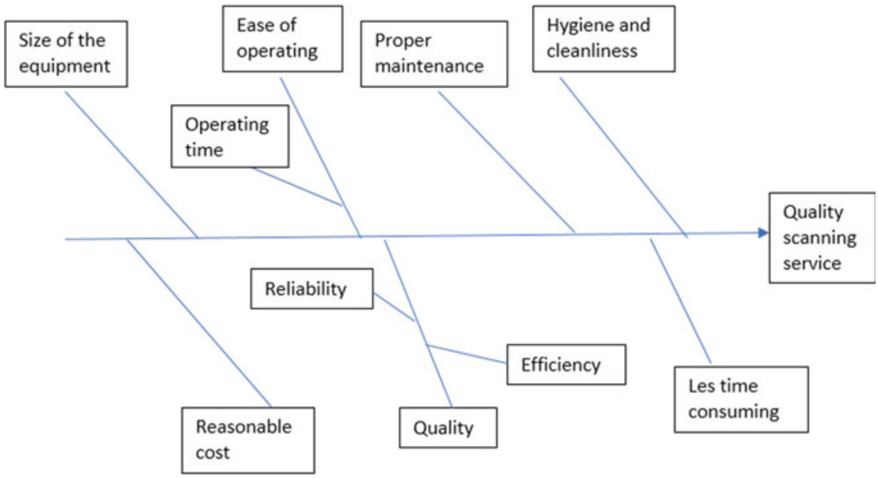


Fig. 1 Fishbone diagram for quality scanning service

4. Does the patient have shivering?
5. Does the patient have sore throat?
6. Is there any bruising or soreness due to the IV drip?

A sample is shown in Table 1.

Patients do not have nausea vomiting, sore throat and bruising from IV drip in any of the anesthesia whereas pain depends on the patients' health, age and sedation depends on the type of anesthesia. The above questions were rated by three doctors based on the number of patients studied and type of anesthesia. The expert's opinion is given in Table 2.

The rating was based on 1–5 scale starting from very less, less, medium, high and very high. Using Chi-square test, it was found that there is no association between expert's opinion and type of anesthesia and hence one cannot conclude anything about the type of anesthesia with respect to patients. Hence only scanning centers were considered for further study.

To record the waiting time of the patient, the team came up with a manual measurement procedure. The time taken by the specialist to examine the patient was noted down by the specialist and the time taken to administer medicines is noted down by the practice nurse. The chief nurse was responsible to note down the time taken to shift the patient to the ward or scanning center and the details of the time taken for various situations are given in Table 3.

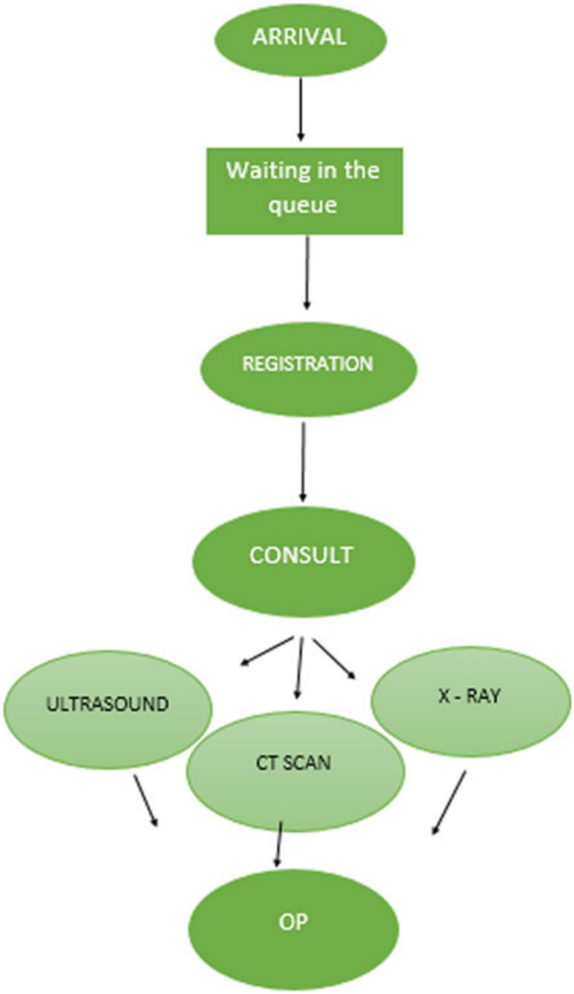
The following null and alternative hypotheses were considered

Ho: The samples come from populations with equal medians

Ha: The samples come from populations with medians that are not all equal.

Since the $\chi^2 = 32.373 > \chi^2$ (table value) $= 7.815$ and P-value < 0.05, it is concluded that the null hypothesis is rejected. Therefore, there is enough evidence

Fig. 2 Analyze the patient waiting time



to claim that the not all population medians are equal at $\alpha = 0.05$ significance level. Also, it is decided to test whether there is any correlation between the factors that are considered. Table 4 gives the rank correlation for the patient waiting time.

Using spearman's rank correlation, it is observed that the total time taken to shift the patient to ward or scanning center is mostly influenced by the time taken to administer medicines. The other two factors that is the time taken by the specialist to examine the patient and the number of skilled persons available partially influence the total time. Hence, there is a lag to administer medicines to the patient. Our team recommended to install a proper medical record near each bed and the trained and skilled nurses can help the patients with the medicine immediately after the doctor examines the patient and gives out instructions.

Table 1 Sample data based on patient based on anesthetic effects

Patients	Type of anesthesia	Pain	Sedation	Nausea and vomiting	Shivering	Sore throat	Bruising from iv drip
1.	Regional	Yes	No	No	Yes	No	No
2.	General	No	Yes	No	No	No	No
3.	General	Yes	Yes	No	No	No	No
4.	Local	No	No	No	No	No	No
5.	Regional	Yes	Yes	No	No	No	No
6.	General	Yes	Yes	No	No	No	No
7.	General	Yes	Yes	No	No	No	No
8.	Local	No	No	No	No	No	No
9.	Regional	No	Yes	No	No	No	No
10.	Regional	No	Yes	No	Yes	No	No

Table 2 Expert's opinion

Questions	Expert 1	Expert 2	Expert 3
Type of anesthesia: *local*			
1.	1	1	1
2.	1	1	1
3.	1	1	1
4.	1	1	1
5.	1	1	1
6.	1	1	1
Type of anesthesia: *regional*			
1.	2	2	3
2.	5	4	4
3.	1	1	1
4.	1	2	1
5.	1	1	1
6.	1	1	1
Type of anesthesia: *general*			
1.	4	4	4
2.	4	3	4
3.	1	1	1
4.	1	1	1
5.	1	1	1
6.	1	1	1

Table 3 Details of time taken for various situations

Sr. No.	Time taken by the doctor to examine the patient	Time taken to administer medicines	No. of skilled persons	Total time taken to shift to the ward or the scanning center
1.	2	15	1	60
2.	3	10	1	45
3.	3	60	2	90
4.	15	20	2	75
5.	2	5	1	60
6.	2	5	1	60
7.	2	5	2	30
8.	5	10	2	60
9.	3	5	2	60
10.	3	10	3	60

Table 4 Rank correlation for the patient waiting time

R_1	R_2	R_3	R_4	D_1	D_2	D_3	D_4	D_5	D_6	D_1^2	D_2^2	D_3^2	D_4^2	D_5^2	D_6^2
2.5	8	2.5	5.5	−5.5	5.5	−3	−3	0	2.5	30.25	30.25	9	9	0	6.25
6.5	6	2.5	2	0.5	3.5	0.5	4.5	4	4	0.25	12.25	0.25	20.25	16	16
6.5	10	7	10	−3.5	3	−3	−3.5	−0.5	0	12.25	9	9	12.25	0.25	0
10	9	7	9	1	2	−2	1	3	0	1	4	4	1	9	0
2.5	2.5	2.5	5.5	0	0	−3	−3	0	−3	0	0	9	9	0	9
2.5	2.5	2.5	5.5	0	0	−3	−3	0	−3	0	0	9	9	0	9
2.5	2.5	7	1	0	−4.5	6	−1.5	−4.5	1.5	0	20.25	36	2.25	20.25	2.25
9	6	7	5.5	3	−1	1.5	3.5	2	0.5	9	1	2.25	12.25	4	0.25
6.5	2.5	7	5.5	4	−4.5	1.5	1	−0.5	−3	16	20.25	2.25	1	0.25	9
6.5	6	10	5.5	0.5	−4	4.5	1	−3.5	1.5	0.25	16	20.25	1	12.25	2.25

Where $D_1 = R_1–R_2$, $D_2 = R_2–R_3$, $D_3 = R_3–R_4$, $D_4 = R_1–R_4$, $D_5 = R_1–R_3$, $D_6 = R_2–R_4$

2.5 Improve Phase

Under improve phase, the outcomes are supposed to be recorded and improvement to see if our recommendations worked out. The following are the certain steps that have to be implemented in order to reduce the waiting time and maintain patient satisfaction.

1. Patients have to be encouraged to early appointments
2. Online check in system should be made mandatory
3. Separate counters or mobile app to get more details of the patients before appointments
4. Encourage patients to use portal

5. Workflow has to be monitored and streamlined
6. Should not encourage late appointments
7. Frequent survey of time spends by the patients in the registration counter, examination room, waiting room and with doctor
8. Incorporate patient's preference only in case of emergency
9. Revamp proper queuing system
10. Improve communication between staffs and patients
11. Bill payment and appointment scheduling can be done using mobile app
12. To ensure the sustainability, doctors can monitor their personal waiting time and make necessary changes if any deviations occur.
13. Outpatient Appointment Reminder System (OARS) should be encouraged.
14. Redesign the entire hospital set up if time management is more
15. Reassigning work responsibilities and reviewing work processes should be done frequently.

3 Conclusion

A preliminary study was made based on the waiting time taking various factors into consideration. The study is considered to be preliminary, because the data obtained were limited and only two factors are considered as root caused (i) cost of the setting up of a hospital and (ii) waiting time of patients. First, in define stage a brief study was made with regard to cost and waiting time in a hospital. In measure phase, an optimization model was developed with regard to minimize waiting time and minimize cost. In analyze phase, a flow chart to analyze the patients' waiting time and a fishbone diagram for scanning quality was explained. In measure phase, the time taken by the specialist to examine and the time taken to administer medicines are noted and hypothesis testing is made to achieve at a decision and noted that all population medians are equal. Also, from Chi-square test, it was found that there is no association between expert's opinion and type of anesthesia. Nonparametric method was used to test the significant difference between certain factors that has been used in the study and found that the total time taken to shift the patient to ward or scanning center is mostly influenced by the time taken to administer medicines. It was also tested and decided that the anesthetic patients need not be considered for this study as the data obtained depend on patients' health and was not related to waiting time. Hence in improve phase, various measures have been suggested for implementation so as to gain patient satisfaction by minimizing the waiting time. The proposed work can be extended to identifying all the root cause for minimizing cost and waiting time in a super multispecialty hospital and hence various advanced measures of six sigma methodology can be implemented.

References

1. Ammar, A., Pierreval, H., Elkosantini, S.: A multiobjective simulation optimization approach to define teams of workers in stochastic production systems. In: Proceedings of IEEE International Conference Industrial Engineering System Management (IESM), pp. 977–986 (2015)
2. Chen, J., Lyu, Z., Liu, Y., et al.: A big data analysis and application platform for civil aircraft health management. In: Taipei: IEEE Second International Conference on Multimedia Big Data (2016)
3. Elstner, S., Theil, M.: The health and social care of people with disabilities in Germany. Adv. Mental Health Intellect. Disabil. **12**(3/4), 99–104 (2018)
4. LI, X., LI, Y.: Monitoring and evaluation of physical and mental quality of middle school students based on big data analysis. Electr. Sci. Technol. **32**(4), 85–90 (2019)
5. Deepa, O.S.: Application of acceptance sampling plan in green design and manufacturing. Int. J. Appl. Eng. Res. **10**(2), 1498–1499 (2015)
6. Deepa, O.S.: Optimal production policy for the design of green supply chain model. Int. J. Appl. Eng. Res. **10**(2), 1600–1601 (2015)
7. Yan, P.: Thoughts and enlightenment of data mining application of Chinese students' physical health test. Sci. Technol. Inf. **15**(22), 199–200 (2017)
8. Panagiotopoulos, C., Apostolou, M., Zachariades, A.: Assessing migrants' satisfaction from health care services in Cyprus: a nationwide study. Int. J. Migr. Health Soc. Care **16**(1), 108–118 (2019)
9. Pradeep Nair, R., Paul, G.: Lean six sigma as a panacea to improve service quality in medical tourism. Int. J. Acad. Res. Dev. **4**(6), 495–499 (2017)
10. Sandoval-Rosario, M., Hunter, T., Durnham, A., Holt, A., Pontones, P., Perry, G.: Chronic conditions and barriers to care: exploring the health of migrant and seasonal farmworkers in Indiana". Int. J. Hum. Rights Healthcare **9**(4), 229–234 (2016)
11. Hinchageri, S., Patil, N.R., Teli, S.: Application of lean six sigma approach in indian hospitals to improve patient care. World J. Pharm. Med. Res. **4**(1), 45–53 (2018)
12. Shruthi, G., Deepa, O.S.: Average run length for exponentiated distribution under truncated life test. Int. J. Mechan. Eng. Technol. (IJMET) **9**(6), 1180–1188 (2018)
13. Phanden, R.K., Demir, H.I., Gupta, R.D.: Application of genetic algorithm and variable neighborhood search to solve the facility layout planning problem in job shop production system. In: 2018 7th International Conference on Industrial Technology and Management (ICITM), pp. 270–274. IEEE (2018)
14. Krishnan, S.M., Deepa, O.S.: Control charts for multiple dependent state repetitive sampling plan using fuzzy poisson distribution. Int. J. Civil Eng. Technol. (IJCIET) **10**(1), 509–519 (2019)

Prioritization of Sustainable Development Methods in the Manufacturing Sector: An Entropy TOPSIS Approach

Mahender Singh Kaswan and Rajeev Rathi

Abstract The intergovernmental policies on climate change and the shorter product lifecycle of the product have forced the organization to adopt sustainable methods. The industrial organizations are in the constant run to search for sustainable technologies that meet the modern demand of the industry. The main concern for the manufacturing organizations is the selection of the approaches that are best suitable for the modern demand of the industry. The present study deals with the selection of a sustainable development approach based on the criterion. The selection of the sustainable methods has been done through the TOPSIS and the weights of the criterion were found through the entropy method. It has been found the Green Lean Six Sigma and Six Sigma methodology has found the prominent sustainable development methods with the closeness coefficients 0.938 and 0.322, respectively. The present will facilitate the practitioners and managers to select a sustainable approach that will make the holistic development of the organization.

Keywords Total quality management · Lean · Six sigma · Lean six sigma · Entropy method · Green lean six sigma · TOPSIS · Sustainability

1 Introduction

The increased level of the emission of harmful gases and reduced material efficiency has forced the manufacturing sector to adopt sustainable methods [1–4]. The industry contributes nearly one-fourth of the carbon emission. These incidents have resulted in a substantial increase in the temperature of the earth since the last decades [5]. This has led to the unprecedented actions of the changing pattern of diseases, endangering of the rare earth species, extreme hot and cold weather worldwide [6]. The industrial want to meet the modern sustainable demand of the customer through the induction of new eco-friendly approaches [7–10]. The industrial organizations are implementing from the mid of the last century the sustainability centered approaches [11–15].

M. S. Kaswan · R. Rathi (✉)
School of Mechanical Engineering, Lovely Professional University, Phagwara, Punjab 144411, India
e-mail: rathi.415@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_40

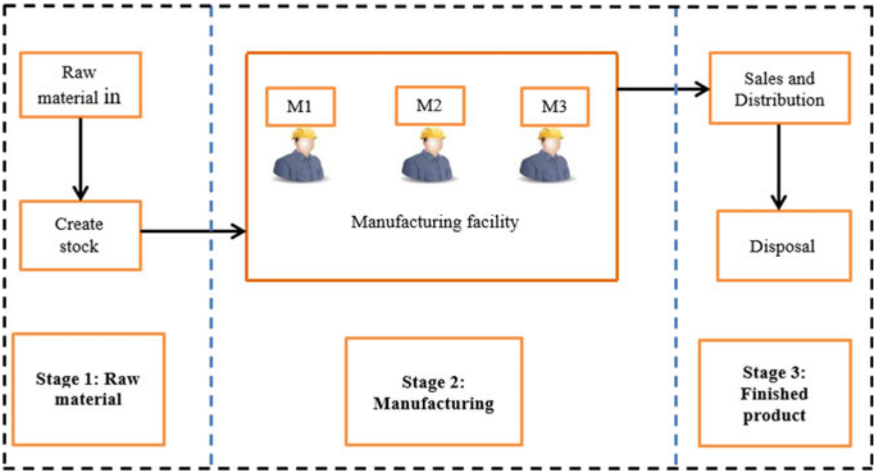


Fig. 1 Various stages of the manufacturing

The industrial organizations are using Lean, Six Sigma, Total Quality Management (TQM), Lean Six Sigma (LSS), and new evolved Green Lean Six Sigma process for managing their operations. Since a bunch of sustainable methods are available, the industrial managers and practitioners face difficultly in selecting a particular approach that has the maximum potential to affect all the dimensions of sustainability [16]. Figure 1 depicts the various dimensions of sustainability. So, the present work deals with the selection of the sustainable development approach based on the four sustainable criteria. The present work deals with the selection of the sustainable development approach that is the best suited to the modern demand of the industry. The present article has divided into five parts. The first section represents the introduction of the present work. The second section represents the literature of the present research work. The third section illustrated the adopted research methodology. The results and discussion related to current work have been presented in the fourth section of the manuscript. The conclusion has been presented in the last section of the manuscript.

1.1 Research Objectives

The present study has carried out with the following objectives:

- To identify and weight the criterion for the selection of the most appropriate sustainability-oriented approach.
- Selection and prioritization of the sustainability-oriented approaches through entropy-based TOPSIS method.

- Facilitate the practitioners and industrial managers to adopt and comprehend sustainability inclined approaches for improved organizational performance at the global stage.

2 Literature Review

The changed quality perception and increased global pressure to mitigate climate change have forced the industries to adopt sustainable methods of production [9, 10]. The clean technologies are that associated form of management practices where all the organizational resources are fully utilized for improved sustainability dynamics [11, 12]. The industries need to reduce the level of the GHGs to mitigate the current challenges of the production. The industries are adopting practices like Lean production, TQM, Six Sigma, and LSS to cope up with challenges of productivity [13, 14]. But after the inclusion of the global common platform to mitigate the environmental emission, the government policy has been more strict [15, 16]. So, to mitigate the ecological challenges, the manufacturing sector has to incorporate green technologies like GLS in their business operations [17, 18]. The sustainable development approaches have enough capacity to meet the current challenge but it is imperative to select an approach that has the maximum potential for sustainability improvement [19].

In the past few decades, various sustainability-oriented approaches have evolved over time. Lean manufacturing is a waste reduction approach that reduced the various nonvalue-added activities by making the system more streamlined. This waste reduction technique was founded by Tachi Ohno to cope up with the mass production system of the USA. The manufacturing industries have faced the problem of the high rejection rate of the end product, due to some assignable causes associated with the process [20]. Lean production is not able to address this challenge of manufacturing. At this juncture, Six Sigma comes to the fore that reduces the defects and leads to high specifications end products [21]. It is a statistical data drive and project-based approach that reduces the defects up to 3.4 M/opportunities [22]. The integrated Lean Six Sigma (LSS) approach leads to reduced wastes and defects that subsequently result in increased organizational capability. But the integrated LSS approach has the constraints that it is not able to mitigate the negative environmental impacts associated with the process. This drawback of the LSS has overcome by the inclusion of the Green technology in the LSS. The integration of Green technology in the LSS leads to the development of a new sustainable development approach named Green Lean Six Sigma (GLS). It is an eco-friendly approach that reduces wastes, defects, and environmental emissions that leads to increased organizational sustainability [4, 23–28]. So from the literature, it is quite obvious that each approach has certain merits and demerits pertain to the inclusive sustainable growth of the industry. So, it becomes quite imperative to select an approach that exhibits the maximum potential for sustainability improvement. So, here the prime question is which approach has the maximum impact on all the dimensions of sustainability. From the best of the knowledge of the authors, no study exists in the literature that deals with the prioritization of the sustainability-oriented practices. The present research makes a rigorous pursuit to facilitate the manufacturing to select a sustainable approach using the advanced decision-making approach Entropy TOPSIS.

2.1 Research Gaps

The changed quality perceptions of the customers and increased governmental pressure on the industries to cut the emission have forced the manufacturing industries to adopt sustainability-oriented manufacturing practices. With the budge word of sustainability, a slew of approaches have evolved over the time horizon but each approach does not affect all the dimension of the sustainability in an equal manner. So, the prime challenge the industries are facing in modern time to select a sustainability-oriented approach that exhibits the sustainable growth of the manufacturing organizations [25]. In the literature, no study pertains to selection and prioritization sustainability-oriented manufacturing practices exist. Moreover, no study exists in the past that has used the integrated application of Entropy and TOPSIS for the selection of the projects or approaches. So, the said gaps prevail in the literature provides the motivational view to conducting the present research work.

3 Methodology

The research methodology adopted in the present is a systematic phase wise (Fig. 2). In the first phase, the responses from the industrial persons from the different manufacturing industries have collected. The responses were collected from the 62 industrial personnel on the Likert scale for each sustainable development method against each criterion. The advanced entropy method has been used to weight the criterion. Besides, to select the most appropriate method, TOPSIS method has been used in the present research work.

4 Results and Discussion

The selection of the sustainable performance improvement approach for the manufacturing was done using the Entropy TOPSIS method. The sustainable development approaches were selected from the literature survey. To select the best process for the manufacturing industry in the scenario of the intense competition and sustainable oriented demand the responses were collected from the 50 industrial personnel (managers, senior engineers, engineers, supervisors). The best sustainable development approach was selected based on the four criteria: finance needed (FN);

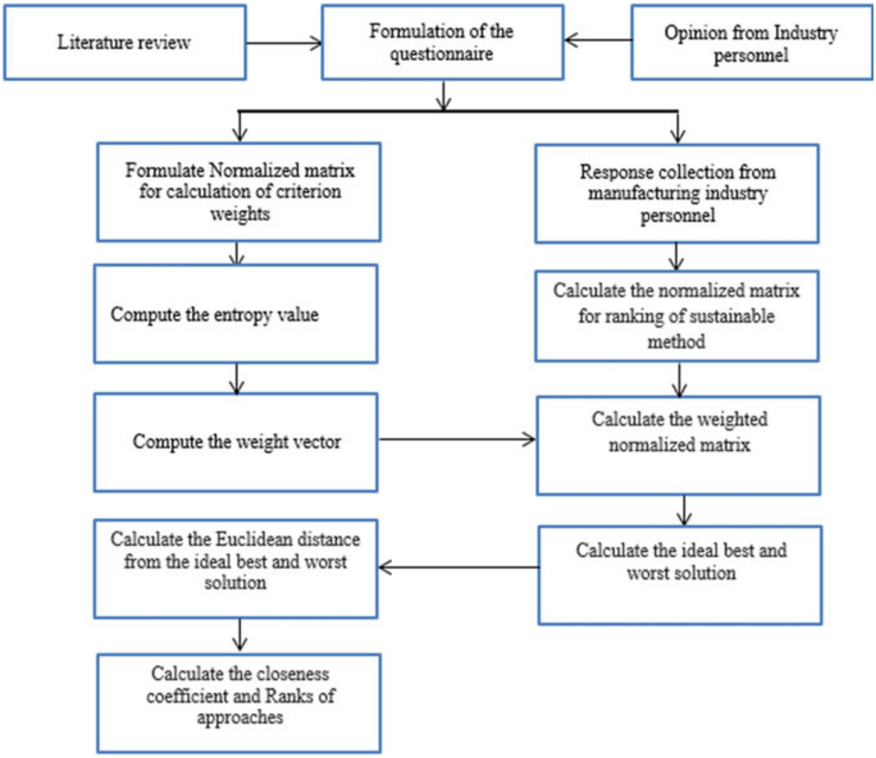


Fig. 2 Research methodology

productivity potential (PP); waste reduction potential (WRP); environmental emission reduction potential (EERP). Table 1 indicates the total sum of responses collected for each approach against each criterion. To weight the criterion the entropy method has been utilized in the present work.

Once the responses have been collected, first, the entropy method has used to calculate the weights of the criterion. The various steps associated with the entropy method are as follows (Tables 2, 3 and 4):

Table 1 Sum of responses collected from the manufacturing personnel

Approach/Criterion	FN	PP	WRP	EERP
LSS	100	118	112	119
TQM	117	119	117	121
Lean	121	105	108	113
Six sigma	124	122	134	128
GLS	131	164	172	170

Table 2 Normalized decision matrix

Approach/Criterion	FN	PP	WRP	EERP
LSS	0.1686	0.1879	0.1742	0.1828
TQM	0.1973	0.1895	0.1820	0.1859
Lean	0.2040	0.1672	0.1680	0.1736
Six sigma	0.2091	0.1943	0.2084	0.1966
GLS	0.2209	0.2611	0.2675	0.2611

Table 3 Entropy value

Approach/Criterion	FN	PP	WRP	EERP
LSS	−0.3002	−0.3141	−0.3044	−0.3106
TQM	−0.3202	−0.3152	−0.3101	−0.3128
Lean	−0.3243	−0.2990	−0.2996	−0.3040
Six sigma	−0.3272	−0.3183	−0.3268	−0.3198
GLS	−0.3336	−0.3506	−0.3527	−0.3506
$\sum$	−1.6055	−1.5973	−1.5937	−1.5978
H	−0.6213	−0.6213	−0.6213	−0.6213
e_j	0.9976	0.9925	0.9902	0.9928

Table 4 Weight vector of criterion

Criterion	FN	PP	WRP	EERP	
e_j	0.9976	0.9925	0.9902	0.9928	$\sum$
$d_j = 1 - e_j$	0.0024	0.0075	0.0098	0.0072	0.0270
W_j	0.0904	0.2787	0.3627	0.2681	

Step 1: Formulate normalizes decision matrix for calculation of the weights of the criterion.

In the first step, the normalized decision matrix is formulated using Eq. (1).

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{1}$$

Here, x_{ij} depicts the sum of responses of the alternative or sustainable method with respect to the criterion.

m number of sustainable methods
n number of criterion.

Step 2: Compute the entropy value.

$$e_j = -h\sum_{i=1}^{m} r_{ij}\ln r_{ij} \quad j = 1, 2, \ldots n \tag{2}$$

$h = \frac{1}{\ln m}$, where m is the number of alternative or sustainable methods.
Step 3: Compute the weight vector

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{n}\left(1 - e_j\right)} \tag{3}$$

$$d_j = 1 - e_j,$$

here, $d_j$is called a degree of diversification.

The TOPSIS process has initiated. The various steps associated with TOPSIS are as follows:

Step 1: Calculate the Normalized Matrix for TOPSIS

In this step, the normalized matrix is obtained using Eq. (4). Table 5 depicts the normalized matrix.

$$\overline{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{j=1}^{\boldsymbol{n}} X_{ij}^2}} \tag{4}$$

Step 2: Calculate the Weighted Normalized Matrix

The weighted normalized matrix has been obtained using Eq. (5). Table 6 depicts the weighted normalized matrix.

$$V_{ij} = \overline{X}_{ij} \times W_j \tag{5}$$

Step 3: Calculate the Ideal Best and Worst Solution

The ideal best and worst solution has obtained using the results from Table 6. Table 7 depicts the ideal best and worst solution.

Table 5 Normalized matrix for TOPSIS

Approach/Criterion	FN	PP	WRP	EERP
LSS	0.376	0.415	0.383	0.404
TQM	0.440	0.418	0.400	0.411
Lean	0.455	0.369	0.369	0.383
Six Sigma	0.466	0.429	0.458	0.434
GLS	0.492	0.577	0.588	0.577

Table 6 Weighted normalized matrix

Approach/Criterion	FN	PP	WRP	EERP
Weightage	0.064	0.379	0.288	0.269
LSS	0.024	0.157	0.110	0.109
TQM	0.028	0.159	0.115	0.111
Lean	0.029	0.140	0.106	0.103
Six Sigma	0.030	0.163	0.132	0.117
GLS	0.031	0.218	0.169	0.155

Table 7 Ideal best and worst solution

V+	0.024	0.218	0.169	0.155
V−	0.031	0.140	0.106	0.103

Step 4: Calculate the Euclidean Distance from the Ideal Best Solution and Worst Solution

The Euclidean distance from the ideal best solution has calculated using Eq. (6) and Euclidean distance from the ideal worst solution has calculated using Eq. (7). Table 8 depicts the Euclidean distance from the ideal best and worst solution.

$$S_i^+ = \left[\sum_{j=1}^{m}\left(V_{ij} - V_j^+\right)^2\right]^{0.5} \tag{6}$$

$$S_i^- = \left[\sum_{j=1}^{m}\left(V_{ij} - V_j^-\right)^2\right]^{0.5} \tag{7}$$

Step 5: Calculate the Performance Score

The performance score for the sustainable development approach has calculated using the equation. Table 8 depicts the Euclidean distances, closeness coefficients, or performance score, and the corresponding ranking of the sustainable development methods (SDM).

Table 8 Ranks of the sustainable development approach

Si+	Si−	P_i	Rank	SDM
0.097	0.020	0.171	4	LSS
0.092	0.022	0.193	3	TQM
0.114	0.002	0.021	5	Lean
0.078	0.037	0.322	2	Six sigma
0.007	0.113	0.938	1	GLS

$$CC_i = \frac{S_i^-}{S_i^- + S_i^+}, \quad i = 1, 2, \ldots m \tag{8}$$

It has found that GLS has found the top rank of TOPSIS with a closeness coefficient of 0.665. Moreover, Lean Six Sigma and Six Sigma have found the second and third positions of the TOPSIS rank with closeness coefficients 0.377 and 0.320, respectively. GLS is an eco-friendly approach and it leads to improved organizational performance in terms of the increased productivity, profitability. Meanwhile, GLS leads to improved organizational sustainability in terms of reduced emission of GHGs and increased material efficiency through the reduction of wastes.

5 Conclusion

The increased concern of sustainability, governmental policies on climate change, and changed quality perception of the customers have forced the industrial organizations to adopt sustainable practices in the business operations. The sustainable development methods are those practices of manufacturing that lead to reduce wastes, emission, improves productivity at the optimum cost. The industrial organizations are making continuous pursuits to develop sustainable methods that are best suited to the requirements of the industry. In the past, various sustainability-oriented practices were developed and each poses its different pros and cons. So, this makes the decision-making complex for the industrial managers to select an approach that is best suited for the industry and covers all the dimensions of sustainability. So, in this paper, a rigorous entropy-based TOPSIS method decision-making approach has been utilized in the present study to rank the available sustainable methods based on four criteria: finance needed, productivity improvement potential, environmental emission reduction potential, and waste reduction potential. The weights of the criterion have found through the entropy method and WRP has found the highest weight of 0.3627. The Green Lean Six Sigma has found the most significant technique among the available techniques or methods with TOPSIS score of 0.938. GLS leads to improved productivity, reduces environmental emission, and leads to improved organization success.

Although the study depicts the sustainability-oriented approach selection, there still areas of improvement. First, the present study considers four major criteria like waste reduction potential, productivity potential, environmental emission reduction potential, etc., and others that are significant in attribute decision-making. However, other criteria like cultural aspects and customer consensus related are also the prominent factors for strategic sustainability-oriented project selection that have not considered here. Second, the present research work prioritizes the approach based on the single decision-making approach to make the findings more consistent in future research work the advanced decision-making techniques like best–worst method (BWM) and grey relational analysis can be used.

References

1. Kaswan MS, Rathi, R.: Investigating the enablers associated with implementation of Green Lean Six Sigma in manufacturing sector using Best Worst Method. Clean Technol Environ Policy 1–12 (2020)
2. Rathi, R., Khanduja, D., Sharma, S.K.: Efficacy of fuzzy MADM approach in Six Sigma analysis phase in automotive sector. Journal of Industrial Engineering International **12**(3), 377–387 (2016). https://doi.org/10.1007/s40092-016-0143-0
3. Cao, X., Wen, Z., Xu, J., De Clercq, D., Wang, Y., Tao, Y.: Many-objective optimization of technology implementation in the industrial symbiosis system based on a modified NSGA-III. J. Clean. Prod. **245**, 118810 (2020)
4. Kaswan, M.S., Rathi, R.: Analysis and modeling the enablers of green lean six sigma implementation using interpretive structural modeling. J. Clean. Prod. **231**, 1182–1191 (2019)
5. Deif, A.M.: A system model for green manufacturing. J. Clean. Prod. **19**(14), 1553–1559 (2011)
6. Govindan, K., Diabat, A., Shankar, K.M.: Analyzing the drivers of green manufacturing with fuzzy approach. J. Clean. Prod. **96**, 182–193 (2015)
7. Dornfeld, D.A. (ed.): Green manufacturing: fundamentals and applications. Springer (2012)
8. Sony, M., Naik, S.: Green lean six sigma implementation framework: a case of reducing graphite and dust pollution. Int. J. Sustain. Eng. 1–10 (2019)
9. Ahn, S.H., Chun, D.M., Chu, W.S.: Perspective to green manufacturing and applications. Int. J. Precis. Eng. Manuf. **14**(6), 873–874 (2013)
10. Sun, Y., Bi, K., Yin, S.: Measuring and integrating risk management into green innovation practices for green manufacturing under the global value chain. Sustainability **12**(2), 545 (2020)
11. Li, K.M., Liang, S.Y.: Modeling of cutting forces in near dry machining under tool wear effect. Int. J. Mach. Tools Manuf **47**(7–8), 1292–1301 (2007)
12. Kumar, M., Kaswan, M.S.: Optimization of surface roughness & MRR in end milling on D2 steel using Taguchi method. Optimization 5(1) (2016)
13. Rusinko, C.: Green manufacturing: an evaluation of environmentally sustainable manufacturing practices and their impact on competitive outcomes. IEEE Trans. Eng. Manage. **54**(3), 445–454 (2007)
14. Simboli, A., Taddeo, R., Raggi, A., Morgante, A.: Structure and relationships of existing networks in view of the potential industrial symbiosis development. In: Industrial symbiosis for the circular economy, pp. 57–71. Springer, Cham (2020)
15. Chuang, S.P., Yang, C.L.: Key success factors when implementing a green-manufacturing system. Prod. Plan. Control **25**(11), 923–937 (2014)
16. Roschangar, F., Zhou, Y., Constable, D.J., Colberg, J., Dickson, D.P., Dunn, P.J., Kopach, M.E.: Inspiring process innovation via an improved green manufacturing metric: iGAL. Green Chem. **20**(10), 2206–2211 (2018)
17. Phanden, R.K.: Multi agents approach for job shop scheduling problem using genetic algorithm and variable neighborhood search method. In: Proceedings of the 20th World Multi-Conference on Systemics, Cybernetics, and Informatics, pp. 275–278 (2016)
18. Phanden, R.K., Jain, A.: Assessing the impact of changing available multiple process plans of a job type on mean tardiness in job shop scheduling. Int. J. Adv. Manuf. Technol. **80**(9–12), 1521–1545 (2015)
19. Rathi, R., Khanduja, D., Sharma, S.K.: A fuzzy-MADM based approach for prioritizing six sigma projects in the Indian auto sector. Int. J. Manage. Sci. Eng. Manage. **12**(2), 133–140 (2017). https://doi.org/10.1080/17509653.2016.1154486

20. Siegel, R., Antony, J., Garza-Reyes, J.A., Cherrafi, A., Lameijer, B.: Integrated green lean approach and sustainability for SMEs: from literature review to a conceptual framework. J. Clean. Prod. 118205 (2019)
21. Kaswan, M.S., Rathi, R., Singh, M.: Just in time elements extraction and prioritization for health care unit using decision making approach. Int. J. Qual. Reliab. Manage. (2019)
22. Garza-Reyes, J.A., Jacques, G.W., Lim, M.K., Kumar, V., Rocha-Lona, L.: Lean and green–synergies, differences, limitations, and the need for Six Sigma. In: IFIP International Conference on Advances in Production Management Systems, pp. 71–81. Springer, Berlin, Heidelberg (2014)
23. Gupta, S., Modgil, S., Gunasekaran, A.: Big data in lean six sigma: a review and further research directions. Int. J. Prod. Res. **58**(3), 947–969 (2020)
24. Rathi, R., Khanduja, D., Sharma, S.: Six Sigma project selection using fuzzy TOPSIS decision making approach. Manage. Sci. Lett. **5**(5), 447–456 (2015)
25. Kaswan, M.S., Rathi, R.: Green Lean Six Sigma for sustainable development: integration and framework. Environ. Impact Assess. Rev. **83**, 106396 (2020)
26. Phanden, R.K., Ferreira, J.C.E.: Biogeographical and variable neighborhood search algorithm for optimization of flexible job shop scheduling. In: Advances in Industrial and Production Engineering, pp. 489–503. Springer, Singapore (2019)
27. Phanden, R.K., Saharan, L.K., Erkoyuncu, J.A.: Simulation based cuckoo search optimization algorithm for flexible job shop scheduling problem. In: Proceedings of the International Conference on Intelligent Science and Technology, pp. 50–55 (2018
28. Phanden, R.K., Demir, H.I., Gupta, R.D.: Application of genetic algorithm and variable neighborhood search to solve the facility layout planning problem in job shop production system. In: 2018 7th International Conference on Industrial Technology and Management (ICITM), pp. 270–274. IEEE (2018)

Green Supplier Selection for Nickel Coating Industries Using a Hybrid GRAF-VIK Model

Sanatan Ratna and B. Kumar

Abstract The traditional supply chain needs to be upgraded in order to address the concerns for environment. The scientists and researchers have stressed that the industrial growth needs to address the sustainability issue in supply chain and the suppliers must be evaluated in order to measure their performance on 'Green' front. The current research work addresses this issue of selecting a Green supplier in the Nickel Coating industry using a hybrid MCDM model. The hybrid MCDM model used is GRAF-VIK model, which consists of Grey Relational Analysis (GRA), Fuzzy analytical hierarchy process (FAHP) and VIKOR. The GRA tool is used for selecting important green supplier selection criteria among a number of criteria. The Fuzzy AHP tool is used for giving weightage to the selected criteria and finally VIKOR is used for selecting the best supplier in Nickel coating industry based on the chosen weighted criteria. Improving solid waste disposal, recycling and complying with the government regulations will definitely lead to a sustainable growth.

Keywords Green supplier · Multi-criteria decision-making · Grey relational analysis · Fuzzy analytic hierarchy process · VIKOR

1 Introduction

There is a growing concern among today's researchers and scientists about the need to integrate Green criteria into the supplier selection problem. The current research work addresses this issue of selecting supplier in the Nickel coating industry based on green criteria using a hybrid MCDM model. The GRAF-VIK model is basically an integration of Grey Relational Analysis (GRA), Fuzzy analytical hierarchy process (FAHP) and VIKOR. The GRA tool is used for selecting important green supplier selection criteria among a number of criteria. The Fuzzy AHP tool is used

S. Ratna (✉)
Amity University, Sector 125, Noida, Uttar Pradesh, India
e-mail: sratna@amity.edu

B. Kumar
Sunrise University, Alwar, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_41

for giving weightage to the selected criteria and finally VIKOR is used for selecting the best supplier in Nickel coating industry based on the chosen weighted criteria. Grey relation analysis (GRA) was basically developed by Professor Julong Deng for tackling real-life problems, which are mostly grey in nature, which means incomplete information [1–3]. Grey stands between white (full information) and black (no information). The real-life problems basically lie between these two extremes of white and black, which are represented by the term Grey [4–7]. The fuzzy AHP (FAHP) tool is used for giving weightage to the criteria shortlisted by using grey relational analysis [8]. The application of FAHP becomes quite a necessity when one needs to capture the logical thinking of human beings focus on the relative importance of the various attributes taken into account. The term VIKOR (Vlse Kriterijumska Optimizacija Kompromisno Resenje, which means multicriteria optimization and compromise solution [9]. VIKOR basically aims at finding a compromise solution, which is nearest to the ideal solution. The VIKOR technique has been utilized in the current research work to select the best supplier in the Nickel coating industry based on the shortlisted green weighted criteria.

2 Literature Review

The AHP method based on pairwise comparison of criteria was developed by Saaty in 1980 and its use in the fuzzy environment was developed by Buckley [10]. In a supply chain, the green supplier is located at the upward direction and hence, it leads to cost-cutting and safety to the environment [11]. The use of Fuzzy AHP is quite a necessity for giving the chosen criteria a weightage, as it takes into account the ambiguity and linguistic terms [12]. The grey theory basically aims at taking into account the partial information and it was developed by Prof. Deng [13]. The VIKOR method is used for alternative selection based on the closeness to a compromise solution, which is nearest to the ideal solution [14–16]. VIKOR is similar to TOPSIS in the sense that both of them aim at finding the best solution based on finding the alternative closest to the ideal one [14].

3 Hybrid GRAF-VIK Model for Supplier Section

In the cut-throat competitive world of today, it is very necessary to find the most suitable supplier in any industry, as it leads to a drastic increase in profitability [17]. The traditional supply chains did not take into account the green criteria, but only considered criteria such as cost, quality and location [18]. There is a world-wide growing concern about saving the environment and making the supply chains sustainable [19]. This has occurred due to government regulations, better community awareness etc. hence, there is need to integrate ‘Green’ factors into the supply chain by today’s industries. The current research work focuses on selecting Green supplier for a Nickel coating SME. The SME is located in the city of Muzaffarpur in the Bela industrial area and falls under Bihar industrial area development authority. The unit has nickelling set up, which is generally used for coating objects like, bicycle parts and some electrical equipment among others. The challenge is to find suppliers based on 'Green' criteria. The author has chosen six criteria through a thorough literature review at the initial stage. The six 'Green' criteria are listed below.

C1 Solid Waste Disposal
C2 Staff Training
C3 Recycling
C4 Compliance with regulations
C5 Product Durability
C6 Green Packaging.

The first step is to select and shortlist the most important criteria out of the six criteria taken initially. For this purpose, GRA technique is used. It is based on providing grey relational grades to each of the criteria.in order to move forward, a survey is taken from 25 industry experts using a questionnaire where the industry experts are asked to rate the chosen criteria on a scale of 1–5, 5 being most important, while 1 being least important. Table 1 shows the survey value from 25 industry experts.

The difference with reference sequence values is calculated and listed in Table 2.

After the difference with reference sequence values is determined, the grey relation coefficients are calculated using Eq. 1 below.

$$\xi i(K) = \frac{(\Delta_{\min} + p\Delta_{\max})}{(\Delta X_i(K) + p\Delta_{\max})} \tag{1}$$

The term 'p' is basically the distinguishing coefficient and is taken as 0.5 here. The tenacity of 'p' is to increase or decrease the range of the grey relational coefficients. Table 3 shows the grey relational coefficients calculated as per Eq. 1 above.

The grey relational grades are calculated by taking the column sums for each of the six 'Green' criteria taken under consideration. The grey relational grades thus calculated are shown here in Table 4. The criteria with high grey relational grades represent higher importance as compared with one with low grey relational grade.

It is quite evident that the three most important 'Green' criteria are C1 (Solid Waste Disposal), C3 (Recycling) and C4 (Compliance with regulations). These three criteria are now selected for giving weightage and finally supplier selection. The three criteria that are selected are the next given weightage using Fuzzy AHP. The use of Fuzzy AHP (FAHP) is very apt here, as it can handle the imprecision, fuzziness and ambiguity related to human judgment. The FAHP used here makes use of triangular fuzzy numbers (TFN) to take into account the ambiguity and is shown in Table 5.

In general, membership for any TFN (l, m, n) can be obtained using Eq. 2 below.

Table 1 Survey values obtained from industry experts

	C1	C2	C3	C4	C5	C6
R1	4	4	5	4	3	3
R2	5	3	3	4	3	4
R3	4	3	3	5	4	4
R4	3	3	5	5	4	2
R5	5	3	3	3	5	4
R6	4	4	3	5	4	2
R7	5	4	5	4	3	3
R8	3	3	4	3	3	3
R9	5	3	3	4	2	3
R10	4	3	4	4	3	5
R11	5	4	5	4	4	5
R12	4	4	5	5	5	5
R13	5	4	4	5	4	4
R14	5	5	4	5	4	4
R15	4	5	4	4	4	5
R16	5	4	5	4	4	4
R17	4	4	5	5	4	5
R18	5	3	4	5	3	5
R19	5	3	3	5	2	3
R20	5	5	3	3	4	4
R21	5	3	4	4	5	4
R22	5	5	5	4	4	4
R23	5	4	4	5	3	4
R24	5	5	4	4	4	5
R25	5	4	4	5	3	4

$$(x) = \begin{cases} (x-l)/(m-l) & x \in [l, m] \\ (u-x)/(u-m) & x \in [m, u] \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

A triangular fuzzy number with varying membership values is shown in Fig. 1. A ‘fairly important’ linguistic expression is represented by the TFN (4 5 6).

The three shortlisted criteria are given weightage using Fuzzy AHP. The Buckley’s geometric mean method is used in the current research work to give relative weights for the alternatives. The pairwise comparison of the shortlisted criteria obtained by industry expert using TFN is shown here in Table 6.

The Buckley’s geometric mean for l, m and n are calculated for each criterion is calculated using Eq. 3.

Table 2 Difference with reference sequence values

	C1	C2	C3	C4	C5	C6
R1	1	1	0	1	2	2
R2	0	2	2	1	2	1
R3	1	2	2	0	1	1
R4	2	2	0	0	1	3
R5	0	2	2	2	0	1
R6	1	1	2	0	1	3
R7	0	1	0	1	2	2
R8	2	2	1	2	2	2
R9	0	2	2	1	3	2
R10	1	2	1	1	2	0
R11	0	1	0	1	1	0
R12	1	1	0	0	0	0
R13	0	1	1	0	1	1
R14	0	0	1	0	1	1
R15	1	0	1	1	1	0
R16	0	1	0	1	1	1
R17	1	1	0	0	1	0
R18	0	2	1	0	2	0
R19	0	2	2	0	3	2
R20	0	0	2	2	1	1
R21	0	2	1	1	0	1
R22	0	0	0	1	1	1
R23	0	1	1	0	2	1
R24	0	0	1	1	1	0
R25	0	1	1	0	2	1

$$\hat{r}_i = \left(\prod_{j=1}^{n} \widetilde{d_{ij}}\right)^{1/n} \tag{3}$$

Here, $\widetilde{d_{ij}}$ is the TFN and n is the number of criteria under consideration. Then the relative fuzzy weights for each criterion can be found by the product of their three GMs with the corresponding ordered reverse vector. For criteria C1, the fuzzy weight is calculated as

$$\begin{aligned} \widehat{W}_{C1} &= (2.88 \times 0.197, 3.27 \times 0.223, 3.63 \times 0.257) \\ &= (0.567, 0.729, 0.932) \end{aligned}$$

Table 3 Grey relational coefficients

	C1	C2	C3	C4	C5	C6
R1	0.500	0.500	1.000	0.500	0.429	0.429
R2	1.000	0.333	0.429	0.500	0.429	0.600
R3	0.500	0.333	0.429	1.000	0.600	0.600
R4	0.333	0.333	1.000	1.000	0.600	0.333
R5	1.000	0.333	0.429	0.333	1.000	0.600
R6	0.500	0.500	0.429	1.000	0.600	0.333
R7	1.000	0.500	1.000	0.500	0.429	0.429
R8	0.333	0.333	0.600	0.333	0.429	0.429
R9	1.000	0.333	0.429	0.500	0.333	0.429
R10	0.500	0.333	0.600	0.500	0.429	1.000
R11	1.000	0.500	1.000	0.500	0.600	1.000
R12	0.500	0.500	1.000	1.000	1.000	1.000
R13	1.000	0.500	0.600	1.000	0.600	0.600
R14	1.000	1.000	0.600	1.000	0.600	0.600
R15	0.500	1.000	0.600	0.500	0.600	1.000
R16	1.000	0.500	1.000	0.500	0.600	0.600
R17	0.500	0.500	1.000	1.000	0.600	1.000
R18	1.000	0.333	0.600	1.000	0.429	1.000
R19	1.000	0.333	0.429	1.000	0.333	0.429
R20	1.000	1.000	0.429	0.333	0.600	0.600
R21	1.000	0.333	0.600	0.500	1.000	0.600
R22	1.000	1.000	1.000	0.500	0.600	0.600
R23	1.000	0.500	0.600	1.000	0.429	0.600
R24	1.000	1.000	0.600	0.500	0.600	1.000
R25	1.000	0.500	0.600	1.000	0.429	0.600
Column total	0.807	0.533	0.680	0.700	0.572	0.656

Table 4 Criteria and their respective grey relational grades

C1	C2	C3	C4	C5	C6
0.807	0.533	0.680	0.700	0.572	0.656

Similarly, $\widehat{W}_{C3}$ and $\widehat{W}_{C4}$ are found as (0.061, 0.08, 0.112) and (0.136, 0.187, 0.257), respectively. The Defuzzification is done using centre of area method by taking the average of the three values. The values of the relative weights obtained after defuzzification are listed in Table 7.

Hence, the weightage given to C1 is 0.728, C3 is 0.082 and C4 is 0.189. Finally, the supplier selection is done, using VIKOR technique. The VIKOR technique aims

Table 5 Set of triangular fuzzy numbers (TFN)

Importance level	Satty's scale	TFN
Equally important (EI)	1	(111)
Weakly important (WI)	3	(234)
Fairly important (FI)	5	(456)
Strongly important (SI)	7	(678)
Absolutely important (AI)	9	(999)
Intermittent important	2, 4, 6, 8	(123) (345) (567) (789)

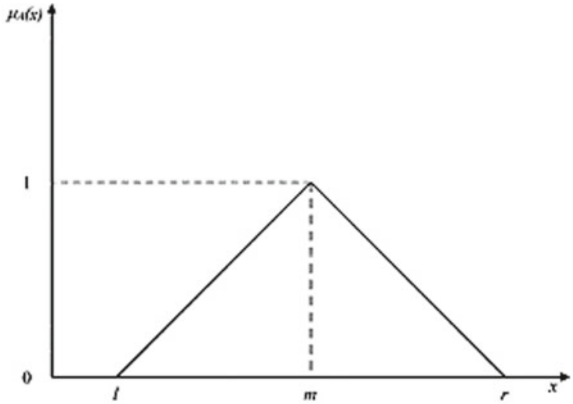


Fig. 1 Triangular fuzzy number (TFN)

Table 6 Pairwise criteria comparison using TFN

	C1	C3	C4	GM for l	GM for *m*	GM for *u*
C1	(1 1 1)	(6 7 8)	(4 5 6)	2.88	3.27	3.63
C3	(1/8 1/7 1/6)	(1 1 1)	(1/4 1/3 1/2)	0.314	0.362	0.437
C4	(1/6 1/5 1/4)	(2 3 4)	(1 1 1)	0.693	0.843	1.00
	Total			3.887	4.475	5.067
	Reciprocal			0.257	0.223	0.197
	Ascending order			0.197	0.223	0.257

Table 7 Normalized crisp weights for the three criteria

Shortlisted criteria	De-fuzzified weight	Normalized weight
C1	0.742	(0.742/1.019) = 0.728
C3	0.084	0.082
C4	0.193	0.189
	Total 1.019	

Table 8 Decision matrix for supplier selection

	C1	C3	C4
Attribute weights	0.728	0.082	0.189
S1	3	4	5
S2	4	2	2
S3	3	3	4
S4	2	5	3
S5	4	5	4
Norm_j	7.348	8.888	8.366

at calculating the regret measure and the utility measure for each of the five suppliers (S1, S2…S5) under consideration. The technique aims at finding a compromise solution nearest to the ideal solution. To begin with, the suppliers are rated on a scale of 1–5 (1 means poor performance and 5 means best performance) for each of the three criteria (C1, C3, C4). Table 8 shows the decision matrix obtained from the industry expert.

The values in Table 8 are normalized using Eqs. 4 and 5. If the attribute is positive/benefit type, the normalized value of x_{ij} is,

$$r_{ij} = \frac{x_{ij}}{\text{Norm}_j} \quad \text{otherwise for negative type,}$$

$$r_{ij} = 1 - \frac{x_{ij}}{\text{Norm}_j} \tag{4}$$

where

$$\text{Norm}_j = \sqrt{\sum_{i=1}^{m} x_{ij}^2} \tag{5}$$

The normalized decision matrix hence obtained is listed in Table 9. The maximum and the minimum criterion function for each criterion are found and listed in Table 10.

Table 9 Normalized decision matrix

	C1	C3	C4
Attribute weights	0.728	0.082	0.189
S1	0.408274	0.450045	0.597657
S2	0.544366	0.225023	0.239063
S3	0.408274	0.337534	0.478126
S4	0.272183	0.562556	0.358594
S5	0.544366	0.562556	0.478126

Table 10 Maximum and minimum for each criterion function

	C1	C3	C4
f_{max}	0.544366	0.562556	0.597657
f_{min}	0.272183	0.225023	0.239063
$f_{max} - f_{min}$	0.272183	0.337534	0.358594

Table 11 VIKOR indices for all the suppliers

	S1	S2	S3	S4	S5
Utility measure (U_i)	0.391333	0.271	0.4816	0.854	0.063
Regret measure (R_i)	0.364	0.189	0.364	0.728	0.063
VIKOR index	0.433859	0.226216	0.490918	1	0

The Utility measure (U_i) for each supplier is calculated using Eq. 6. Here W_j is the weightage of the three individual criteria.

$$U_i = \sum_{j=1}^{m} \frac{W_j\left(f^{\max} - f_{ij}\right)}{\left(f^{\max} - f^{\min}\right)} \tag{6}$$

The Regret measure (R_i) for each supplier is basically the maximum value of the component present in the expression for the utility measure. Finally, the VIKOR indices are calculated for each of the five suppliers using Eq. 7 and are listed in Table 11. While calculating the values of VIKOR indices, the value of α is assumed as 0.5.

$$V_i = \frac{\propto .(U_i - U_{\min.})}{(U_{\max.} - U_{\min.})} + \frac{(1- \propto).(R_i - R_{\min.})}{(R_{\max.} - R_{\min.})} \tag{7}$$

4 Conclusion

It is quite evident from the table above that the supplier S5, with the lowest VIKOR index is the one which is closest to the ideal solution and hence is chosen as the best supplier based on the three shortlisted 'Green' criteria. The three most important/central criteria are chosen from an amalgam of six initial criteria. The three 'Green' criteria chosen by using grey relational analysis (GRA) are, Solid waste disposal, recycling and compliance with regulations. The three criteria are given weightage using Fuzzy AHP. Based on the weighted selected criteria, the suppliers under consideration are ranked using VIKOR technique. The supplier has the lowest VIKOR index is selected finally as the best supplier as it is closest to the ideal solution. In future, the newly developed GRAF-VIK method may be used for supplier selection in other sectors too to integrate sustainability in the supply chain.

References

1. Ju-Long, D.: Control problems of grey systems. Syst. Control Lett. **1**(5), 288–294 (1982)
2. Deng, J.L.: Introduction to grey system theory. J. Grey Syst. **1**, 1–24 (1989a)
3. Deng, J.L.: Grey information space. J. Grey Syst. **1**(2), 103–117 (1989b)
4. Zeng, B., Tan, Y., Xu, H., Quan, J., Wang, L., Zhou, X.: Forecasting the electricity consumption of commercial sector in Hong Kong using a novel grey dynamic prediction model. J. Grey Syst. **30**(1), 157–172 (2018)
5. Zeng, B., Duan, H., Bai, Y., Meng, W.: Forecasting the output of shale gas in China using an unbiased grey model and weakening buffer operator. Energy **151**, 238–249 (2018)
6. Zeng, B., Liu, S.F.: A self-adaptive intelligence grey prediction model with the optimal fractional order accumulating operator and its application. Math. Meth. Appl. Sci. **23**(1), 1–15 (2017)
7. Golinska, P., Kosacka, M., Mierzwiak, R., Werner-Lewandowska, K.: Grey decision making as a tool for the classification of the sustainability level of remanufacturing companies. J. Clean. Prod. **105**(15), 28–40 (2015)
8. Chan, F., Kumar, N.: Global supplier development considering risk factors using fuzzy extended ahp-based approach. Omega **35**(4), 417–431 (2007)
9. Opricovic, S.: Multicriteria optimization of civil engineering systems. Fac. Civ. Eng. Belgrade **2**, 5–21 (1998)
10. Buckley, J.: Fuzzy hierarchical analysis. Fuzzy Sets Syst. **17**(3), 233–247 (1985)
11. Qin, J., Liu, X., Pedrycz, W.: An extended todim multi-criteria group decision making method for green supplier selection in interval type-2 fuzzy environment. Eur. J. Oper. Res. **258**, 626–638 (2016)
12. Zadeh, L.: The concept of a linguistic variable and its application to approximate reasoning—I. Inf. Sci. **8**(3), 199–249 (1974)
13. Deng, J.L.: The Foundation of Grey System. Huazhong University of Science and Technology Press, Wuhan, China (2002)
14. Opricovic, S., Tzeng, G.H.: Compromise solution by MCDM methods: a comparative analysis of VIKOR and TOPSIS. Eur. J. Oper. Res. **156**(2), 445–455 (2004)
15. Opricovic, S.: Multi-Criteria Optimization of Civil Engineering Systems. Faculty of Civil Engineering, Belgrade, Serbia (1998)
16. Opricovic, S., Tzeng, G.H.: Multicriteria planning of post-earthquake sustainable reconstruction. Comput.-Aided Civil Infrastruct. Eng. **17**(3), 211–220 (2002)
17. Mohammadi, H., Farahani, F., et al.: Green supplier selection by developing a new group decision-making method under type 2 fuzzy uncertainty. Int. J. Adv. Manuf. Technol **93**(1–4), 1–20 (2017)
18. Hamdan, S., Cheaitou.: A supplier selection and order allocation with green criteria: an MCDM and multi-objective optimization approach. Comput. Oper. Res. **81**, 282–304 (2016)
19. Luthra, S., Govindan, K., et al.: An integrated framework for sustainable supplier selection and evaluation in supply chains. J. Clean. Prod. **140**, 1686–1698 (2017)

Reducing the Time Delay in Curing Process by the Implementation of DMAIC in Tyre Production

M. Sreelakshmi, J. Devika, Ananya Theres John, and O. S. Deepa

Abstract Evidence shows that six sigma and its tools have helped in the manufacturing process in a medium and small-scale organization. However, there are still many industries where six sigma implementations are not been so predominant. Hence this paper deals with the application of DMAIC methodology in the tyre production process to reduce the cycle time in the curing process. Steam that is needed to generate heat and pressure has many disadvantages like the price of steam energy, difficulties during handling, the nonexistence of tractability in fixing parameters, risk in quality due to overheating and many other factors. Hence to enrich the quality of tyre and to maintain sustainability, it is necessary to implement optimization techniques. In this paper, integration of DMAIC and multi-objective optimization is carried out, which offers companies and managers a better understanding of the strategies and their operational measures. Balancing six sigma and multi-objective optimization is a complicated and challenging task to reduce variability. DPU and DPMO are carried out for each sub-process in the curing process to find the root cause of the problem. Also, studies on multiple linear regression and signal to noise ratio have been implemented to strengthen the work. The objective of this paper is to reduce the cycle time in the curing process so that defects are reduced, which leads to good quality by the implementation of planning strategies thereby stabilizing the process by continuous improvement.

Keywords Curing process · DMAIC · Optimization · Quality function deployment · Regression and signal to noise ratio

1 Introduction

Six sigma aims to improve the quality of different products to improve customer satisfaction. Six Sigma is defined as a set of statistical tools and techniques for process improvement. Six Sigma is a data-driven method that serves tools and facilities, to

M. Sreelakshmi · J. Devika · A. T. John · O. S. Deepa (✉)
Department of Mathematics, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, India
e-mail: os_deepa@cb.amrita.edu

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_42

analyze each path of a process. It also plays an important role in uplifting a business structure to improve the profit and also the quality. Conventionally, production efficiency, profitability, quality, flexibility, and customer contentment appeared as new economical benchmarks [1, 2]. The industries had decided to change their approach and concentrate more on process and operations even though with the increasing stress from many stakeholders for increasing social and environmental performance [3, 4]. A systematic factory-in-factory (FiF) framework of the production system is studied by minimizing wastes according to the unresolved issues of the current continuous improvement program [5]. Recently, a case study was studied and implemented on lean six sigma framework in a large-scale industry [6–9]. An improved modified FMEA model for prioritization of lean waste risk was modelled by the inclusion of the waste-worsening factors and Taguchi loss functions, which has enabled the FMEA team to articulate the severity level of waste [1]. Fuzzy Interpretive Structural Modelling (FISM) approach has been used to analyze the interrelationships among the health care factors [7, 8]. Control charts are used to check whether the system is in control or not. Control charts have been extensively used in an attribute sampling plan and variable sampling plan [6–11] and it is the most commonly used in industries to monitor the production process. Synergizing an Ecosphere of Lean for Sustainable Operations is also studied [12].

2 Case Study

Many factors affect the profit of the organization in an industry like the selection of materials, selection of correct steps involved in the process, skilled operators the technical requirement and so on. The authors have implemented six sigma process to increase the efficiency of tyre production.

2.1 Define Phase

The objective of this phase is to express the goals of the project. The cause and effect diagram expresses the entire scenario of the tyre manufacturing process. The cause and effect diagram in Fig. 1 based on the maximization of sales and customer satisfaction.

2.2 Measure Phase

In the measure phase, a detailed study of the production process is done followed by quality function deployment and multi-objective optimization. This combination made the authors understand the root cause of the underlying problem.

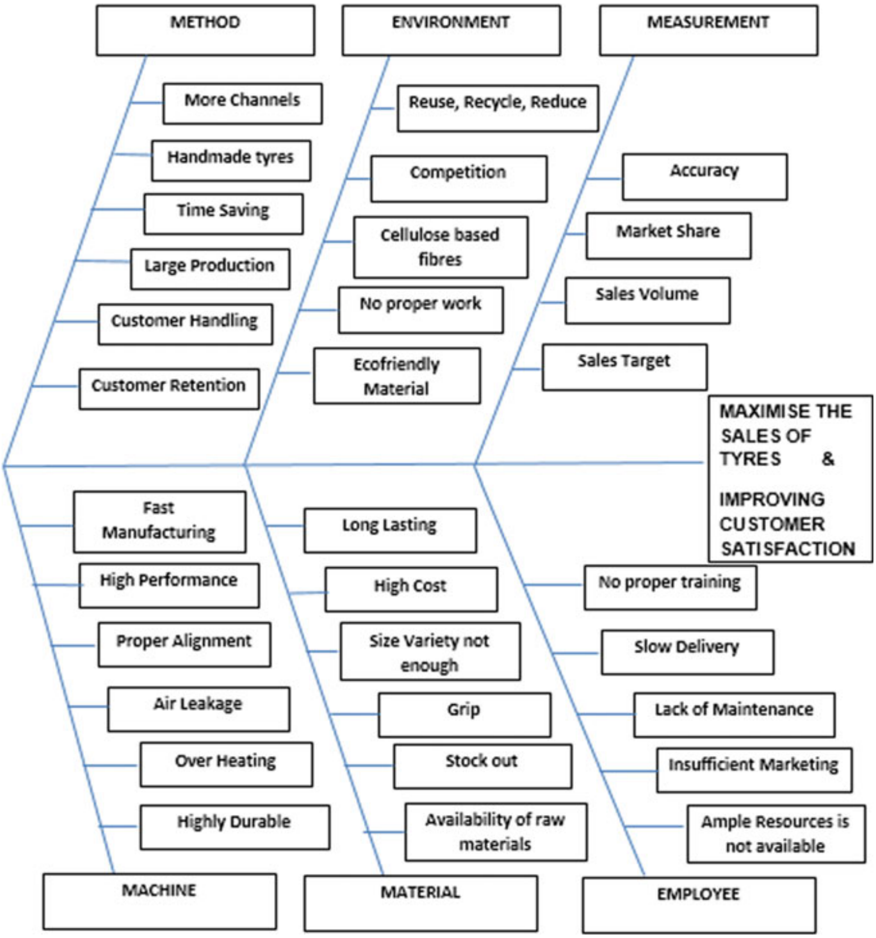


Fig. 1 Cause and Effect diagram

2.3 Production Process

The tyre manufacturing starts from the yarn. The thread for the tyre manufacturing is taken from the textiles and those fabrics are sent to fabric bias cutter and sheet cutters. They are subjected to tyre building machines. The rubber and chemicals and are sent to Banbury mixer wherein they are mixed thoroughly and are passed through extruders. These extruder products also send to the tyre building machines. The bread wires that are surrounded by a layer of textile carcass and the belt which is found between the tread and the carcass together are transferred to two directions: (1) for the bead construction and (2) for the wire calendar. The wire calendar is sent to the tyre building machines, where the main ingredients are mixed and then subjected to the curing press and then are visually analyzed to set the balance. After setting the balance, the force deviation is noted down and rectified and are subjected to X-ray scanning to form a complete tyre. Figure 2 explains the production process.

Ishikawa diagrams are causal diagrams created by Kaoru Ishikawa to show the potential causes of a specific event. Common uses of the Ishikawa diagram are product design and quality defect prevention. A cause and effect diagram explains happening of an event into smaller categories. It can also be useful for showing relationships between contributing factors. One of the reasons cause and effect diagrams are also called fishbone diagrams is because the completed diagram ends up looking like a fish's skeleton with the fish head to the right of the diagram and the bones branching off behind it to the left. In this paper cause and effect, the diagram is focused on measurement, method, machine, environment, employee and materials to maximize sales of tires and improve customer satisfaction.

- In measurement—accuracy is considered as a major factor. In the method, the company's channel, reduction of time to increase the production, customer handling and customer retention are considered.
- In machine check for proper alignment, high performance, overheating, air leakage and high durability. Air leakage is because of bead damage and any sealing surface between rubber and metal can cause loss of air. In case of overheating, mileage of the tyre decreases when temperature increases, which lead to decreases in utility.

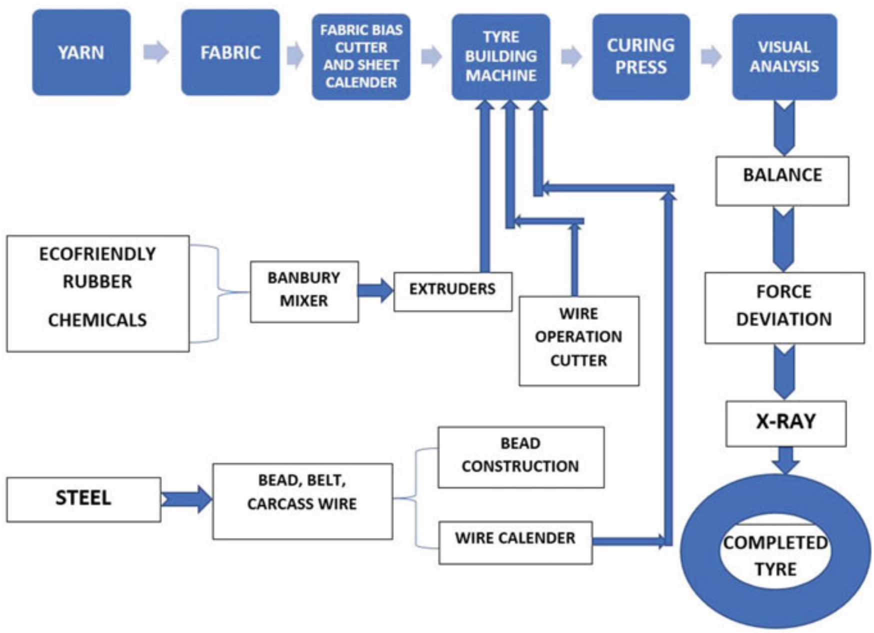


Fig. 2 Tyre production process

- In materials, availability of raw materials plays a major role, the tyre should be long lasting and should have a proper grip. High cost and less size variety will affect the sale.
- In the environment, the materials used should be eco-friendly, reusable, recyclable and reducible. A clean and healthy environment should be maintained, and proper and systematic work should be assigned. Finally, properly trained and skilled employees should be appointed. Slow delivery lack of maintenance, ample resources and insufficient marketing will affect the sales and hence care has to be taken to avoid the loss.

2.4 Quality Function Deployment

QFD aims at making the right design of the product according to customer requirements. The primary data include customer needs, technical requirements and critical parts. It uses a 1–15 scale rating. It calculates the improvement factor for each technical requirement for the product based on planned customer satisfaction rating and existing customer satisfaction. Then various characteristics of a tyre are considered and their relationship with the requirements is noted. Further comparison with other company products is also done. The main reason for including the QFD method is to analyze customer needs and to improve the product and processes. The implementation of this method can bring positive results in the production process and it also distinguishes the technical features that are important in the product and the unnecessary be eliminated. Therefore, this can be a good tool for planning and controlling development. QFD was also explained based on the customer requirement and technical requirements for tire production. The results obtained are shown in Fig. 3.

Using various parameters from the manufacturing process, the authors along with expert team decided to consider three important criteria—Maximize profit, maximize production and minimize defects. In order to select one criterion from the three criteria's, a multi-objective optimization is done. The following are the parameters and the functions are considered.

Parameters are

£	Profit
D_i	Unit sales price of product i
R_i	Production Quantity of product i for Company T
q_i	Remaining quantity for producing a unit of product i
y_i	Number of machine required to produce product i
T_i	Purchase cost of product i
B_i	Storing cost of product i
d_i	The no. of batches for material handling of product i
M_{ik}	Maximum holding capacity of product i
X_{ik}	The requirements of material k for producing a unit of product i
e_{ij}	Number of machine hours required to produce 1 unit product i, j 1…0.6

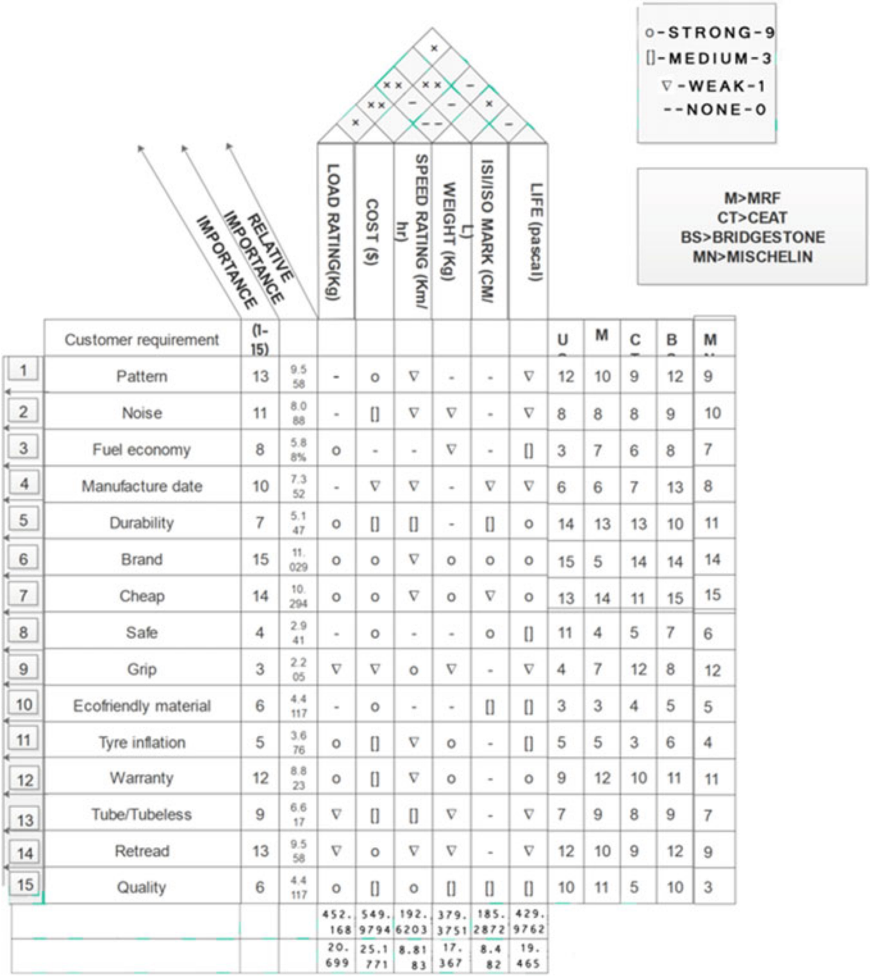


Fig. 3 QFD for tire production

P_k	The unit cost of material k
J_k	Quantity of material k available for use
WC_0	Direct labour cost
WC_1	Over time labour cost
WC_2	Maximise labour cost
$DMTC_1$	Natural rubber tax cost
$DMTC_2$	Synthetic rubber tax cost
$DMTC_3$	Carbon black tax cost
$DMTC_4$	Rubber chemical tax cost
$DMTC_5$	Nylon fabric tax cost
$DMTC_6$	Bead wire tax cost

$DMTC_7$	Rubber process oil tax cost
$DMTC_k$	Total raw materials
I	Minimize defect
P_i	Pressure
TR_i	Temperature Resistance
LR_i	Load Rating
K-	Unnecessary money uses
LT_1	Maximising labour time
LT_2	Maximising labour number
LT_3	Increasing experienced labours
Q	production
α_i	Stess
G_i	Strain
Δ_1, Δ_2	Non-negative variables.

Equations

$$\begin{aligned}\text{Max}\,£ = {} & \sum_{i=1}^{a} D_i R_i - \sum_{k=1}^{c} P_k J_k - [WC_0 + \triangle_1\ (WC_1 - WC_0) + \triangle_2\ (WC_2 - WC_0)] \\ & - \sum_{i=1}^{a} (T_i - B_i) d_i - [DMTC_1 + DMTC_2 + DMTC_3 + DMTC_4 \\ & + DMTC_5 + DMTC_6 + DMTC_7]\end{aligned} \tag{1}$$

$$\text{Max } Q = \sum_{i=1}^{a} q_i \sum_{k=1}^{c} X_{ik} R_i + \sum_{i=1}^{a} e_{ij} y_i + (LT_1 + LT_2 + LT_3) - k \tag{2}$$

$$\begin{aligned}\text{Max } I = {} & \sum_{i=1}^{a} P_i \sum_{k=1}^{c} M_{ik} + \sum_{i=1}^{a} (\mathrm{TR})_i \sum_{k=1}^{c} M_{ik} \\ & + \sum_{i=1}^{a} \alpha_i \sum_{k=1}^{c} M_{ik} - \sum_{i=1}^{a} G_i \sum_{k=1}^{c} M_{ik} \\ & + \sum_{i=1}^{a} (\mathrm{LR})_i \sum_{k=1}^{c} M_{ik}\end{aligned} \tag{3}$$

Constraints

$$\sum_{i=1}^{a} e_{ij} y_i \le R_i \qquad j = 1 \ldots 6$$

$$\begin{aligned}
&\sum_{i=1}^{a}(T_i + B_i)d_i \le MH_j \quad j = 1\ldots7\\
&\sum_{i=1}^{a} D_i R_i \le Q\\
&[DMTC_k]y_i \le R_i \qquad k = 1\ldots7\\
&\mathrm{LR}_i \times \mathrm{TR}_i \times P_i \le M_{ik}
\end{aligned} \tag{4}$$

It is observed on discussing with the experts of the industry that minimization of defects is an important aspect and has to be concentrated more. Hence it was decided to compute DPMO for all the sub-process.

2.5 Analyze Phase

In analyzing phase 4, major defects during production are considered: Blemishes, Inner liner, Foreign Materials Contamination and Flowcrack for computing DPMO. The factors that are considered for the production are:

Blemishes

Any type of imperfections ranging from cosmetic to more serious problem like missing steel radial belt, rubber poured may not fill the mould correctly; too short tread results in a tyre termed as blemished. The classification is done by someone fully trained in the area of tyre inspection.

Inner Liner

The inner liner is a calendared halo butyl rubber sheet compounded with additives that result in low air permeability. The inner liner assures that the tire will hold high-pressure air inside, minimizing diffusion through the rubber structure.

Foreign Material Contamination

Any particle other than the raw materials is termed as foreign matter. Due to the presence of this matter that particular portion will show irregularities creating air bubbles and blisters.

FlowCrack

One of the major defects observed in tyres is flowcrack, which occurs in the sidewall region. The main reason for this defect is the improper viscosity level of sidewall compound.

Defects per million opportunities (DPMO)—the ratio of the number of defects in 1 million opportunities when an item can contain more than one defect.

$$\mathrm{DPMO} = \frac{\mathrm{DPU}}{\text{Opportunities per unit}} * 1 \text{ million}$$

Table 1 Defects for each sub-process

Defects	Opportunities	Rejected out of 1000	Number of defects/Rejected	Number of defects
Blimishes	72	19	7	133
Inner linear blisters	57	16	6	96
Foreign materials contamination	150	20	8	160
Flowcrack	81	18	7	126

Table 2 DPMO for each sub-process

Defects	DPU	DPMO
Blimishes	0.133	1847
Inner linear blisters	0.096	1684
Foreign materials contamination	0.16	1066
Flowcrack	0.126	1555

Defects per unit (DPU): the average number of defects per unit of product.

$$\mathrm{DPU} = \frac{\text{Number of Defects}}{\text{Total units Inspected}}$$

Table 1 gives the defects for each sub-process and Table 2 gives DPMO for each sub-process. In case of blemishes, Number of defects = Number of defectives*defects per unit.

No. of defects = 19 * 7 = 133

$$\mathrm{DPU} = \frac{\text{Number of Defects}}{\text{Total units Inspected}} = \frac{133}{1000} = 0.133$$

$$\mathrm{DPMO} = \frac{\mathrm{DPU}}{\text{Opportunities per unit}} * 1\text{ million}$$
$$= \frac{0.133}{73} * 1{,}000{,}000 = 1847$$

Finally, it was inferred that the blemishes in the curing process contain more defects, and more care should be given at that stage. Curing is one of the most important steps in the tyre manufacturing process. During this process, a green tyre is formed to the desired shape and the compound is converted to a strong, elastic material to meet tyre performance needs. The process of curing is usually accomplished under pressure and an elevated temperature provided by the mould. The curing process is energy consuming and has a strong effect on material properties. In the curing process, cycle time is an important criterion. To know whether the cycle time has any effect on mileage, strength and hardness (independent variable) of the tyre a multiple linear regression is computed. The model is given by

$$y = 2137 - 143.75x_1 - 36.75x_2 + 2.5x_1x_2$$

There is no linear association between cycle time with respect to hardness and strength during tyre production. The results of the regression Table 3 are showing the regression model.

It was found that p-value is less than 0.05 and hence all predictors have to be considered and need not be removed. The summary of the overall fit is given in Table 4. Table 5 gives the ANOVA for regression stating that there is a strong relationship between the variable under study. Figure 4 gives the normality probability plot. Since from Fig. 5, the residuals found in the variable are more it is decided by the authors in discussion with the experts of the production to find an optimal value for the variables. To attain an optimal state during the curing process, it is needed to concentrate on cycle time. Hence an optimum value for the variables is required and is obtained by means of signal to noise ratio.

Signal to Noise Ratio

Signal-to-noise ratio is defined as the ratio of the power of a signal to the power of background noise. The main important factor of communication is the signal to noise

Table 3 Regression model

Predictor	Coefficient	Estimate	Standard error	t-Statistics	p-value
Constant	β_0	2137	214.16	9.979	0.0002
x_1	β_1	−143.75	14.55	−9.878	0.0002
x_2	β_2	−36.75	3.58	−10.278	0.0001
x_1x_2	$\beta_1\beta_2$	2.5	0.242	10.351	0.0001

Table 4 Various measures for the predictor's variables

R-squared	0.9981
Adjusted R-squared	0.997
Residual standard error	0.9487 on 5 degrees of freedom
Overall F statistic	886.56 on 3 and 5 degrees of freedom
Overall p-value	0

Table 5 ANOVA for Regression

Source	df	SS	MSS	F-statistic	p-value
Regression	3	2393.91	797.91	886.56	0
Regression Error	5	4.5	0.9		
Total	8	2398.2	299.78		

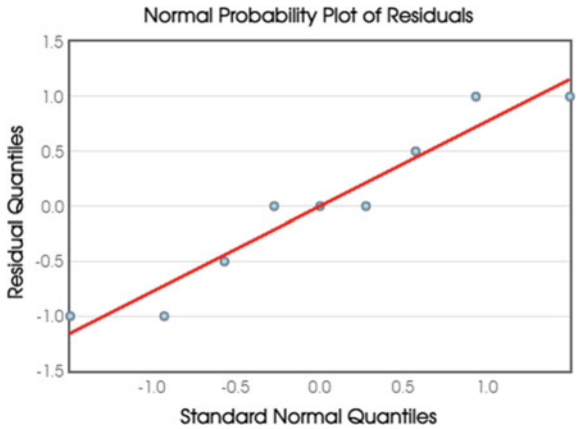


Fig. 4 Normal probability plot

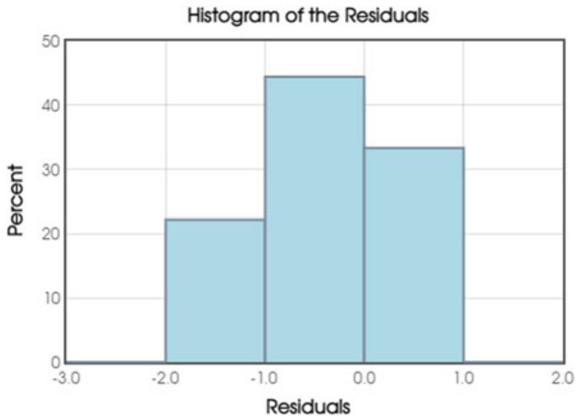


Fig. 5 Residual plot

ratio. The main cause of signal loss is due to the interference of the random noise, which affects the required signal. Thus, in order to achieve the actuals, signal which we required, the noise has to be removed or minimized.

$$S/N = 10 * \log\left[\frac{y^2}{\sigma}\right]; \quad \text{where} \quad \sigma = \sqrt{\frac{\sum y_j\left(y_j - \overline{y}^2\right)}{n-1}}$$

$$\text{and} \quad \overline{y} = \frac{\sum j y_j}{n}.$$

In the curing process, the parameters considered are mileage, strength, temperature, pressure, weight, hardness, worn out and size with respect to a varying time. Whereas temperature and time are inversely proportional. Since the variation of temperature, the pressure is very small, the values are not entered in the table below. Table 6 gives the levels needed for the signal to noise ratio.

Table 6 Levels for variables

Category	Mileage	Strength	Worn out (in.)	Time	Hardness (shore *A*)
Passenger 195/65 R15	35,000 40,000 45,000	12 14 12	0.1 0.1 0.1	20 23 21	58 58 58
Bus 205/60 R15	20,000 22,000	16 16 16	1 1 1	45 44 46	62 62 62
Track 315/80 R22.5	20,000 22,000	18 18 18	2 2 2	60 61 62	64 64 64

Table 7 Improvement in cycle time

Process parameters	Before Implementation (min)	After implementation (min)	Percentage Improvement (%)
1st Process	30	20	6
2nd Process	35	25	8
3rd Process	2	4	12

With various combinations of the above table using L9 orthogonal array, the cycle time was computed for 9 samples of each category and optimal values are obtained as strength = 14, 18, 16, temperature = 382 °F, pressure = 185 csi and mileage = 40,000, 22,000, 22,000.

2.6 Improve Phase

Before the implementation, the defects occur due to inaccurate timing of the processing. Using *S*/*N* ratio, the optimum time is set and alignments were exactly matched and further processed. The tires are subjected to high-temperature processing followed by a treatment with hot water along with treated with normal water. Process-I Treatment with high temperature; Process-II Treatment with hot water and Process-III Treatment with cold water. Table 7 gives the improvement in cycle time after discussion with the experts of the production department. This change may not occur always but can be noted and taken care.

2.7 Control Phase

To make sure about the other processes are in control, the following questions were discussed with the experts of the production process to know whether there is an improvement in the entire production process by fixing the optimal cycle time obtained from signal to noise ratio.

YES/NO QUESTIONS

Mixing

1. Are the mixtures are common for trunk Bus Radials and passenger Car Radials? YES
2. Are the raw materials added together? YES.

Extrusion

1. Are they dipping into a special liquid to prevent the sheets from sticking to each other? YES
2. Does any super long conveyor belts maintain the right tension on the rubber section as it passes through the multiple presses? YES.

Calendaring

1. Is it maintains the exact distance between each cord? YES
2. Is the steel cords fed into the Calendaring machine? YES.

Curing

1. Is the weight of the tire maintained such a way that it increases friction between it and road? YES
2. Is the stretching ratio of the tire kept in balance? YES.

Inspection

1. Are the lightest or heaviest part of a tire represented by red or yellow markings? YES
2. Are the finished goods ready for dispatch stored in the warehouse? YES.

The above questionnaire suggests that if the cycle time has been improved then the entire quality can be improved thereby reducing the defects.

3 Conclusion

The DMAIC methodology was implemented on tyre production. In the define phase, the entire production process was studied. In the measure phase, the three important factors are considered. Fishbone diagram, Quality function deployment and Multi-objective optimization. From MOO, it was decided to concentrate on minimization of defects and hence in analyse phase, DPMO was computed for each sub-process.

The defects were found to be more during the curing process and hence to know the significance of the variables in the process, a multiple linear regression was computed. It was found that there is a strong relationship between variables, but residuals were slightly above the prescribed level and hence an optimum value has been computed by signal to noise ratio. Hence after fixing the desired optimum values, discussion was done with the experts of the organization and suggested the percentage of improvement.

References

1. Sutrisno, A., Gunawan, I., Vanan, I., Asjad, M., Caesarendra, W.: An improved modified FMEA model for prioritization of lean waste risk. Int. J. Lean Six Sigma **11**(2) (2020)
2. Garza-Reyes, J.A.: Green lean and the need for six sigma. Int. J. Lean Six Sigma **6**(3), 226–248 (2015a)
3. Garza-Reyes, J.A.: Lean and green—A systematic review of the state of the art literature. J. Clean. Prod. **102**, 18–29 (2015b)
4. Garza–Reyes, J.A., Jacques, G.W., Lim, M.K., Kumar, V., Rocha–Lona, L.: Lean and green—synergies, differences (2014)
5. Ani, M.N.C., Kamaruddin, S., Azid, I.A.: Factory-in-factory concept as a new business model for automotive production system. Int. J. Six Sigma Compet. Adv. **11**(2/3) (2019)
6. Deepa, O.S.: Application of acceptance sampling plan in green design and manufacturing, Int. J. Appl. Eng. Res. **10**(2 Special Issue), 1498–1499 (2015)
7. Deepa, O.S.: Optimal production policy for the design of green supply chain model, Int. J. Appl. Eng. Res. **10**(2 Special Issue), 1600–1601 (2015)
8. Ajmera, P., Jain, V.: A fuzzy interpretive structural modeling approach for evaluating the factors affecting lean implementation in Indian healthcare industry. In. J. Lean Six Sigma **11**(2) (2020)
9. Phanden, R.K., Demir, H.I., Gupta, R.D.: Application of genetic algorithm and variable neighborhood search to solve the facility layout planning problem in job shop production system. In: 2018 7th International Conference on Industrial Technology And Management (ICITM), pp. 270–274. IEEE (2018)
10. Shruthi, G., Deepa, O.S.: Average run length for exponentiated distribution under truncated life test. Int. J. Mech. Eng. Technol. (IJMET) **9**(6), 1180–1188 (2018)
11. Krishnan, S.M., Deepa, O.S.: Control charts for multiple dependent state repetitive sampling plan using fuzzy poisson distribution. Int. J. Civil Eng. Technol. (IJCIET) **10**(1), 509–519 (2019)
12. Wong, W.P., Wong, K.Y.: Synergizing an ecosphere of lean for sustainable operations. J. Clean. Prod. **85**(15), 51–66 (2014)

Digitization of Biogas Plant for Improving Production Efficiency

Kural Azhagan, Sumit Gupta, and Rakesh Kumar Phanden

Abstract In the current competitive world, the digitization of biogas plants is much needed. This can be achieved by employing the most modern technologies in the biogas plant. In the traditional biogas plant, the process is uncontrolled, and the efficiency of the model is low as it requires high inputs and the chances of leakage of gas are high. To overcome these issues, Industry 4.0 practices are implemented to improve the efficiency of the system. This paper is focused on the modification of the existing biogas plant. In the modified biogas plant, a closed chamber with the help of a gate valve is developed that closed the digester with no leakage of gas and add safety features to the process. In the proposed design, heat efficiency has been significantly improved and produced optimum methane gas during the winter session. In the proposed automated plant, human work has been optimized.

Keywords Organic waste · Industry 4.0 · Bio-methane

1 Introduction

India has a population of about 1.36 billion [1] making it difficult to meet its energy needs from its resources. India with its vast population also produces a large amount of waste amounting to about 160 billion tons per year. Organic waste comprises about 71% of the total waste produced, amounting to about 81 billion tons per year, This is waste usually left to decompose in the open or disposed into the sea. There is a small amount of this waste employed in biogas production, however, it is very low when compared with the possible potential in a country like India. Because of the huge population, they have very few skilled workers and handling organic waste requires a lot of care as it may lead to unwanted diseases if not properly handled. India is the second most populated country produces a significant amount of waste, which is poorly handled throughout the country leading to poor sanitation, development

K. Azhagan · S. Gupta (✉) · R. K. Phanden
Department of Mechanical Engineering, ASET, Amity University, Noida, UP 201313, India
e-mail: sumitgupta2007@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_43

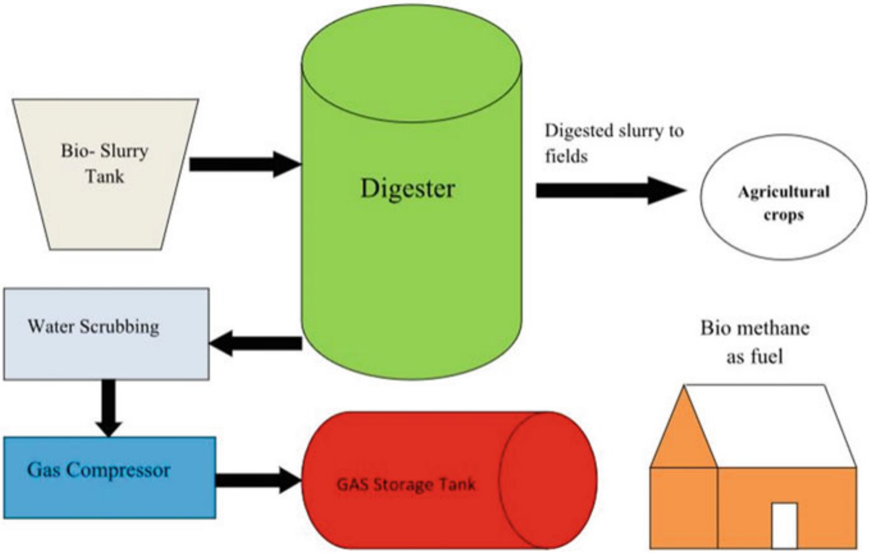


Fig. 1 Controlled process of Biogas plant

of disease-causing microorganism and poor living conditions India also consumes a very large amount of fossil fuels to meet its energy needs.

The objective of this research has been derived from the technological barriers involved biogas production facility and also to minimize the human effort involved in the production cycle and enhances the traditional design to a new modified design (refer Fig. 1), which has higher efficiency and producing very low wastage and the parameters are an open loop in old biogas model that is changed to closed-loop model using Industry 4.0. So, this presents the modernization of biomethane plant and optimization process parameters to enhance the efficiency of the system by the controlled process.

2 Review of Background

Industry 4.0 is the name given to the current industrial revolution, which is taking place on the face of the plane [2]. It includes a combination of the multiengineering field, which includes the concepts of Electronics, Computer science, IT, Mechanical and Civil engineering to build a system which is self-sufficient and does not require any external inputs as in the conventional systems [3]. The term Industry 4.0 was first coined in 2011. This requires expertise from all the engineering fields to implement on a facility. Paelke et.al [4] exhibited the underlying encounters on utilizing increased reality in help frameworks inside a smart plant condition. Through open tests with a few hundred clients, we could demonstrate that AR is a promising UI idea in this application space [4]. Lasi et.al [5] have proposed to be presumed that the expression Business 4.0 depicts diverse IT driven—changes in assembling frameworks [5]. Li et.al [6] have exhibited a review of modern Wireless Networks WNs (IWNs), talk about IWN includes and related methods, and after that give another engineering dependent on the nature of administration and nature of information for IWNs [6]. Owamah et al. [6] have told that the digestive biofertilizer from the anaerobic digestion of food waste and human excreta can be utilized to improve soil fertility [1]. The results from this investigation show critical decreases in BOD, COD and natural carbon content in the stomach related when contrasted with the feedstock. The temperature was seen to keep up a mesophilic go all through the time of processing demonstrating that the biofertilizer can be created at such temperature [7]. Batstone et.al [8] have proposed an anaerobic absorption system typically comprises of a reactor with a fluid volume, and a fixed gas headspace at environmental weight with the gas evacuated to downstream usage [8]. From literature, it is found that there exists a gap between the fields of engineering and biology as they are completely different from each other. This also exists in biogas industry, all the biogas plants require humans to perform certain tasks, which are dangerous and require engineering attention**.**

3 Methodology

In traditional biogas plant, inlet and outlet have not closed with a valve. So, the efficiency of methane was less. To increase the efficiency of biogas, the newly fabrication model has been closed with a knife edge valve with pneumatic actuator. Many changes have made to a new model to increase the efficiency of methane gas. The outlet valve position has been changed. The gas outlet has changed with the solenoid valve. Because in the old model, they use ball-operated valve that to have open and close manually. In traditional model, digester is fully closed so the temperature, pressure, gas, P_H cannot be measured and we have to calculate manually for gas production. So, in the new model, every parameter is monitored online using a sensor that is implemented inside the digester. By the sensor value, the actuator is actuated according to condition requirements for the bioplant. In the new model, water scrubber has added for purifying CO_2 and H_2S that increase the efficiency of methane gas.

3.1 Uncontrolled Process of System

This system has human effort and efficiency also less. The picture has been taken from the traditional model, which is located at Hisar, Haryana. It shows the design false of health safety as there is no proper sanitation and a skill. Gas output is not purified, and the gas being used has impurities of H_2S, which is very poisonous when

Fig. 2 **a** Uncontrolled process of Biogas plant. **b** Traditional model

inhaled. The partially digested slurry is exposed to air and produces foul odor in the surrounding atmosphere as shown in Fig. 2a, b. There is a possibility of leakage of gas as the transmission system installation is very conventional.

3.2 *Controlled Process of System*

In this process, uncontrolled has been changed to controlled process as shown in Fig. 3. All parameters to be monitored inside the digester have done using a sensor

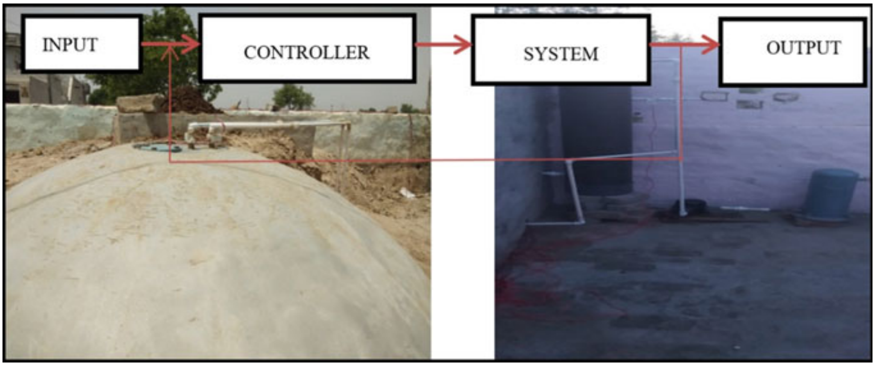


Fig. 3 Controlled process in Biogas plant (Modified model)

module. From sensor value, the actuator is actuated according to condition inside the digester. In the new model as shown in Fig. 3, the process has been controlled, the optimum temperature has maintained inside the digester because inlet and outlet slurry are not leaving frequently inside the digester and outside the digester. The process has been changed to fully automate and there is no human intervention.

3.3 Experimental Procedure

The physical resources are sensors and actuators. DHT 11 temperature sensor is used to measure the temperature and humidity inside the digester. The optimum temperature has found in the research paper. According to the optimum temperature condition, DHT 11 will be actuated. The moisture sensor is used to measure the water content in slurry. If less water content in slurry, the solenoid valve will be actuated, the water get into the digester. The water content is more the solenoid valve will turn off. P_H Sensor is used to measure the slurry has hydrogen-ion activity. It works according to the optimum P_H value of biogas. BMP 280 sensor is used to measure the pressure inside the digester. MQ 5 sensor is used to measure the gas content in the digester. If pressure, temperature, $P_{H,}$ gas value formed inside the digester solenoid valve of gas will be open the gas pass through water scrubber. The actuator is started according to the sensor value from Arduino Nano that value sends to the base node (Arduino Nano) the valve, compressor is actuated. From the base node, the value is sent to the server by Node MCU. The values are monitor in IoT tweet application in gadgets. The IoT tweet application is used to monitor the parameters in Cloud-based system. It is a free IoT platform for monitoring the value in the cloud. Now they are developing APK for android/apple OS. Now the biogas plant value is seen in IoTtweet application.

The temperature mean of April month is given by:

$$\text{Mean} = \frac{T_1 + T_2 + T_3 + T_4 + \cdots + T_n}{\text{Number of Days}}$$

$$\text{Mean} = \frac{45 + 47 + 41 + 40 + 41 + 43 + 46}{7} = 43$$

Temperature mean of the month May

$$\text{Mean} = \frac{45 + 48 + 43 + 50 + 50 + 46 + 44}{7} = 46.5$$

In Fig. 4, graph is plotted for temperature variation in April and May. Both months have the optimum temperature for methane production.

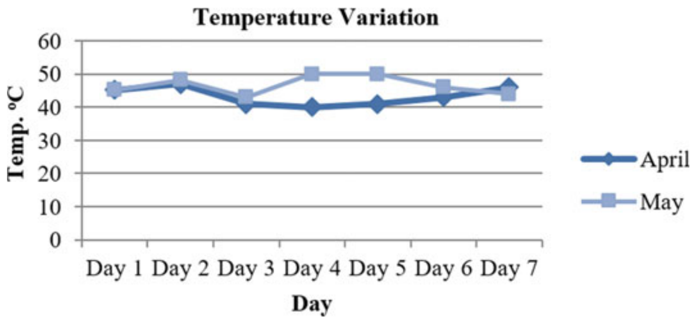


Fig. 4 Temperature variations in April and May

4 Results and Discussion

The efficiency of different factors affecting the yield of biogas has been considered. The model is very heat efficient as the temperature of the system is 43 °C in April and in May it is 46.5 °C. As per the literature, the most optimum temperature for a biogas plant is between 40 and 50 °C at this temperature, the maximum yield is obtained and this can also be observed with the rise in pressure and gas concentration inside the digester in a period of time [8, 9].

From Table 1, it can be concluded that the temperature retention of the slurry in the new model is efficient and is more efficient than the traditional model as temperature directly affects the production of gas. The optimum temperature of biogas is between 40 and 50 °C. The value got from the new model lies between the optimum temperatures. So, the new model is more efficient and human intervention has been reduced. Figure 5 compares the model of biogas plant for April and May. From that new model has high heat efficiency. The temperature of the digester remains in the range as there is no slurry output, the slurry stays in the digester for about 70 days until the gas concentration drops below 30%, making it a very efficient process as the maximum output of the organic material is obtained, at the end of about 70 days, the slurry is completely digested and is ready to be used as fertilizer and is completely inactive of bacteria as the bacteria dies after the slurry is completely digested. From the results of industry 4.0 implementation, the traditional biogas plant parameters cannot be monitored and when the gas formed inside, the digester human has to open the valve for getting gas for household uses or other application. But in the new model biogas plant, this problem has been removed and human intervention

Table 1 Comparison of mean temperature

Month	Traditional model mean temperature (°C)	New model mean temperature (°C)
April	29	43
May	34	46.5

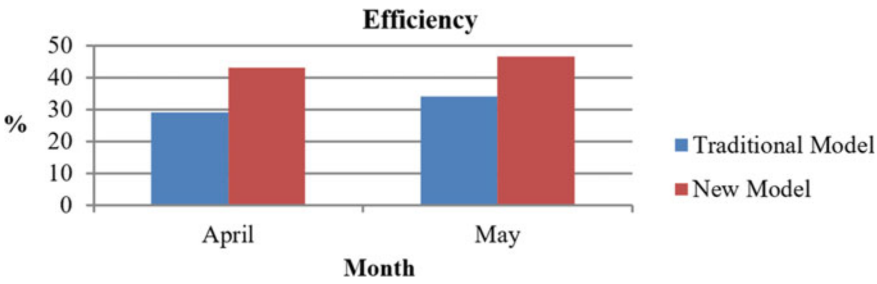


Fig. 5 Traditional models versus new model

has reduced. All the values have been digitized and the values are viewed in the UI on desktop or mobile.

5 Conclusions

The traditional biogas plant is digitized to enhance its efficiency. In improved design, heat efficiency has been significantly improved and produced optimum methane gas during the winter session. In the proposed automated plant, human work has been optimized. In future, the cow dung can be replaced with kitchen waste, plastic waste, and human waste for gas production. This system could also be employed in rural areas where there is a lot of social stigmas associated with handling waste as this system does not require much human intervention and making ideal for this purpose.

References

1. Owamah, H.I., et al.: Fertilizer and sanitary quality of digestate bio fertilizer from the co-digestion of food waste and human excreta. Waste Manage. **34**(4), 747–752 (2014)
2. Aggarwal, A., Gupta, S., Ojha, M.K.: Evaluation of key challenges to Industry 4.0 in Indian context: A DEMATEL approach. In:Advances in Industrial and Production Engineering, pp. 387–396. Springer, Singapore (2019)
3. Li, L.: China's manufacturing locus in 2025: With a comparison of "Made-in-China 2025" and "Industry 4.0." Technol. Forecast. Soc. Chang. **135**, 66–74 (2018)
4. Paelke, V.: Augmented reality in the smart factory: Supporting workers in an Industry 4.0. environment. In: Proceedings of the 2014 IEEE Emerging Technology and Factory Automation (ETFA). IEEE (2014)
5. Lasi, H., et al.: Industry 4.0. Bus. Inf. Syste. Eng. **6**(4), 239–242 (2014)
6. Li, X., et al.: A review of industrial wireless networks in the context of Industry 4.0. Wirel. Netw. **23**(1), 23–41 (2017)
7. Pathak, P., Gupta, S., Dangayach, G.S.: Sustainable waste management: a case from Indian cement industry. Braz. J. Oper. Prod. Manag. **12**(2), 270 (2015)
8. Batstone, D.J., et al.: The IWA anaerobic digestion model no 1 (ADM1). Water Sci. Technol. **45**(10), 65–73 (2002)

9. Kishore, V.V.N., Raman, P., Pal, R.C., Sharma, S.P.: The TERI fixed dome biogas plant model—A case study of development through user interaction and field research. Int. J. Ambient Energy **19**(4), 199–210 (1998)

Identification of Drivers in Implementing Green Supply Chain in Indian Perspective

Neeraj Lamba and Priyavrat Thareja

Abstract It's a well-known fact that the Japanese Automobile Sector identified the various approaches for improvement in the business performance which caused the transition of manufacturing sector from push to pull production. Eventually, the major role in this transition phase was played by Supply Chain Management approach with which the industries integrate the whole industrial setups in a network to balance the supply and demand gap. In the early stage, Supply Chain was having the major concern to fill/eliminate the gap between supply and demand through efficient information processing systems. Later the earlier concern of SCM includes the environmental aspect because of eco-friendly products/services demand. Such kind of concerns in manufacturing sector solicits the deeper intervention from all the allied network partners. The present paper discusses the role played by GSCM in the industries to produce the eco-friendly product and in addition, utilizing the environment-friendly processes. In addition, the paper reveals the drivers responsible for driving the GSCM implementation smoothly in Indian Context and helping in achieving the excellence in terms of tangible and intangible outcomes both.

Keywords Sustainability · Environmental issues · Traditional supply chain · Green supply chain · GSCM drivers

1 Introduction

The literature on manufacturing industries reveals the status of the manufacturing context and the environment under which they were working before 1979s. At that time, the manufacturing context was only based on push manufacturing aspect, i.e., selling the product in market without considering the customer demand. With this kind of business model, most of the industries were failed to retain the customer in

N. Lamba (✉)
Mechanical Department, Punjab Technical University, Jalandhar, India
e-mail: nlamba33@gmail.com

P. Thareja
Ex-Professor, Punjab Engineering College, Chandigarh, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_44

the long-term aspect. As the time passed, the concept of supply chain management was picked by most of the manufacturing industries. The basic supply chain model was based on the flow of material from the supplier to customer and money flow from customer to supplier side [17]. In addition to this, the main consideration in that model was flow of the information which was designed for both sides (from supplier to customer and vice-versa) [1, 6]. The basic model was the main objective of economic growth as well as the bridging the gap between supply and demand. This model was recognized as the revolution in the manufacturing context which helped in transiting from push to pull type production to the manufacturing industries [15]. Now, the traditional supply chain is not enough to meet with the customer demand, because of increased the government initiatives in the consumer awareness regarding the environment issues in manufacturing context [1, 9]. This would further affect the entire supply chain because the end product delivered to customer is the result of integration of various departments/workstations from the supply of raw material to the manufacturing to the delivery point. The possible solution to come out from this problem is the greening of supply chain, i.e., implementation of green supply chain management in the industries [4, 5]. GSCM, in general, a practice that encompassing all the activities as in the traditional supply chain with an addition of green concept [36, 44]. GSCM is the combined effort of green purchasing (at the initial stage), green manufacturing and materials management (during the transformation stage), green distribution (delivery stage), and the reverse logistics (disposal stage) [15]. In present scenario, the Indian manufacturing context is also transiting from the traditional supply chain to the green supply chain. The reason for this transition is very simple and logical, i.e., It is the demand of present. In present scenario, the increased awareness among both the producer (business entrepreneur) as well as the consumer (end customer) put them in the situation to design and develop the goods inclusive the environmental aspect [1, 41]. Table 1 represents the comparison on the basis of parameters among the traditional and the green supply chain in the manufacturing context.

The most of the organizations contain the financial soundness in the industry, i.e., huge availability of capital for production. Now, the industries want to use this capital in such activity where financial inputs lead to create the competitive advantage for the industry in the long-term sustainability aspect [26]. The present study reveals the various drivers for the green supply chain.

2 Literature Survey

The year-by-year passing trend in the present decade depicts the importance of Green Supply Chain Management (GSCM) in the manufacturing context. In addition, the awareness among the consumer and supplier (both) regarding eco-friendly products through various platforms puts a pressure on industries to imply the GSCM [31, 34]. The basic objective of GSCM is to attain both the tangible (profit) and intangible (market share) benefits by diminishing the environmental threats. In the present-day

Table 1 GSCM v/c TCSM

Parameters type	TSCM	GSCM
Objectives [1, 35]	In the TSC, the economic aspect is the main objective	In GSC, both Economic as well as environment concerns are put on front to address the market
Expectation by customers [6, 18]	The Customer expectation most of the time overlooked just for the sake of economic benefits	The customer expectation is too high because they are paying more and the availability of the products is limited
Supplier selection [6, 17, 41]	The input material cost and the capability to fulfill the demand is mainly considered for the supplier selection	The supplier selection as in TSCM including the Long-term sustainability and reliability of supplier
Economic aspects [24, 28]	In both the short term and long term based on the industry	Preferred in Long-run business models
Delivery rate [23, 37]	Rate of product delivering in TSC is much higher just because of its implementation. This approach is easy to implement and having low impact by the external environment	In this approach, the delivery rate is generally low because of having high impact by both the internal and external environment
Flexibility [6, 23, 32]	Flexibility is quite high which provides this approach competitive advantage over other approaches	This approach is relatively flexible. The reason is having the dependency on external environment to the industry who always limited the scope of flexibility
Scope [12, 18]	The approach scope is high and can be implemented in Micro-scale industries also	Scope is limited because implementation cost is the biggest concern

manufacturing context, it is very important to understand that what is in returning from a product as the byproduct in the environment while in use or after the shelf life [32]. These return to the environment threats and draw the major setback on the process quality which is being used in designing and development of the product, in terms of both economics and ecology [45]. The implementation of GSCM was the toughest task in the earlier days because industries are not aware that how they can transmit the traditional supply chain to the GSCM [3]. Furthermore, while transiting from TSCM to GSCM, what would be the financial impact on the industries? Now, GSCM has become more popular because the fact-based empirical researches were done on the industries to validate the GSCM impact on the business performance. The research reported on GSCM provides an insight to the industries how they can undergo the transition process. Further, few researchers on manufacturing context reported the industrial conscientiousness regarding the survival in the long-term aspect [11]. Simultaneously, they reported the GSCM as the sustainable growth approach which aims to effective utilization of the resources (including energy) [18]. By implementing GSCM, the industries can produce the environmental-friendly products because it includes the all the operations, i.e., from the purchasing from the supplier to the delivery to end customer through the manufacturing setup [7, 41]. In the legal term, there is clarity requisition in the industry visions, i.e., no compromise with the quality and environment concern will lead to the industry growth in sustainable manner. The literature also depicts the various barriers in the way of implementing GSCM and categorized on the basis of four main categories, i.e., Organizational (Internal), Technical (Especially external), Economic Barriers (both external and internal), Social and Legal Barriers (External) [40].

3 Research Gap

Traditional SCM concentrates on economy as single objective, whereas the GSCM includes the environmental aspect in addition to economical aspect. The most of the researches on GSCM report that the GSCM approach has the potential to improve the environmental situation worldwide; still there is doubt on the final output because the output is based on the drivers who actually drive the whole business strategy [18]. Till date, very few researches reported the GSCM drivers with which it can be implemented very easily to sustain the business performance in the long run. The present study reveals the drivers of GSCM in Indian Context.

4 GSCM Drivers

The present scenario is the competitive one and almost all the manufacturing industries are striving for the business excellence through the competitive advantage. Further, this competitive advantage is now encashed by the industries in terms of finding the no of consumers [23]. While the important point remains untouched that is how the product will react during its life cycle. The product life cycle in general defined as series of stages through which it passes during its lifetime [9]. The product will pass on the stages, which is known as the supply chain from the supplier to the consumer.

Table 2 Parameters helps in driving the GSCM implementation

Drivers with explanation	Working area
1. The management commitment: The engagement of all the activities within the restricted freedom of action is referred to as the commitment. The industrial growth is mainly focused on the desperation of Top Level Management toward the achievement of the desired goal In the present scenario, going with green operations is more in steerage because of the management commitment. The literature reveals that in most of the manufacturing industries, where GSCM application was successfully done and finds the optimum results, the top-level management plays the important role [5, 8, 10, 13, 17, 26]	*Operational areas*: Planning and decision-making
2. IT enable system: Doing business in today's scenario is mainly dependent on the information as a resource which helps industries to understand the market need and ways to cater to that needs. Now, the manufacturing context of India is shifting toward the IT-enabled system and utilizing resources more efficiently. This factor tremendously contributed to the growth of Green Concept implementation in the supply chain [7, 18, 24, 26]	*Operational areas*: All kind of business transactions like order, delivery, receiving, etc
3. Government policies and regulations: In the present scenario, the government and other regulatory bodies are bound to frame the various policies (may be law or an ordinance by the government agencies) which are directly related to the preserving of environment. These laws/policies further guide the local/national administration/body to guide the industries (dependent on type of industry) to plan and incorporate the mandatory eco-friendly measures in their operations. In addition, failure/negligence in the incorporation of the mandatory disclosures is now punishable (varies upon the category and the incompetency). These kinds of policies/laws are now helpful in pushing the businesses to adopt and incorporate the concept of greening in entire supply chain [26, 35, 41, 42]	*Operational areas*: Focused on all operations in an organization

(continued)

Table 2 (continued)

Drivers with explanation	Working area
4. Economic consideration: Going green is not an easy task because it involves a huge investment. The manufacturing industries want to imply the Green practices but while considering the cost as one of the effective decision factors few will succeed with the implementation of the green practice. But increasing awareness among Green Concepts among all the stakeholders the cost factor is now reduced and increasing the demand in GSCM. In addition, the waste reduction while value addition in the product is also the considerable contributor in GSCM implementation [23, 27, 28, 43–46]	*Operational areas*: Somewhat dependent on what scale GSCM is applied
5. Consumer contribution (awareness): In the management practice, the end customer is treated as the source of profit for any organization. While reviewing the literature, the end customer awareness regarding the GSCM is now one of the most driving factors for GSCM implementation. The awareness among end customers leads to the increase in the market share in compared with traditional products. The customer is now enjoying the benefit of GSCM [1, 18, 28, 29, 47–49]	*Operational areas*: Ordering and utility related considerations
6. GSCM pathway: In most of the manufacturing units in India, the GSM implementation is done under the kind supervision of the experts of SCM. Few of them are aware of the fact Why GSCM and how it can be implemented? And rest others follow the same pattern as in traditional SCM. Now, the GSCM pathway (varies from industry to industry) is and the training modules are developed by the experts which help in implementation of GSCM in the easiest way [18, 21, 38, 50, 51]	*Operational areas*: Dependent on type of industry and on what scale GSCM is applied

(continued)

5 Conclusions

GSCM is emerged as the approach for industries to have better control over environmental issues. In addition, the industries also find their applications to have more profit and the market share as this approach reduces the environmental risks/impacts [25]. The present paper discussed an overview of the development of GSCM with the help of literature. While going through the literature extensively in the Indian manufacturing context, it is revealed that there are the drivers who actually help in promoting the GSCM implantation in the industries as listed in Table 2. This paper provides a close insight into the drivers of the GSCM approach to the industries and the working areas. In the future, the identified drivers will be ranked on the basis of

Table 2 (continued)

Drivers with explanation	Working area
7. Skilling and knowledge: In industries, the individual manpower skill and knowledge help in defining the output as the productive one. The experienced individuals sharing their pre-owned experiences among the learners and by this process the output is approximated. While implementing GSCM, the skilling and knowledge of the individuals is the most important one because if any point missed out throughout the chain will affect the output or the performance of the system. In the earlier days, it was not an easy task to find out the skilled person having experience in dealing with environment concern. Nowadays, few nonprofit organizations in association with government bodies set up their cells (networking of environment specialist) to help the industries to implement green supply chain management such as CII [12, 16, 52]	*Operational areas*: Directly related with the manpower, i.e., Internal strength of an organization
8. Eco-friendly organizational culture: The organizational culture is the most important contributor to promote the GSCM implementation in the manufacturing context. Most of the leaders concede the culture as a powerful tool that can create and sustain performance. So, it is important to have dynamic leadership in the manufacturing unit to confront the work culture-related issues, i.e., creation and maintenance [19]. The present-day Indian manufacturing context especially automotive parts manufacturers are implementing the GSCM through the eco-design of the assembly/production line [16, 23, 37]	*Operational areas*: Both the internal and external environment
9. Intra-inter market sustainable practices: To find out the desired share in market, almost all the manufacturing unit's plans for the world-class manufacturing system evolution in their manufacturing setup. The best way of implementing GSCM is the taking advantage from the intra-inter market sustainable practices used by the industries. The basic vision behind this is to get benefitted not only from the industry itself but also from the efforts of other stake holders to achieving the sustainability [14, 21, 37]	*Operational areas*: Internal Decision-Making and capabilities of stakeholders

(continued)

Table 2 (continued)

Drivers with explanation	Working area
10. Encashment of brand image: By designing and developing the eco-friendly products, the manufacturing sector tends to gain the advantages such as increased market share (both in volume and value) and creating the brand image which they could cash in long term. The present-day manufacturers are aware with the fact that the brand image will lead to reduce the customer consciousness about the product as well as industry. Going green would help in creating the brand image, that's why the more and more no of industries are implying it [4, 24, 29, 53–55]	*Operational areas*: Looking for the customer desires
11. Focused on being socially responsible: For an organization, being socially responsible is treated as the corporate issue. The majority of the industries are now taking the CSR initiatives so that they can express the industry sense for the well-being of the society. By giving due consideration to the environment concern as CSR (Voluntary and intrinsic concern), the industries are now implementing and promoting the green operations throughout the value chain. The responsibility regarding the social concern especially preserving the environment is also counted as one of the driver who drives the need of GSCM implementation in manufacturing context [10, 20, 32, 55]	*Operational areas*: Dependent on the type of CSR and how it is executed
12. Increased product characteristics: Prior to the GSCM, the manufacturing industries are mainly dealing with the four major drivers for the traditional supply chain, i.e., Inventory, Facility, Transportation, and information. In general, these drivers were utilized to find out the various solutions/alternatives related to product characteristics such as quality, cost, time, and delivery. Now, day by day increased awareness regarding the environment-related issues enforced the industries to consider one more characteristic that is environment friendly (designed and developed) products [43–46]	*Operational areas*: Eco-friendly considerations throughout the value chain

their contribution toward the GSCM implementation by using the advanced MCDM approaches like AHP and ISM.

References

1. AlKhidir, T., Zailani, S.: Going green in supply chain towards environmental sustainability. Glob. J. Environ. Res. **3**(3), 246–251 (2009)
2. Alhola, K.P.: Promoting environmentally sound furniture by green public procurement. Ecol. Econ. **68**(1–2), 472–485 (2008)
3. Bowen, F., Cousins, P., Lamming, R., Faruk, A.: The role of supply management capabilities in green supply. Prod. Oper. Manage. **10**(2), 174–189 (2001)
4. Chen, Y.S.: The driver of green innovation and green image—Green core competence. J. Bus. Ethics **81**(3), 531–543 (2008)
5. Dashore, K., Sohani, N.: Green supply chain management-barriers & drivers: a review. Int. J. Eng. Res. Technol. **2**(4), 2021–2030 (2013)
6. Deshmukh, A.J., Vasudevan, H.: Emerging supplier selection criteria in the context of traditional versus green supply chain management. Int J Managing Value Supply Chains **5**(1), 19–33 (2014)
7. Diabat, A., Govindan, K.: An analysis of the drivers affecting the implementation of green supply chain management. Resour. Conserv. Recycl. **55**(6), 659–667 (2011)
8. Digalwar, A.K., Metri, B.A.: Performance measurement framework for world class manufacturing. Int. J. Appl. Manage. Technol. **3**(2), 83–101 (2004)
9. Gunasekaran, A., Spalanzani, A.: Sustainability of manufacturing and services: investigations for research and applications. Int. J. Prod. Econ. **140**(1), 35–47 (2012)
10. Henriques, I., Sadorsky, P.: The relationship between environmental commitment and managerial perceptions of stakeholder importance. Acad. Manag. J. **42**(1), 87–99 (1999)
11. Holt, D., Ghobadian, A.: An empirical study of green supply chain management practices amongst UK manufacturers. J. Manuf. Technol. Manage. **20**(7), 933–966 (2009)
12. Hosseini, A.: Identification of Green Management of system's factors: a conceptualized model. Int. J. Manage. Sci. Eng. Manage. **2**(3), 221–228 (2007)
13. Hsu, C.W., Hu, A.H.: Green supply chain management in the electronic industry. Int. J. Sci. Technol. **5**(2), 205–216 (2008)
14. Hu, A.H., Hsu, C.W.: Critical factors for implementing green supply chain management practice: an empirical study electrical and electronics industries in Taiwan. Manage. Res. Rev. **33**(6) (2010)
15. Kumar, R., Kumar, V., Singh, S.: Role of lean manufacturing and supply chain characteristics in accessing the manufacturing performance. Uncert. Supply Chain Manage. **2**(4), 219–228 (2014a). https://doi.org/10.5267/j.uscm.2014.7.007
16. Kumar, R., Kumar, V., Singh, S.: Effect of lean principles on organizational efficiency. Appl. Mech. Mater. **592–594**, 2613–2618 (2014b). https://doi.org/10.4028/www.scientific.net/amm.592-594.2613
17. Kumar, R., Kumar, V., Singh, S.: Relationship establishment between lean manufacturing and supply chain characteristics to study the impact on organizational performance using SEM approach. Int. J. Value Chain Manage. **7**(4), 352 (2016). https://doi.org/10.1504/ijvcm.2016.080435https://doi.org/10.1504/ijvcm.2016.080435
18. Luthra, S., Garg, D., Haleem, A.: Green supply chain management: implementation and performance—A literature review and some issues. J. Adv. Manage. Res. **11**(1), 20–46 (2014)
19. Madu, B.C.: Organization culture as driver of competitive advantage. J. Acad. Bus. Ethics **5**(1), 1–9 (2011)
20. McWilliams, A., Siegel, D.: Corporate social responsibility and financial performance: correlation or misspecification? Strategic Manage. J. **21**(5), 603–609 (2000)
21. Mezher, T., Ajam, M.: Integrating quality, environmental and supply chain management systems into the learning organisation. Green. Supply Chain 67–85 (2008)
22. Mittal, V.K., Sindhwani, R., Shekhar, H., Singh, P.L.: Fuzzy AHP model for challenges to thermal power plant establishment in India. Int. J. Oper. Res. **34**(4), 562–581 (2019)
23. Mittal, V.K., Sindhwani, R., Kalasariya, V., Salroo, F., Sangwan, K.S., Singh, P.L.: Adoption of integrated lean-green-agile strategies for modern manufacturing systems. Procedia CIRP **61**(1), 463–468. Elsevier, Kamakura, Japan (2017)

24. Mittal, V.K., Sindhwani, R., Singh, P.L., Kalsariya, V., Salroo, F.: Evaluating significance of green manufacturing enablers using MOORA method for indian manufacturing sector. In: Proceedings of the International Conference on Modern Research in Aerospace Engineering. Lecture Notes in Mechanical Engineering, pp. 303–314. Springer, Singapore (2018)
25. Mohanty, R.P., Prakash, A.: Green supply chain management practices in India: an empirical study. Prod. Plann. Control **25**(16), 1322–1337 (2014)
26. Mudgal, R.K., Shankar, R., Talib, P., Raj, T.: Greening the supply chain practices: an Indian perspective of enablers' relationships. Int. J. Adv. Oper. Manage. **1**(2/3), 151 (2009)
27. Phanden, R.K., Ferreira, J.C.E.: Biogeographical and variable neighborhood search algorithm for optimization of flexible job shop scheduling. In: Advances in Industrial and Production Engineering, pp. 489–503. Springer, Singapore (2019)
28. Phanden, R.K., Saharan, L.K., Erkoyuncu, J.A.: Simulation based cuckoo search optimization algorithm for flexible job shop scheduling problem. In: Proceedings of the International Conference on Intelligent Science and Technology, pp. 50–55 (2018)
29. Piplani, R., Pujawan, N., Ray, S.: Sustainable supply chain management. Int. J. Prod. Econ. **111**(2), 193–194 (2008)
30. Qadri, M.A., Haleem, A., Arif, M.: Identification of drivers for greening of supply chain in India. Int. J. Construct. Proj. Manage. **3**(3), 1–17 (2011)
31. Rao, P.: Greening of the supply chain: a new initiative in South East Asia. Int. J. Oper. Prod. Manage. **22**(6), 632–655 (2002)
32. Rao, P., Holt, D.: Do green supply chains lead to competitiveness and economic performance? Int. J. Oper. Prod. Manage. **25**(9), 898–916 (2005)
33. Reijonen, S.: Environmentally friendly consumer: from determinism to emergence. Int. J. Consumer Stud. **35**(4), 403–409 (2011)
34. Sarkis, J.: How Green is the Supply Chain? Practice and Research. Clark University, Worcester, MA (1999)
35. Sarkis J.:A boundaries and flows perspective of green supply chain management. In: GPMI Working Papers, October 7th edn. (2009)
36. Sharma, S.: Managerial interpretations and organizational context as predictors of corporate choice of environmental strategy. Acad. Manage. J. **43**(4), 681–697 (2000)
37. Shen, L.Y., Tam, W.Y.V.: Implementing of environmental management in the Hong Kong construction industry. Int. J. Proj. Manage. **20**(7), 535–543 (2002)
38. Sindhwani, R., Malhotra, V.: Barriers evaluation for agile manufacturing system with fuzzy performance importance index approach. Int. J. Agile Syst. Manage. **9**(4), 292–301 (2016)
39. Sindhwani, R., Mittal, V.K., Singh, P.L., Kalsariya, V., Salroo, F.: Modelling and analysis of energy efficiency drivers by fuzzy ISM and fuzzy MICMAC approach. Int. J. Prod. Qual. Manage. **25**(2), 225–244 (2018)
40. Sindhwani, R., Malhotra, V.:An integrated approach for implementation of agile manufacturing system in an Indian manufacturing industry. Benchmark.: Int. J. **25**(4), 1106–1120 (2018)
41. Sindhwani, R., Mittal, V.K., Singh, P.L., Aggarwal, A., Gautam, N.: Modelling and analysis of barriers affecting the implementation of lean green agile manufacturing system (LGAMS). Benchmark.: Int. J. **26**(2), 498–529 (2019)
42. Sindhwani, R., Singh, P.L., Chopra, R., Sharma, K., Basu, A., Prajapati, D.K., Malhotra, V.: Agility evaluation in the rolling industry: a case study. In: Advances in Industrial and Production Engineering, pp. 753–770. Springer, Singapore (2019)
43. Sindhwani, R., Singh, P.L., Iqbal, A., Prajapati, D.K., Mittal, V.K.: Modeling and analysis of factors influencing agility in healthcare organizations: an ISM approach. In: Advances in Industrial and Production Engineering, pp. 683–696. Springer, Singapore (2019)
44. Sindhwani, R., Singh, P. L., Prajapati, D. K., Iqbal, A., Phanden, R. K., & Malhotra, V. (2019). Agile System in Health Care: Literature Review. In Advances in Industrial and Production Engineering (pp. 643–652). Springer, Singapore.
45. Singh P.L., Sindhwani, R., Dua, N.K., Jamwal, A., Aggarwal, A., Iqbal, A., Gautam, N.: Evaluation of common barriers to the combined lean-green-agile manufacturing system by two-way assessment method. In: Advances in Industrial and Production Engineering, pp. 653–672. Springer, Singapore (2019)

46. Srivastava, S.K.: Green supply chain management: a state of the art literature review. Int. J. Manage. Rev. **9**(1), 53–80 (2007)
47. Walker, H., Di Sisto, L., McBain, D.: Drivers and barriers to environmental supply chain management practices: lessons from the public and private sectors. J. Purchas. Supply Manage. **14**(1), 69–85 (2008)
48. Wang, N.M., Yang, T., Qiao, J.M.: Study on green supply chain management. Ind. Eng. J. **10**(1), 11–17 (2007)
49. Wee, Y.S., Quazi, H.A.: Development and validation of critical factors of environmental management. Ind. Manage. Data Syst. **105**(1), 96–114 (2005)
50. Yuksel, H.: An empirical evaluation of cleaner production practices in Turkey. J. Clean. Prod. **16**(1), 50–57 (2008)
51. Zhang, D.W., Hamid, A.B.A., Thoo, A.C.: Sustainable supplier selection: an international comparative literature review for future investigation. Appl. Mech. Mater. **525**, 787–790 (2014)
52. Zhu, Q., Geng, Y.: Drivers and barriers of extended supply chain practices for energy saving and emission reduction among Chinese manufacturers. J. Clean. Prod. **40**, 6–12 (2013)
53. Zhu, Q., Sarkis, J.: An inter-sectoral comparison of green supply chain management in China: Drivers and practices. J. Clean. Prod. **14**(5), 472–486 (2006)
54. Zhu, Q., Sarkis, J.: Effects of institutional pressures on GSCM. Int. J. Prod. Res. **45**(18/19), 4333–4355 (2007)
55. Zhu, Q., Sarkis, J., Geng, Y.: Green supply chain management in China: pressures, practices and performance. Int. J. Oper. Prod. Manage. **25**(5/6), 449–469 (2005)
56. Zhu, Q., Sarkis, J., Lai, K.H.: Initiatives and outcomes of green supply chain management in China. J. Environ. Manage. **85**(1), 179–189 (2007)

Understanding the Blockchain Technology Beyond Bitcoin

Javeriya Shah and Suraiya Parveen

Abstract A blockchain is a decentralized distributed public and digital ledger consisting of blocks that record transactions across many systems, ensuring security as these blocks cannot be altered retroactively. This technology enables individuals and companies to participate with trust and transparency. A well-known application of blockchain is the cryptographic currencies Bitcoin, an emerging technology like Ethereum and many more applications are possible. Blockchain, with great potential, allows us to create, value, trust, truthfully by clever use of distributed ledger, cryptography, and computation. It emphasizes the potential of a decentralized world, where users of technology can be empowered without being bound by a third-party power broker and many other benefits this technology presents to us. Blockchain technology is the driving force behind the next basic change in information technology. Many uses of blockchain technology are widely available today, each with the potential of a specific application domain. A blockchain is a diary that is almost impossible to forge. Blockchain technology is an interesting and a safe alternative for people, using this does not demand you to have a technical background, it will somehow have a positive effect on citizens. It will prove to be a better financial system and excites us to make blockchain more mainstream. Here, we have provided a brief survey on blockchain technology and how it is establishing itself to make an impact on the future of technology.

Keywords Blockchain technology · Bitcoin · Decentralization

1 Introduction

The concept of blockchain was first presented in Satoshi Nakamoto's Bitcoin whitepaper, the fundamental technologies drawn from years of research across cryptography, computing, and economics. The global financial crisis of 2007–08 highlighted the problem with centralization. In October 2008 amid the financial crisis,

J. Shah (✉) · S. Parveen
School of Engineering Sciences and Technology, Jamia Hamdard University, New Delhi, India
e-mail: shahjaveriyashah@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_45

Satoshi Nakamoto published the Bitcoin whitepaper entitled “Bitcoin: a peer to peer electronic cash system”. Satoshi’s invention allowed a participant to digitally transact, directly with another participant without depending on a single centralized intermediary. To introduce you to the concept [1], a blockchain is a decentralized ledger that records transactions between two participants permanently with verification. This verification is done in the form of reviewing cryptographic functions and timestamps. Transactions can be verified on multiple computers which are called to as nodes. This makes the blockchain decentralized and transparent. Blockchain technology is the idea behind Bitcoin, but BCT can be detached from Bitcoin and can be used for other types of cryptocurrencies. It can be applied across industries to a variety of use cases. With the surge in cognizance of the Bitcoin codebase and whitepaper, Vitalik Buterin saw some restrictions in the design of Bitcoin and began designing Ethereum an open-source protocol that operates on blockchain and extends its features. The characteristics of blockchain technology like credibility, trustability, collaboration, organization, identification, and transparency have made it find its way in sectors like finance, medicine, manufacturing, and education enabling them to gain maximum profit. Introducing this technology will have a constructive effect on the mainstream society. Blockchain can promote social well-being by encouraging the ecosystem to drive a behavior in the public sense that is embedded in token or property. If we want to encourage people to use renewable energy, digital assets can be built with renewable energy. Here, in this paper, we have conducted a brief study on blockchain technology and how it establishes itself to make an impact on the future of technology.

2 Blockchain

Like the name suggests, blockchain technology consists of a chain of blocks that comprise information. This was discovered back in 1991 and was originally intended to Timestamp Digital documents as it records the date and time which indicates when was the document received or sent out so that it’s not possible to antedate them, mutate them or to tamper them, however, it went mostly idle until it was adopted by Satoshi Nakamoto in 2009 to create digital cryptocurrency Bitcoin [1] “ a system in which a record of transactions made in Bitcoin or another cryptocurrency are maintained across several computers that are linked in a peer-to-peer network ” (refer Fig. 1).

A blockchain is a distributed platform that is completely open to anyone, with an interesting asset that once you have entered certain information it gets recorded inside the blockchain and it becomes very difficult to change it. Thus, blockchain is the demarcation of a democratized system. Let us look at the anatomy of the block. Block sizes are usually limited to prevent network congestion. Every block has a unique number called its height, since the blockchain is linear these numbers again or height increment. There can be only one block at a given height. Blocks also contain a timestamp, a strange number called nonce, hash of the previous block, and some other information. Validity is a difficulty that can be experienced in a

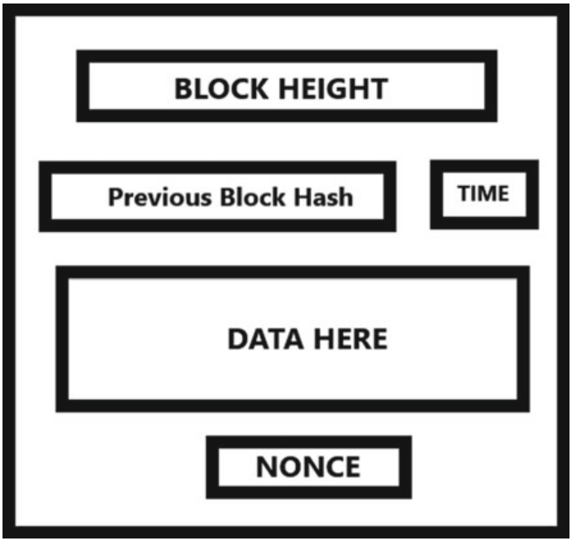


Fig. 1 The basic block structures

blockchain. Anyone could just create blocks and throw them on the chain, and there would be no value there and the network would never agree on which block should go in the chain. Having created a block means you must have done a lot of work. That is what proof of work means. A block is defined valid if the hash value of the entire block is below a threshold number, so we take a block and hash the whole thing and we get a unique signature for all the data it contains. Then, we determine if this block is valid by checking if the block's hash is below the difficulty threshold. The critical part of including a block into a blockchain is the inclusion of a cryptographic hash of the previous block. In this way, blocks are linked all the way back to the very first genesis block and are verified by hashes. Because each block contains the previous hash and that gets hashed within the next block, in a sense, all the previous hashes are baked into all future block hashes. This is where the real immutability comes in. All blocks are connected by a combination of all their hashes. There is a sequence of each block with its corresponding data, hashes, and nonces. Changing anything on any chain creates a weird effect, making all the blocks invalid afterwards. We have a money transfer going on where A has initially $15. As the money transfer is going on and each node is accepting and transferring some amount [2], a record is also being maintained. This record is known as a ledger, and since all the nodes in this network can access and refer to it therefore it's known as an open ledger (refer Fig. 2).

But this open ledger is centralized and therefore hampering the basic idea of blockchain which relies on P2P networking. Therefore, this open ledger is modified to form a distributed ledger such that nodes have their own ledger (refer Fig. 3).

Now, since the ledger is distributed a new problem arises, there are different copies of the ledger in the network so it's important to make sure that these ledgers at each node are synchronized and all nodes see the same copy of the ledger. Let us understand how these nodes understand and synchronize the ledger. For this,

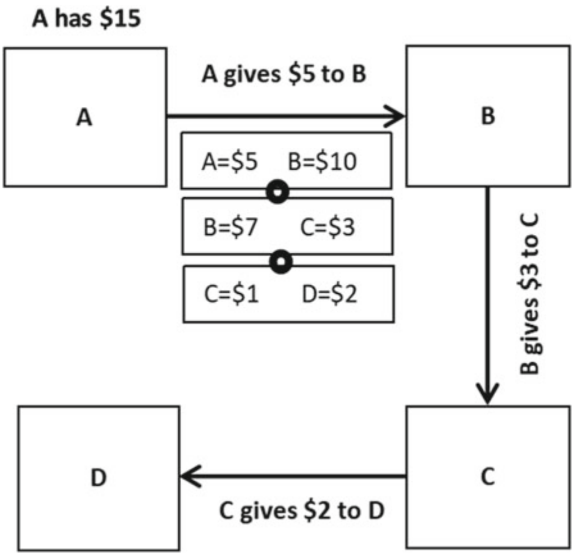


Fig. 2 Open ledger having nodes *A B C D*

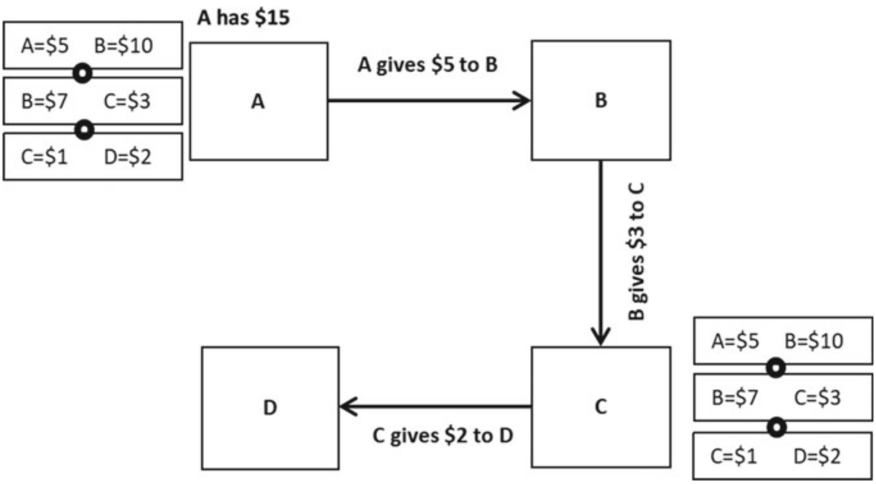


Fig. 3 Transformation of open ledger to distributed ledger

consider the following diagram where *B* is sending $5 to *D*, and it publishes this transaction details and broadcasts it for the other nodes to know. The point to ponder over here is that this transaction is not getting into the ledger, as a result of which this transaction is marked invalidated transaction. So, to get this transaction into the ledger the concept of miners arises. They are special nodes that compete with one another to validate a transaction. In our example, Nodes A and C are miners. The miners compete to earn a financial reward. To add a transaction to the ledger, a Miner needs to do 2 things: (1) Authenticate the transaction (2) Find the special key (refer Figs. 4, 5, and 6).

- Validation of the transaction can be done easily by checking in the open ledger whether *B* has required funds for the transaction to take place.

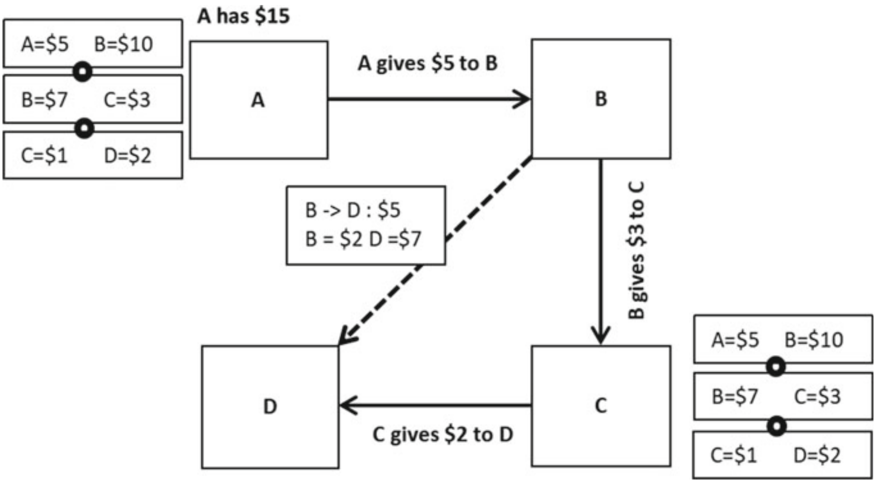


Fig. 4 When a new transaction is introduced at *B*

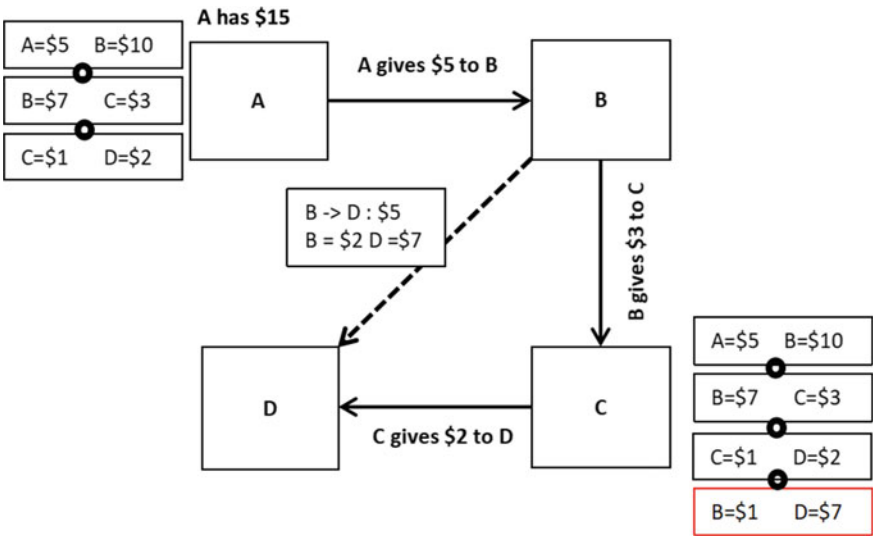


Fig. 5 *C* node was able to generate the key and validate the new transaction as a result it added the new transaction into its own ledger and earned the financial rewards

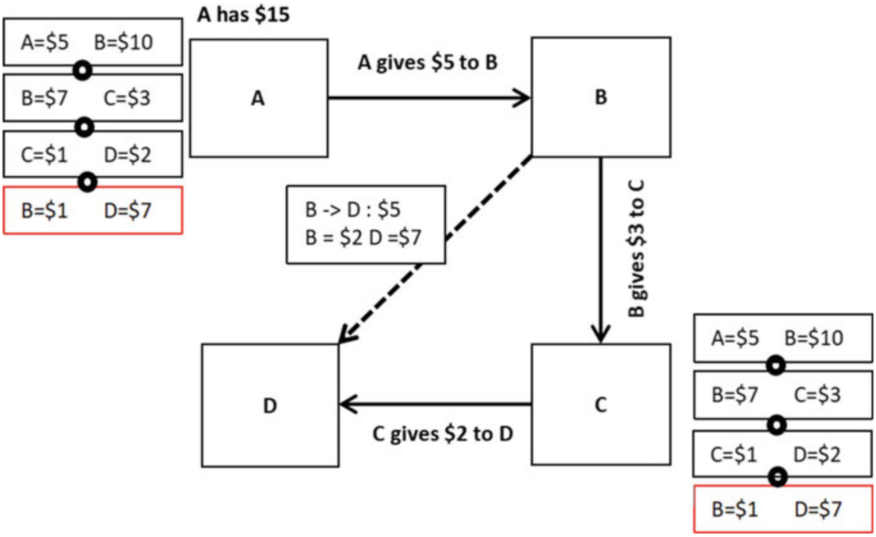


Fig. 6 The transaction is published to the entire network

- As for the KEYS, it enables the miner to take the previous transaction and to lock the new transaction.
- To find the key, the Miner invests a large amount of computational power and time, frequently producing different keys until the right key that matches the puzzle of the previous transaction is found.

KEYS are of two types [3]:

1. Public Key: these are publicly known and important for identification
2. Private keys: these are kept under wraps and are used for authentication and encryption.

3 Example: Bitcoin Blockchain

Let us consider that there is some transaction that's taking place using Bitcoin and the blocks of data look somewhat like these. Here, if we individually analyze each data block, they resemble a word document having data about some transaction. Chronologically, Block 1 shows data about initial transactions, Block 2 showing mid transactions, and finally Block 3 showing end transactions. 1 MB here signifies that blocks in a blockchain consist of around 1 MB of data each. The first block is also known as Genesis Block (refer Figs. 7 and 8). Once the block is equipped with data, now it is time to give it is unique identification, i.e., the hash. For instance, block 1 has a hash of "X32". Now, we link block 1 with block 2 using this unique signature.

Fig. 7 Blocks of data

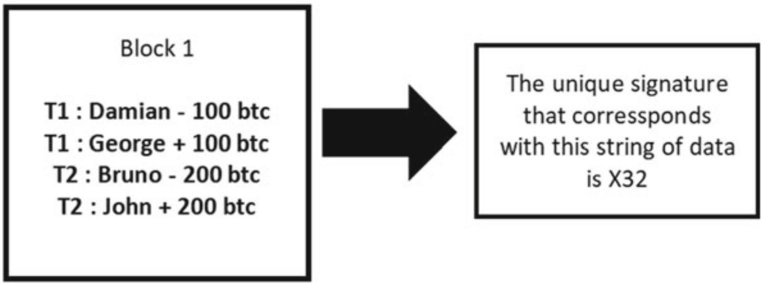


Fig. 8 Architecture of a single block

This signature links both the blocks as a result a blockchain is established (refer Figs. 9 and 10).

In case of alterations in a block like changing or adding some data, the hash gets transformed meaning that the block gets a new signature (say W10). Now since blockchain can't be mutable, this will face rejection, and there will be a shift to the

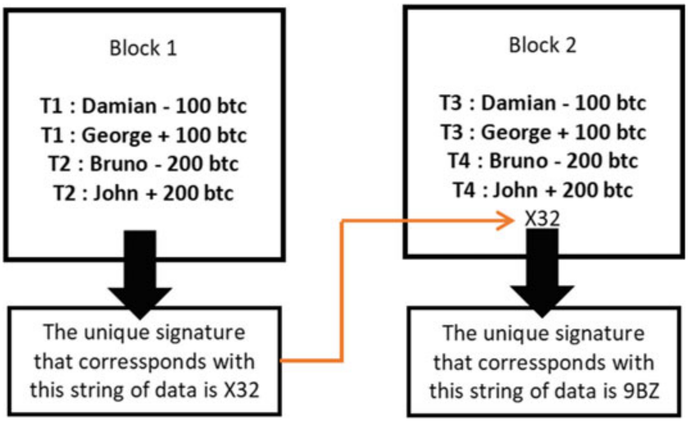


Fig. 9 Blocks linked through unique signature

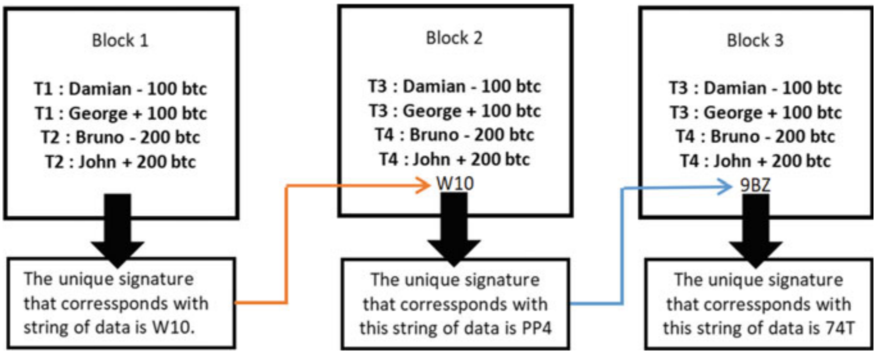


Fig. 10 Chaining of blocks in case of alterations

previous state. This can be prevented by replacing the new signature say for block 1 in block 2. Therefore, the blocks remain chained to each other.

4 Role of P2P Networking in Blockchain

Well, P2P networks also known as peer-to-peer networks are distributed applications, where two or more PCs are connected to each other directly, i.e., without an intermediate server PC working in between them. Blockchain technology makes use of this type of networking to solve the problem of Money Transfer.

For example, let's say a person wants to transfer some money from India to Malaysia, following the old school method he will send this money using an intermediate third trusted party. Even though the transfer will be successful, it will be a very tedious task. Therefore, blockchain comes very handy here as it cuts off this third trusted party and causes interaction between the two people between whom money transfer is taking place. Also, it will be much easier now and can be done within minutes. The basic principle of blockchain technology helps us trust the outputs of the system without trusting any actor within it. Individuals and institutions who do not know or trust each other can now communicate online without the need for trusted third parties such as banks and Internet platforms. All networks in the network have a duplicate copy of the payment ledger, which serves as a single data point. Storing data thus eliminates the problems arising from the vulnerability of a centralized server that uses different cryptographic methods to achieve network security. Blockchain therefore provides a global data set that each individual can rely on or may not know or trust. This kind of distributed data storage and management prevents the double-spending problem of existing value transfer through the Internet.

5 Backbones of Blockchain Technology

5.1 Decentralization

In early times, we all were restricted by centralized systems, where all the data is stored by a centralized authority and to access the information we need to interact with this central authority [4]. For example, the traditional client–server model, where we search for a query, this query is sent to the server which gives us the relevant information. This is a simple client–server model. But the centralized systems present to us several vulnerabilities:

1. Centralized systems become easy targets of potential hackers.
2. System upgrades are necessary, but they may cause the whole system to halt and therefore contribute to delay.
3. Worst case scenario, what if the central authority gets corrupted, all the data stored will be compromised.
4. Therefore, to tackle these problems and to prevent them we have the Decentralized Systems.

The word decentralization describes the process of the transfer of authority from a centralized entity to local participants present in a network .It is fundamentally about shifting power and authority in a community away from one central entity and making that power available to members themselves. It is a concrete tangible benefit for networked systems. The benefits offered by decentralization make the systems less likely to fail when based on redundant components, and it is hard to attack a decentralized network since users are not all in one place. So, how can we adopt this concept in BCT? Right now, the database and internet structures that we created have typically been driven by internet service providers. The world on the internet became an oligopoly of a handful of internet service providers that access and serve as a thin line of intermediation to us. Take Facebook, Twitter, retail banking account, basically we pay or in many cases we are the products, our data is shared and monetized. Decentralization eliminates the centralized intermediary custody, now we will have the self-sovereignty of our digital assets and are digital personas. The individual users have control over their data assets, reputation and we will have essentially peer-to-peer transactions. Through the implementation of decentralization, data does not have to be stored in centralized systems. Data can be verified independently, and individuals can transact directly with each other, instead of requiring a centralized entity to verify these interactions. Decentralization dis-intermediates central control of systems.

Table 1 This shows how transparency is achieved

TxHash	Block	Age	From	To	Value
0x234tg4…	5674890	16 s ago	0x34hjkl987olas4…	0x7jh20lam9uuilgh…	0.09823 ether
0x345ujk…	5674890	16 s ago	0xcvnuf986yy33r…	0x34njzxc98pqasf…	0.765 ether
0x2edght…	5674890	16 s ago	0x98drclk8e433o…	0 × 878kjaskdeh7rt…	0 ether

5.2 Transparency

Here, in the image, we can see the person's real identity is hidden, and we can only see the transactions they've done, with the help of their public address [5]. In a financial system, this kind of transparency has never existed before. This therefore adds that level of accountability that is needed for these big institutions (refer Table 1).

5.3 Immutability

The concept of immutability about blockchain highlights that once we have entered some data into the blockchain it's difficult to make alterations to it [5]. Cryptographic hash functions render this property to blockchain. Simply, hashing means entering a string of any length and pulling out an output of a fixed length. This attribute grants blockchain reliability and makes it pioneer.

6 Concepts in Blockchain Technology

6.1 Public Key Cryptography

Today, cryptography is essential to pretty much every part of cybersecurity. But it has been around for a long time. From the Greek, cryptography translates to hidden writings and is as old as the earliest messages we ever wrote using code or ciphers. The basic idea is that we use algorithms to scramble our messages before sending them so they look like gibberish to anyone who might read them. The only ones who can read the message are those we share the algorithm with.

The problem is that we live in a world of unencrypted networks. On the internet, there is always a third party handling our communications. Communicating over a public unencrypted network means that anyone along the path of internet traffic from say point A to B can intercept and read the message. Public key cryptography to the rescue. Here, we need two related cryptographic keys, a public key that we one which can be shared with anyone who wants to send a message and a private key that we keep to ourselves. We get the hashed version of the public key when someone sends us crypto coins over a blockchain. Another type of key called private key, or the hidden key is used to derive the public key. Public key is used for encryption or perhaps locking the content/message, and private key decrypts the messages only if they were encrypted with matching public key. Think of it as a mathematical one-way process where once a message is encoded with someone's public key, the only way to read it is with that person's private key. It is impossible to decrypt without it. Public key cryptography is used to create verifiable historical records of transactional data. It makes it possible to build decentralized systems run by the global community.

6.2 Cryptographic Hash Functions

Hash functions are the single most important thing to understand in order to know how blockchains work, specifically cryptographic hash functions (refer Table 2).

A hash function takes as its input just about any kind of digital data; number, text, images of any size, and outputs what seems like a long string of random outputs.

A hash function can be defined as a digital mechanism that compresses data into a specific length. Blockchain uses SHA-256 hashing algorithm, which stands for secure hashing algorithm having a hash length of 256 bits. Hashing algorithm called Ethash is used by Ethereum [5]. Change in only a single bit in the input values in Tables 1 and 2 will create a completely different sequence of numbers and letters. When data is written to a block, it is hashed. Therefore, if a single piece of data within a block were to be changed at another point in time, the hash would completely change. This principle allows the nodes participating in the blockchain to detect any changes to data. This hashed data is used to create a link between each specific block. This is accomplished by writing the hash of each previous block into the next block in the chain. When a block is created, a hash of the data within it is created, and that hash that is created includes the prior block hash. If a piece of data is changed in any prior block that is part of the chain, each following hash would change. The change cascades allowing for the detection of change to any piece of data within the chain by comparing block hashes to each other across the nodes in the network. This prevents changes to the blockchain after blocks are created and accepted by the network. Therefore, data written to the blockchain is permanent [6]. The permanence of data written to the blockchain is why you will hear a blockchain referred to as being immutable. In addition to hashing, the blockchain relies on the public cryptography key to inform the patent on the blockchain. Specifically, blockchain participants have a secret key that allows them to access their personal information stored with their public key. Public and private keys are related, but a malicious player cannot find the private key in the public key. Private keys are not intended for sharing because a private key is used to unlock its corresponding public key. These buttons sign up for a blockchain transaction. Hashing and public key secretly work together to maintain consistency in the system. Consistently, the entire system has the same information on what is happening on the platform and any action is recorded and made available on the platform. This solves the problem of an unreliable system with

Table 2 An example showing the hashed output for the given inputs

Input	Hash
Hi	3875JNVSA67KLO0Z8RMBAXPQW89OK120345MNHUWILKAAAOPP0011RTY346
Welcome to blockchain technology	7362ONCSVWU8389QEBCBYRUWO934837HUDWH8273898000JCDQQIODOO7

intermediaries because now, and blockchain participants have permanent validation on the platform. The miners' process of verifying actions on the blockchain is known as proof of work. Mining ensures that the permanent status of the book has a whole new transaction. This prevents attacks and false information from proceeding within the system, ensuring lasting performance. Public key cryptography is also used for digital signing which helps the blockchain know that it's you who has initiated a transaction and not someone else. It verifies the legitimacy of the transaction.

7 Blockchain Security

Blockchains are secured as they make use of advanced cryptographic techniques and mathematical models of behavior and decision-making, thus making it difficult for hijackers to break it down and improve security. The digital money is prevented from being duplicated or destroyed because the underlying principle of most cryptographic systems is blockchain technology. Blockchain technology is being explored in situations where data and data insecurity are of utmost importance [6]. However, blockchain is not an easy subject, and it is necessary for us to understand these concepts and mechanisms with the help of which it provides robust protection to these innovative systems.

7.1 Concept of Immutability and Consensus

The two main concepts that are associated with blockchain security are immutability and consensus.

- CONSENSUS refers to the capability of objects within a blockchain network to acknowledge the actual network status and confirm the transaction. Usually, this process of finding unanimity is dependent on the consensus algorithm which decides whether to commit a distributed transaction to a database that designates nodes as a leader for some distributed task, and synchronizes state machine replicas and ensures consistency among them.
- IMMUTABILITY refers to the ability to prevent conversion of transactions already guaranteed. This transfer is integrated into cryptocurrencies; they also include records of other non-monetary forms of digital data. Consensus and immutability provide a base for data protection on the blockchain, where a consensus algorithm ensures that the rules of the program are complied with and all alliances agree on the state of the network while immutability checks the shortfall of data integrity and transaction records after each new block of data are verified.

7.1.1 Consensus Algorithms in Blockchain

A consensus algorithm is a process whereby peers in the blockchain system reach a general assent about the status of a shared ledger. Allowing us to achieve trustworthiness and establish trust among anonymous peers in the computerized distribution space [7]. The protocol complies and ensures that the new blockchain added to blockchain is the only and only version and is agreed upon by all blockchain nodes. The main objectives of a blockchain sync agreement include coming to agreement, collaboration, collaboration, equal rights everywhere, and the mandatory participation of each process in the consensus process. Let us discuss various consensus protocols and see their working [8].

- PROOF OF WORK: PoW is the original consensus algorithm at BCN, which validates transactions and selects a miner to generate new blocks in the chain. The basic idea behind which these algorithm works is to solve a complex mathematical puzzle [9]. This math puzzle requires great computing power to find solutions. The node that solves the puzzle, mine is the new block.
- PROOF OF STAKE: It is an alternative for PoW, and it makes the consensus mechanism virtual. There are validators that are selected based on staking age, randomization, and nodes wealth. Here, there is no competition and no reward is given for making a block, instead a transactional fee is to be given.
- PROOF OF BURN: It addresses the high energy consumption issue of the PoW system. It allows the miners to burn virtual currency tokens and new blocks are written compensating to burnt coins. Burning is sending coins to addresses from where they are irretrievable. Also, it avoids cryptocurrency coin double spending.
- PROOF OF CAPACITY: According to Proof of Capacity, validators are investing in hard drives rather than expensive equipment. The harder drive space they have, the greater the prospect of mining the next block and the rewards of blocking.
- PROOF OF ELAPSED TIME: This algorithm selects the next miner. Blockchain network of permission where permission is needed to access the network using this algorithm. Here, everyone on the network must wait a certain amount of time. As soon as they have done waiting (for a limited time) they could be on the ledger and build a new block.

7.2 Role of Cryptography in Blockchain Security

Achieving blockchain data security is largely based on cryptography. Here, the cryptographic hash functions are very important. In the process of hashing, an algorithm detects the incoming data of a certain size and returns an output of a specified length. Everything is done at an extremely fast pace and appended in the block. While Hashing the input value is given where the hashing algorithm is applied, and a new value is known as the hash digest. Depending on the algorithm used, the hash digest is of predetermined length, also it is impossible to guess the value of the digest and even a small change in value can change the digest completely. Now, this exchange list is included in the block title and block hash of the previous block, and together a new block hash is generated. Now the same procedure is followed by the head of the next block. This way the cryptographically secure hash function is used to create a series of blocks. But all transactions are digitally signed. Let us take the example of Bitcoin, suppose we want to send a few Bitcoins to *xyz*. So, following the above procedure, the message will be cryptographically hashed with the help of our private key and this hash is sent along with the address of *xyz*. So, everyone present in the network will be able to see the transaction and using our public key they can validate it, but only xyz will be able to add those Bitcoins in his wallet. Therefore, everyone can see what they are doing but no one can steal it [7]. The blockchain network is only as secure as its infrastructure. When establishing a blockchain network, we must look for the best platform for deployment. Although blockchain has certain features that provide security, known cases on the ground can be controlled by malicious participants. Therefore, we need integrated security infrastructure. Blockchain technology is still emerging and new, and it is improving day by day. Blockchain researchers are working to compensate for security vulnerabilities. But in extreme cases, we can have a new version of that blockchain. Looking at the bigger picture, blockchain stores a much better solution for many of the enterprises. But still, it is important to develop and improve the blockchain ecosystem to make it a secure platform.

8 Applications of Blockchain

8.1 Finance

Banking and technology are very much associated, over the period banking have experienced a drastic change due to innovation. One such disruptive innovation is blockchain that is changing the banking sector globally. Havard business review that blockchain will do to banks what the internet has done to the media. Well BCT possesses all the attractive characteristics that have the potential to solve a lot of financial and money related matters. It is safe, secure, decentralized, transparent, and comparatively cheaper [10]. These make BCT a reliable and in-demand solution for banking. BCT has many applications in finance that include Smart Contracts, Digital Currency, Record Keeping, Securities, therefore, creating opportunities to recreate the financial world.

8.2 Healthcare

Blockchain technology has immense applications and uses in the health sector. Its ledger-like aspect provides secure transfer of patient's medical data [11], manages medicine supply chain and helps researchers decode genetic code.

8.3 Manufacturing Industries

BCT has the capacity to disrupt any industry or business model. Without any disparity in the business model complexity or size, BCT makes significant changes in the business activities. Blockchain has helped financial transactions, traceability, and enhanced customer experience, to regain the lost trust, simplicity, accuracy of carrying various tasks. Adoption of BCT in manufacturing provides good performance, product authenticity, consumer experience in quality of care and, therefore, transforms performance [2]. Supply chain of manufacturers is the most complex association and it's very challenging when it comes to establishing transparency and accountability in business. But [12], with BCT manufacturers can have a clear visibility of manufacturing processes.

8.4 Education

Blockchain technology is perfect to store student credentials. This will allow learners to have convenient and speedy access to their records. As a result, they can share these records with potential employees, who will have a direct relation with the student instead of contacting and seeking data from college or university. This will save time and presents the full picture of the student's skillset [13].

8.5 Government

Blockchain has gone way further than just Bitcoin. The crisscross application of blockchain technology has made hundreds of government leaders realize and join GSA blockchain group to share use cases and best practices [14]. As a result of incorporating BCT, there can be trust building with citizens, protection of sensitive data and cost reduction and efficiency.

The applications of BCT can also be witnessed in fields like Asset Management: Commercial and Residential Processing, Insurance: Claims processing, Payments: Deadline Payments, Unusual Loans/Hard Debtors, Your Car/Smartphone, Blockchain Internet-of-Things (IoT), Smart Devices, Blockchain Music/Public

Value, Vested Obligation, Blockchain ID, Passport, Birth, Marriage and Death Certificates, your identity.

9 Challenges That Blockchain Can Experience as an Emerging Technology

As the blockchain technology will advance and evolve, there is a possibility that organizations can face an array of potentially complex issues. Some of which are listed below [8].

- **Awareness and cognizance**: The main hampering of ideas is seen when it comes to using technology in sectors other than finance and banking. It has been seen that other sectors do not have the required understanding needed for using this technology.
- **Cost and efficiency**: The speed and effectiveness with the help of which blockchain networks make transactions from one peer to another comes at a high aggregate cost increasing inefficiency.
- **Security and privacy**: Feasible applications of the blockchain involve unquestionable linking of smart transactions and contracts to known identities, and this raises an important question concerning the privacy and the security of the data stored and available on the shared ledger.

10 Conclusion

Blockchain has appeared as a relative obscurity to become a relatively popular conversation topic across the industries. We are hearing increasingly about Fintech, digital assets, virtual token, cryptocurrencies, smart contracts, and initial coin offerings. Each of these concepts depends on blockchain technology which is an ever increasingly revolutionary technology that promises efficiency [15]. Due to its compact, digitally enhanced, ledger-like quality, it gives the capacity of storing immense data. The security protocols make the data immutable. Also, the decentralization of blockchain makes the data transparent and accessible at any point of time. Presumably, this technology can be used and adopted in every industry that deals with storing and managing big data. Adopting this will benefit healthcare, finance, art, music, IoT, banking sector, governmental establishment, educational sector, and many others. Blockchain technology is promising but being an extremely young technology, the investors and venture capitalists often underestimate the time needed for its adoption.

Acknowledgements The completion of this undertaking could not have been possible without the participation and assistance of my professor Dr. Suraiya Parvenn; her contributions are sincerely appreciated and highly acknowledged.

References

1. Nakamoto, S.: Bitcoin: A Peer-to-Peer Electronic Cash System. ResearchGate, Berlin, Germany (2008)
2. Haber S., Stornetta, W.S.: How to time-stamp a digital document. In: Proceedings of the Conference on the Theory and Application of Cryptography, Santa Barbara, CA, USA, 11–15 Aug 1990, pp. 437–455. Springer, Berlin, Heidelberg, Germany (1990)
3. Wood, G.: Ethereum: a secure decentralised generalised transaction ledger. In: Ethereum Project Yellow Paper, vol. 151, pp. 1–32
4. Coron, J.S., Dodis, Y., Malinaud, C., Puniya, P.: Merkle-Damgård revisited: how to construct a hash function. In: Proceedings of the Annual International Cryptology Conference, Santa Barbara, CA, USA, 14–18 Aug 2015, pp. 430–448. Springer, Berlin, Heidelberg, Germany (2005). Sensors **20**, 282 24 of 28
5. Coursera Blockchain: Foundations and Use Cases 2020 edition. https://www.coursera.org/learn/blockchain-foundations-and-use-cases/home/welcome
6. Goranovic A., Meisel, M., Fotiadis L., Wilker S., Treytl A., Sauter, T.: Blockchain applications in microgrids an overview of current projects and concepts. In: Proceedings of the IECON 2017—43rd Annual Conference of the IEEE Industrial Electronics Society, Beijing, China, 29 Oct–1 Nov 2017, pp. 6153–6158
7. Theodouli, A., Arakliotis, S., Moschou, K., Votis, K., Tzovaras, D.: On the design of a Blockchain-based system to facilitate Healthcare Data Sharing. In: Proceedings of the 2018 17th IEEE International Conference on Trust, Security and Privacy in Computing and Communications/12th IEEE International Conference on Big Data Science and Engineering (TrustCom/BigDataSE), New York, NY, USA, 1–3 Aug 2018, pp. 1374–1379
8. Arredondo, A.: Blockchain and certificate authority cryptography for an asynchronous on-line public notary system. Ph.D. thesis, The University of Texas, Austin, TX, USA (2018)
9. Zhang, P., Walker, M.A., White, J., Schmidt, D.C., Lenz, G.: Metrics for assessing blockchain-based healthcare decentralized apps. In: Proceedings of the 2017 IEEE 19th International Conference on e-Health Networking, Applications and Services (Healthcom), Dalian, China, 12–15 Oct 2017
10. Gordon, W.J., Catalini, C.: Blockchain technology for healthcare: facilitating the transition to patient-driven interoperability. Comput. Struct. Biotechnol. J. **16**, 224–230 (2018)
11. Hölbl, M., Kompara, M., Kamišalić, A., Nemec Zlatolas, L.: A systematic review of the use of blockchain in healthcare. Symmetry **10**, 470 (2018)
12. Fernández-Caramés, T.M., Fraga-Lamas, P.: Towards next generation teaching, learning, and context-aware applications for higher education: a review on blockchain, IoT, fog and edge computing enabled smart campuses and universities. Appl. Sci. **9**, 4479 (2019)
13. Martinovic, I., Kello, L., Sluganovic, I.: Blockchains for Governmental Services: Design Principles, Applications, and Case Studies. Center for Technology and Global Affairs, University of Oxford (2017)
14. Mayer H.: Ecdsa Security in Bitcoin and Ethereum: A Research Survey. 2016. https://blog.coinfabrik.com/wp-content/uploads/2016/06/ECDSA-Security-inBitcoin-and-Ethereum-a-Research-Survey.pdf. Accessed 1 Jan 2020
15. Yuan Y, Wang F,-Y.: Blockchain and cryptocurrencies: model, techniques, and applications. IEEE Trans. Syst. Man Cybernet. Syst.

The Impact of Internet of Things in Manufacturing Industry

Vishal Jain, Anand Kumar Mishra, and Manish Kumar Ojha

Abstract The study was done to understand the impact of internet of things on manufacturing industry. It was a 2-part research in which first the previous research and findings were studied to understand the IoT technologies and the overall impact these technologies were having on various industries, and in the second part, a survey was conducted to find out how application of internet of things technology can affect the manufacturing industry. Literature study was done to understand the parameters and the factors that affect manufacturing industries. On the basis of the study, five crucial parameters that were having the maximum impact on manufacturing were found, namely Quality, Reduction of Errors, Employee Satisfaction, Productivity, and Cost Reduction, and a linear grading was done to see if there was a positive or negative impact of IoT technologies on these parameters. Through survey and single-tailed t-Test, it was found that IoT was having positive impact on all the parameters, and it was interpreted that with time IoT technologies could be integrated into manufacturing industries for sustainable growth and increased overall profitability.

Keywords Internet of things · Manufacturing

1 Introduction

The rise of new digital industrial technology, known as Industry 4.0, is a revolution that allows data to be collected and analyzed through computers, allowing quicker, more versatile, and more efficient processes to produce goods of higher quality at reduced costs [1–6]. With the support of interconnectivity through the Internet of Things (IoT), access to real-time data, and the introduction of cyber-physical systems, Industry 4.0 has put the emphasis on digital technology from recent decades to a whole new level. Industry 4.0 provides a wider, more interlinked, and integrated industrial approach. It integrates physical with digital, and facilitates greater communication and access through agencies, partners, suppliers, product,

V. Jain · A. K. Mishra · M. K. Ojha (✉)
Department of Mechanical Engineering, Amity University, Sector 125, Noida, Uttar Pradesh, India
e-mail: mkojha@amity.edu

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_46

and individuals [1–8]. Industry 4.0 empowers business owners to better control and understands every aspect of their business and enables them to use instant data to boost productivity [9–12].

Since the industry is evolving and customer demand patterns are changing, there is a dire need of changing the way our manufacturing works. There new challenges that are coming up into the world of manufacturing and it's important that we find out smart ways to get way out of these challenges, otherwise the companies will lose the competitiveness. The major challenge is that there is no predictive planning; manual paper-based system leads to information delay and no live update of floor activities. Current technologies limit our ability to visualize possible failures and changing consumer demand patterns [12–25].

Conventional manufacturing system has low energy conservation leading to tax penalties, financial losses, and environment damage, and there is no task-based energy [17, 26]. In the present case scenario, safety measures are based on past incidents, and we lack real-time fault and error tracking, leading to big safety concerns [16, 27–32]. The objective of this study was to study what impact IoT is having on different parameters like Quality, Productivity, Employee satisfaction, Cost reduction, Reduction of errors, which affect manufacturing industries.

2 Key Characteristics of IoT in Supply Chain

These are few important manufacturing parameters which if kept in mind, results in higher revenue generation for the industry and leads to better customer retention. These parameters have their own factors by which they are affected, and the point of this study is to see that if IoT impacts these factors, then is it a positive, neutral, or a negative impact.

2.1 Impact of IoT on Quality

IoT is leading to predictive manufacturing and maintains, which enables machines to collect information, by identification, analyzation, and monitoring of machine functions [32–35]. Thus, there is continuous improvisation of quality of the manufactured product. IoT is being also used for detection of defects, and these are leading to much better detection of products which do not meet the set quality standard. Manual sorting and checking of components are completely dependent on the accuracy of the human eye, and with the increasing production volume, it's becoming mammoth task even for a trained quality assurance person to look and find out the defect. New techniques are being used for non-destructive testing, and prediction of possible causes of failure in the machine [10].

2.2 Impact of IoT in Reducing Errors

There is study that proposes the use of IoT tool to improve medical facilities and provide better and high-quality health care by the use of Raspberry PI [22]. Another issue that IoT solves in particular is health care industry which is collection and provision of database to monitor patient's health and regularly provides with sustainable health care services. And to facilitate this there is use of IoT tools like, RFID, Bluetooth, Wi-Fi, to reduce medical errors and increase overall patient safety [18]. Application of IoT tools can result in predictive control, and as a result, there will be much less failures and the profits will go up, and the customer demand will be successfully catered [27]. A study indicates that human inspectors who were tasked to find out defects in a certain item missed 20% of those defected products, and this indicates that we cannot rely just on human capability to find out errors and can trust that human inspection is done with high accuracy [30].

2.3 Impact of IoT in Employee Satisfaction

It has been seen that employees are more loyal and productive when they are happy with the job, and these happy employees have direct impact on customer happiness and productivity of the organization [28]. Ensuring that employees are satisfied in the job and are able to develop good career should be the topmost priority of the employer. And factors like lack of recognition, nepotism, wrong biases lead to discouragement of the employees [29]. And here IoT plays a role in ensuring that employees are happy, by ensuring that the appraisals and the recognition that is being given that is fair, and there is no unfair bias in that, and there is transparency in the system. There is a proposed use of IoT tools like Artificial Neural Fuzzy Inference System (ANFIS) to reward employees for their performance by tracking their real-time activities [19]. Another factor that increases employee satisfaction is a sense of safety, and it can be done by monitoring employee health and implementing safety automation model, which will use sensors to alert about any possible misshaping [16]. IoT tools are proposed to increase in personal thermal comfort at individual levels, using IoT tools to measure biometric level data like heart rate and skin temperature and change room conditioning based on that data and thus adding on to happiness and satisfaction quotient [23].

2.4 Impact of IoT on Productivity

Productivity is an important factor when any industrial work is taken into consideration. It is been observed that industries with higher labor productivity tend to be more profitable [31]. IoT is being used in making the industrial plants more efficient, these tools are giving higher visibility, which is making the part tracking easy, unlike the conventional systems where we have batch level visibility. There is predictive maintenance and scheduling of processes and there is seen and improved operational frequency [20]. There are some factors that have a negative impact on productivity, and they are rapidly becoming big challenges as demand is becoming sensitive and the industrial standards are going up. We face problems like material shortage, lack of experienced and skilled labor, as we see altercation in planned work and the executed work, as there are issues is misunderstanding between labor and management [32].

2.5 Impact of IoT on Cost Reduction

Cost is a factor that has direct impact on profitability, so it is important to consider cost as a parameter and see if IoT can create a positive impact on Cost Reduction; IoT tools are proposed to be used in making manufacturing eco-efficient, which will in turn reduce the cost as it'll monitor and cap energy wastage. Integration of IoT to SC is not limited to monitoring only, but also helps in machine to machine communication, thus resulting in faster information flow, and also assists in smart production planning. This leads to big saving in energy consumed in the processes [17].

3 Enabling Technologies of IoT

3.1 Wireless Sensor Network System

Wireless Sensor Network (WSN) is a group of sensors for which is used for the monitoring of the physical conditions of the environment and organizing the data which is collected at the central location. It measures the physical conditions of the environment like temperature, humidity, levels of pollution, pressure, etc. [12]. The utilization of WSNs is the checking of the earth. Remote Sensor Networks are put in different urban communities in request to watch and screen the convergence of hurtful and perilous gases [13]. Remote sensor frameworks have been delivered for equipment condition-based upkeep (CBM) as they offer basic cost hold reserves and engage new convenience. This can be as essential as watching the temperature in a fridge or the level of water in flood tanks in nuclear power plants. The genuine information would then have the option to be used to show how systems have been working. The advantage of WSNs over standard loggers is the "live" data feed that is possible [11].

3.2 RFID

Radio Frequency Identification (RFID) utilizes electromagnetic fields to consequently distinguish and follow labels joined to objects. An RFID label comprises a little radio transponder, a radio recipient, and transmitter [8]. RFID Tags are made out of three pieces: a scaled down scale chip, a getting wire for tolerating and transmitting the sign, and a substrate [12]. The RFID tag gets the message and a short time later responds with its unmistakable evidence and other information. This may be only an outstanding mark successive number, or maybe thing related information, for instance, a stock number, package or bunch number, creation date, or other express information [9]. RFID has been utilized in different territories. RFID is utilized in recognizable proof identifications supplanting the previous attractive stripe card, etc., without manual data area. Betting clubs can use RFID to affirm poker chips and can explicitly invalidate any chips known to be taken [14].

3.3 Bluetooth

In 2010, the Bluetooth Special Interest Group (SIG) proposed BLE in the Bluetooth 4.0 specification [22], nowadays updated to version 4.1. BLE is a smart low energy version of Bluetooth, still designed for short-range communication. An adaptive frequency hopping algorithm is used on top of the data channels, to reduce sensitivity to interference, and multi-path fading [3]. BLE has emerged in parallel with other low-power solutions, such as ZigBee, 6LoWPAN, and Z-Wave, which were targeting applications with multi-hop scenario. BLE is destined to be a key sectionalize technology for a few short-range net of Things applications, like in care, good energy, and good home domains [4]. Its potential was recognized since its early birth, as shown by the interest it gained quickly at IETF, wherever the 6LoWPAN social unit (today 6lo), developed a specification for permitting the transmission of IPv6 packets over BLE [23].

4 Methodology Adopted

The research has been done on three levels. In the first level, literature was studied to understand what impact IoT is having on the five different parameters including quality, productivity, employee satisfaction, cost reduction and errors, in all the industries, and on the basis of that, mapping of the possibility of the same impact on Manufacturing Industry has been done. Initially, 50–55 research papers were selected on the basis of title and abstract and then selected 36 were found to be suitable and reviewed as per the requirement of this study.

In the second level, questions were framed on the basis of the study that was done, and then through those questions a survey was conducted; where people of Industry and Academicians were surveyed on the extent of impact of IoT on different aspect of manufacturing industry, and also tried to analyze its cost efficiency.

70% of respondents were academicians and 30% respondents were people from industry. Academicians comprised of researchers, concerned faculties, PG/UG students. Industrial people comprised of operators, line and shop floor managers, people from export department, and material handling supervisors.

The third level of the study was data collection from the survey and its interpretation was done. In the third level, single-tailed t-test was used to verify our null hypothesis and to validate results from the research and the survey that was done.

4.1 Questionnaire and Hypothesis on the Basis of Literature Survey for Manufacturing Industry

The grading will be done using a linear scale of 5 points, where 1—Very Negative, 2—Negative, 3—Neutral, 4—Positive, and 5—Very Positive. So, for every question there'll be this grading system. Here, the respondents will have to choose one option out of the five, all compulsory questions For the result of the survey, the Mean and the Standard Deviation will be found out, for each parameter and for each parameter, based on the data collected, and generate bar graphs, and see a pattern in the marking and grading done by the respondents.

Sample Questionnaire for parameter Quality. Each of the question was rated on a scale of 1–5.

1. Use of IoT in making process more reliable.
2. Use of IoT in determining the best material combination.
3. Use of IoT tools in implementing quality assurance.
4. Use of IoT tools in fastening the information flow across the production facility.
5. Use of IoT in detection of defects.
6. Use of IoT tools in better implementation of Six Sigma process.
7. Use of IoT in implementation of Quality control process.
8. Use of IoT in feedback-based mechanism.
9. Use of IoT tools in M2M communication.
10. Use of IoT tools in operation management.

5 Result and Discussion

Here is the result of the survey that was conducted with the help of the developed questionnaire. The graphs generated the results, and these graphs are in accordance with the study that was done and the information that was studied from the literature review (Figs. 1, 2, 3, 4 and 5).

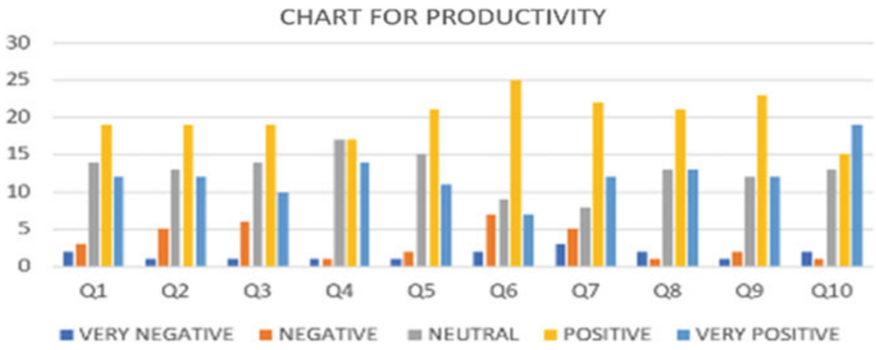


Fig. 1 Impact of IoT on productivity

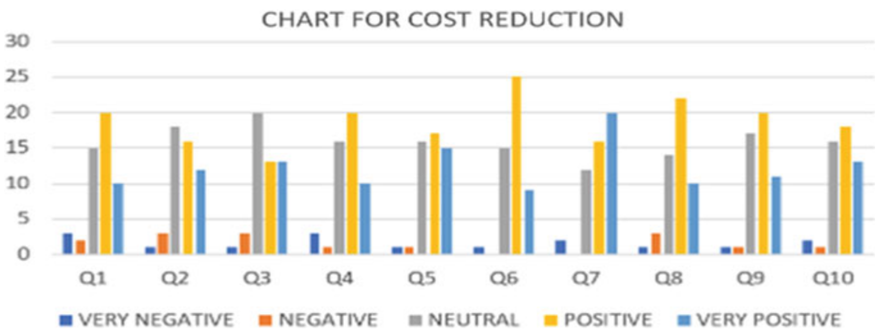


Fig. 2 Impact of IoT on cost reduction

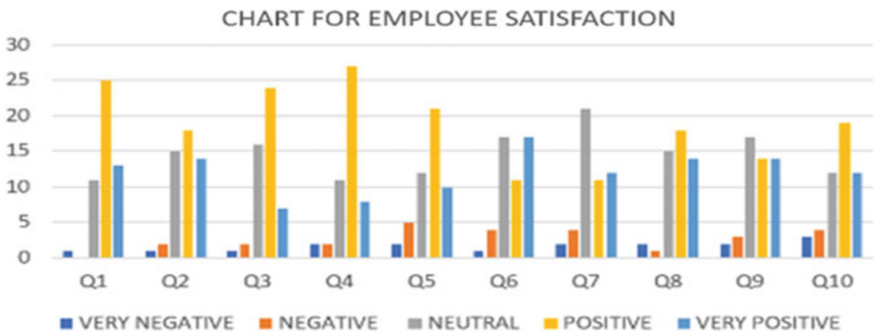


Fig. 3 Impact of IoT on employee satisfaction

6 Validation of the Survey

It is required to validate these results, and to validate these results, we have done single-tailed t-test. Based on the survey, we suggest that the overall impact of IoT

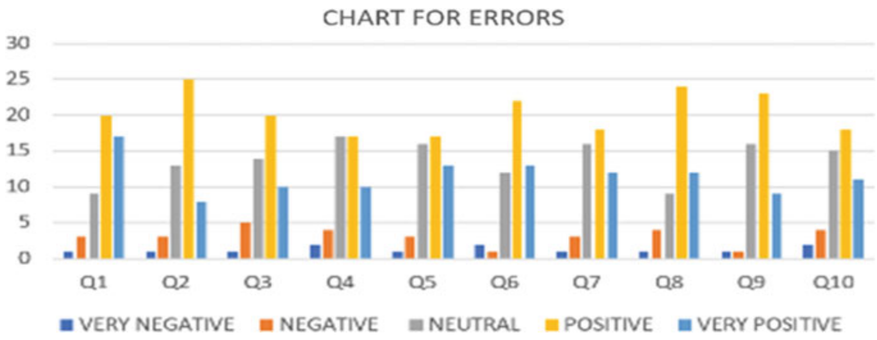


Fig. 4 Impact of IoT on errors

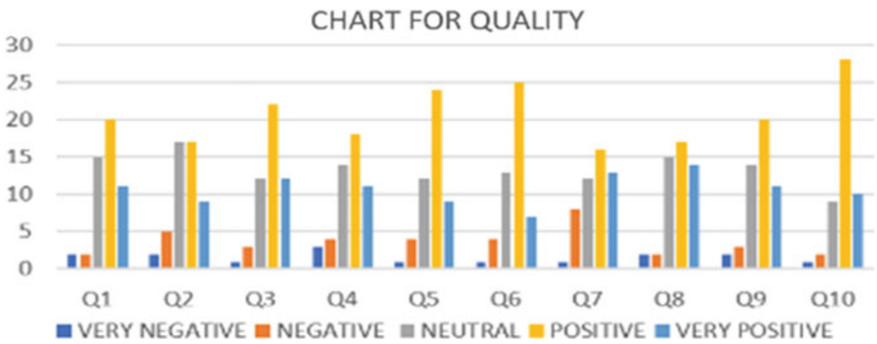


Fig. 5 Impact of IoT on quality

is Positive on the different parameters, and to justify that one-tailed t-test is done, where the population mean is assumed to be 4, which is an indicator of positive impact of IoT in the given parameters. Taking 5% significance level, when the test is conducted, to validate the null hypothesis, the T value should be less than the critical factor of 1.96. If the null hypothesis gets accepted, this will mean that implementation of IoT tools and technology in the discussed parameters will lead to that parameter be impacted in a positive manner and we'll observe that parameter getting better.

However, if the null hypothesis is rejected, i.e., the value is greater than the critical factor of 1.96 then that would indicate that the null hypothesis is not true, which in turn will imply that there will be either no impact of IoT tools on the discussed parameter, or it may even lead to an overall negative impact. It is very important to do this hypothesis test, so as to understand, that the result is being validated and the idea that is being proposed here is valid and with an implementation of IoT can actually result in positive impact on the parameter in discussion. Population parameter is verified through calculating the critical factor for the single-tailed t-test by using the following formula

Table 1 Hypothesis table

Hypothesis	$\bar{x}$	σ	μ	T	Accepted
1—Quality	3.704	0.98812	4	1.7781	Yes
2—Productivity	3.76	0.9971	4	1.6197	Yes
3—Employee satisfaction	3.738	0.99466	4	1.862	Yes
4—Cost reduction	3.772	0.92002	4	1.752	Yes
5—Error reduction	3.754	0.96045	4	1.811	Yes

$$Z = (\bar{x} - \mu)/(\sigma/\sqrt{n}) \tag{1}$$

where

$\bar{x} \rightarrow$ Mean, $\mu \rightarrow$ Targeted Population Mean, $\sigma \rightarrow$ Standard Deviation, $n \rightarrow$ Sample Size.

The Null Hypothesis H_0 states that our population parameter, i.e., μ is equal to hypothesized value of 4. The Alternative Hypothesis H_1 states that our population parameter, i.e. μ is smaller to hypothesized value of 4 (Table 1).

All of the five null hypotheses have been accepted, and this means that implementation of IOT tools will have a positive impact on all the considered parameters.

7 Conclusion

The entire proposed hypothesis was accepted, thus it can be seen that, when IoT tools will be implemented in manufacturing industry, the factors like Quality, Productivity, Cost Reduction, Employee Satisfaction, and reduction of Errors will be positively impacted. Overall, positive impact on these factors has been proven to have direct correlation to the profitability of the industry, so this implies that application of these IoT tools will result in increase in the profitability of the companies. And the positive impact is not limited to the industries. There would thus be better product and services for the consumer, and implementation of these IoT tools will make lives of the customers better. The value generation is impacted in a positive manner, and there'll be higher employee satisfaction, which in today's time is a prime factor in determining the growth of any industry. Implementation of IoT technologies will result in overall cost reduction; due to reduced failures, accidents though predictive maintenance and through better inventory management as IoT technologies would result in more accurate demand forecast. As the errors would be reduced, it will lead to increase in customer happiness and will would lead to overall increased goodwill and profitability for the industries.

References

1. Pastor-López, I., la Puerta, J.G.D., Sanz, B., Goti, A., Bringas, P.G.: How IoT and computer vision could improve the casting quality. In: Proceedings of the 9th International Conference on the Internet of Things, pp. 1–8 (2019)
2. Palattella, M.R., Dohler, M., Grieco, A., Rizzo, G., Torsner, J., Engel, T., Ladid, L.: Internet of things in the 5G era: Enablers, architecture, and business models. IEEE J. Sel. Areas Commun. **34**(3), 510–527 (2016)
3. Bamigboye, F.O., Ademola, E.O.: Internet of things (IoT): it's application for sustainable agricultural productivity in Nigeria. In: Proceedings of the 6th iSTEAMS Multidisciplinary Cross_Border Conference, pp. 621–628. University of Professional Studies, Accra Ghana (2016)
4. Carmona, A.M., Chaparro, A.I., Velásquez, R., Botero-Valencia, J., Castano-Londono, L., Marquez-Viloria, D., Mesa, A.M.: Instrumentation and data collection methodology to enhance productivity in construction sites using embedded systems and IoT technologies. In: Advances in Informatics and Computing in Civil and Construction Engineering, pp. 637–644. Springer, Cham (2019)
5. Heiskanen, A.: The technology of trust: How the Internet of Things and blockchain could usher in a new era of construction productivity. Construct. Res. Innov. **8**(2), 66–70 (2017)
6. Yang, H., Kumara, S., Bukkapatnam, S.T., Tsung, F.: The Internet of Things for smart manufacturing: A review. IISE Trans. **51**(11), 1190–1216 (2019)
7. Mostafa, N., Hamdy, W., Alawady, H.: Impacts of Internet of Things on supply chains: a framework for warehousing. Soc. Sci. **8**(3), 84 (2019)
8. Lou, P., Liu, Q., Zhou, Z., Wang, H.: Agile supply chain management over the internet of things. In: 2011 International Conference on Management and Service Science, pp. 1–4. IEEE (2011)
9. Yan, B., Huang, G.: Supply chain information transmission based on RFID and Internet of Things. In: 2009 ISECS International Colloquium on Computing, Communication, Control, and Management, vol. 4, pp. 166–169. IEEE (2009)
10. Zhang, J., Tian, G.Y., Zhao, A.B.: Passive RFID sensor systems for crack detection & characterization. NDT&E Int. **86**, 89–99 (2017)
11. Liu, W., Zhang, Y., Lou, W., Fang, Y.: Managing wireless sensor networks with supply chain strategy. In: First International Conference on Quality of Service in Heterogeneous Wired/Wireless Networks, pp. 59–66. IEEE (2004)
12. Evers, L., Havinga, P.J., Kuper, J., Lijding, M.E.M., Meratnia, N.: Sensor scheme: supply chain management automation using wireless sensor networks. In: 2007 IEEE Conference on Emerging Technologies and Factory Automation (EFTA 2007), pp. 448–455. IEEE (2007)
13. Gaynor, M., Moulton, S.L., Welsh, M., LaCombe, E., Rowan, A., Wynne, J.: Integrating wireless sensor networks with the grid. IEEE Internet Comput. **8**(4), 32–39 (2004)
14. Angeles, R.: RFID technologies: supply-chain applications and implementation issues. Inf. Syst. Manage. **22**(1), 51–65 (2005)
15. Yang, C., Shen, W., Wang, X.: Applications of Internet of Things in manufacturing. In: 2016 IEEE 20th International Conference on Computer Supported Cooperative Work in Design (CSCWD), pp. 670–675. IEEE (2016)
16. Gorli, R.: A new approach for employee safety in industries with IoT. i-Manage J Inf Technol **7**(2), 22 (2018)
17. MiraglIoTta, G., Shrouf, F.: Using Internet of Things to improve eco-efficiency in manufacturing: a review on available knowledge and a framework for IoT adoption. In: IFIP International Conference on Advances in Production Management Systems, pp. 96–102. Springer, Berlin, Heidelberg (2012)
18. Turcu, C.E., Turcu, C.O.: Internet of things as key enabler for sustainable healthcare delivery. Procedia-Soc. Behav. Sci. **73**, 251–256 (2013)
19. Dhir, K., Chhabra, A.: Automated employee evaluation using fuzzy and neural network synergism through IoT assistance. Pers. Ubiquit. Comput. **23**(1), 43–52 (2019)

20. Anita, R., Abhinav, B.: Internet of Things (IoT)–Its impact on manufacturing process. Int. J. Eng. Technol. Sci. Res. IJETSR **4**(12), 889–895 (2017)
21. Kaur, J., Kaur, K.: A fuzzy approach for an IoT-based automated employee performance appraisal. Comput. Mater. Continua **53**(1), 24–38 (2017)
22. Kumar, R., Rajasekaran, M.P.: An IoT based patient monitoring system using raspberry Pi. In: 2016 International Conference on Computing Technologies and Intelligent Data Engineering (ICCTIDE'16), pp. 1–4. IEEE (2016)
23. Laftchiev, E., Nikovski, D.: An IoT system to estimate personal thermal comfort. In: 2016 IEEE 3rd World Forum on Internet of Things (WF-IoT), pp. 672–677. IEEE (2016)
24. Lu, Y., Morris, K.C., Frechette, S.: Current standards landscape for smart manufacturing systems. Natl. Inst. Stand. Technol. NISTIR **8107**, 39 (2016)
25. Zheng, P., Sang, Z., Zhong, R.Y., Liu, Y., Liu, C., Mubarok, K., Yu, S., Xu, X.: Smart manufacturing systems for Industry 4.0: Conceptual framework, scenarios, and future perspectives. Front. Mech. Eng. **13**(2), 137–150 (2018)
26. Kusiak, A.: Smart manufacturing. Int. J. Prod. Res. **56**(1–2), 508–517 (2018)
27. Ahmad, S., Badwelan, A., Ghaleb, A.M., Qamhan, A., Sharaf, M., Alatefi, M., Moohialdin, A.: Analyzing critical failures in a production process: Is industrial IoT the solution? Wirel. Commun. Mobile Comput. (2018)
28. Sageer, A., Rafat, S., Agarwal, P.: Identification of variables affecting employee satisfaction and their impact on the organization. IOSR J. Bus. Manage. **5**(1), 32–39 (2012)
29. Gregory, K.: The importance of employee satisfaction. J. Div. Bus. Inf. Manage. **5**, 29–37 (2011)
30. Andrew, J.B.: Human error and the implications for industry. Hum. Fact. Arch. **1**, 11 (1997)
31. Sauian, M.S.: Labour productivity: an important business strategy in manufacturing. Integr. Manuf. Syst. (2002)
32. Enshassi, A., Mohamed, S., Mustafa, Z.A., Mayer, P.E.: Factors affecting labour productivity in building projects in the Gaza Strip. J. Civil Eng. Manage. **13**(4), 245–254 (2007)
33. Ehrlenspiel, K., Kiewert, A., Lindemann, U.: Factors that influence manufacturing costs and procedures for cost reduction Cost-Eff. Des. 143–384 (2007)
34. Curtin, J., Kauffman, R.J., Riggins, F.J.: Making the 'MOST' out of RFID technology: a research agenda for the study of the adoption, usage and impact of RFID (2007)
35. Nikolic, B., Ignjatic, J., Suzic, N., Stevanov, B., Rikalovic, A.: Predictive manufacturing systems in Industry 4.0: trends, benefits and challenges. In: Annals of DAAAM & Proceedings, vol. 28 (2017)

Big Data-Based Structural Health Monitoring of Concrete structures—A Perspective Review

Priyanka Singh

Abstract Structural health monitoring (SHM) comes with the real data that is collected and calculated from the structures, which is not possible by mere visual inspection. The working principle of SHM is basically collecting essential data, including strain, temperature conditions, moisture content, etc., which are further transformed into digital data for the interpretation. It serves a tool in the synchronizing of the collected data, also with the responsibility of making it available at all times. It stores the data for the meticulous research and analysis. SHM is enabled with the leading-edge technology of big data, which has an added advantage of collecting and storing extensive data related to the structures. Different types of sensors are used for collecting the data; hence, with these data, real-time information about the structures is extracted. The elaborate process involves the big data, for exploring and analyzing a variety of datasets with different patterns to determine damages, and defects lying under the structures. Hence, health monitoring of the existing structures is possible and with high precision and information. SHM is a continuous process of measurement, collection, processing, and storage of massive amounts of data of the existing structures for diagnosing structural health. Hence, in this paper, various examples of the contemporary structural monitoring system and the ongoing efforts being made in the big data-based structural health monitoring of concrete structures has been presented. The work is dedicated to present the different monitoring sensors of structures to evaluate damage, defects, and serviceability by taking account of available literature.

Keywords Big data · Structural health monitoring · Concrete structures · Corrosion · Sensors

P. Singh (✉)
Department of Civil Engineering, Amity School of Engineering & Technology, Amity University Uttar Pradesh, Noida, India
e-mail: priyanka24978@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_47

1 Introduction

Structural health monitoring (SHM) has grown rapidly in engineering disciplines, especially in civil engineering. Innovative SHM technologies and SHM systems have boomed in engineering and academia. Practical experience available has shown that progressive advancement of sensing techniques will undoubtedly accelerate SHM technology evolution. Structural Health Monitoring framework incorporates sensors, securing of information, data, its transmission and its control. The information and data collected are being stored in the computer system server equipped with adequate capacity storage [1–3]. SHM is exceptionally furnished with innovative features that give a tremendous amount of information about the structures. The enormous amount of data collected by the SHM, through its sensors in the form of data, is further utilized to extract real-time information about the structures [4–6]. The SHM serves the purpose of screening and determining the structural soundness. It is an advanced method of damage detection of existing structures that involves collecting, handling, and analyzing of data collected through sensors [7, 8]. It diagnoses severe or light deformation and damage in the structures. The deformities in the structures are dictated by finding the connections between the readings taken by various sensors [9–11]. SHM shows maximum potential for utilization in real-time prediction of structural health [12–14]. Damages or failure of the structures is diagnosed through the data collected by sensors in SHM system. The response collected through different types of available sensors and its parameters is illustrated in Fig. 1.

The SHM further puts forward the possibilities of applying data processing research for the development of more effective SHM systems with real-time configurations [16]. Structural health monitoring (SHM) system detects and diagnoses damage and perform prediction of future states of the structures. This paper provides an effort in big data-based SHM system for precise and accurate prediction of damages, defects, and serviceable life of the existing structures.

The material degradation of the concrete can accelerate during the lifetime of a structure, due to conditions such as wear, overload, environment deterioration, and natural disasters. Structural health monitoring (SHM) is a dynamic tool to ensure that the structure is reliable within the design life and also to potentially extend service life beyond the intended life. It is utilized in conducting the analysis to figure out damages and loss to property due to earthquakes or floods and also other possible calamities

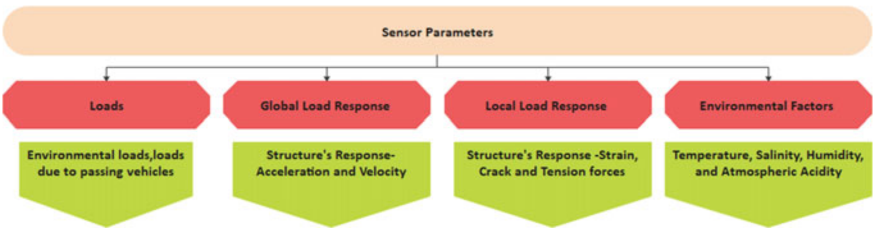


Fig. 1 Response collection through sensors for SHM [15]

[17–19]. The defects in the structures are determined with the data collected taken by different sensors. Multi-storeyed buildings to the vast bridges and tunnels; too many sectors have encompassed big data in structural health monitoring [20, 21].

2 Structural Health Monitoring

Due to aggressive environmental conditions, the concrete structures are subjected to wear and tear on the external surfaces. Sometimes damages or failure of the structural components may occur due to accidents, operational activity, and excessive weathering agents [22–24]. These agents may cause unexpected changes in the structures or their components also. It damages the external surfaces as well as the constituent's materials of the structures. The degradation of the structures may get accelerated by the aggressive weathering agents and, in some cases, by natural disasters [25]. The reasons such as freezing and thawing of concrete, carbonation, chloride penetration in the concrete, the reaction between alkali and silica, etc., are responsible for the concrete damage. The weathering agent also plays a pivotal role in the deterioration of the concrete. The primary constituents of the concrete, i.e., cement, coarse aggregate, fine aggregate, water, reinforcing steel, along with chemical admixtures, also leads to the deterioration and damages in the concrete. It is visible in the form of spalling, cracks, delaminating.

Therefore, the comprehensive quantifiable assessment of the integrity of the structure and its performance is of utmost importance. The traditional method of evaluation was based on visual inspection, to assess the structural health of the existing complexes and civil structures [26, 27]. The process of assessment with a visual check was highly tedious, and it deploys heavy labor for the execution. There was a possibility of varying results in less visible damages below the surfaces, by visual inspection. Hence, the method of SHM was introduced to have the real-time assessment of the structural health for existing structures. SHM employs basically two techniques, primarily data-driven and model-based. In both data-driven and model-driven method, the data are being collected from the non-destructive evaluation (NDE) techniques. However, it is further categorized as active and passive techniques [28]. Electromagnetic testing (ET) and ultrasonic guided wave testing (UGWT) are examples of Active Non-destructive Evaluation Technique. Passive NDE techniques are acoustic Emission, digital image correlation (DIC), fiber-optic sensing (FOS), and infrared thermography (IR). From both the techniques, data are obtained either in the form of wave signals (ET, UGWT, AE) or in form of images (IR, DIC).

Data collection and its analysis is very critical in structural health monitoring. Different types of sensors which are being utilized for structural health monitoring system is illustrated in Fig. 2. With the advent of modern sensors data are generated and collected in the terabyte (TB), which require tools like big data mining in SHM. Application of big data is key element for prediction of structural health of structures. Structural health monitoring systems include structure, sensors, data acquisition systems, data transfer and storage mechanisms, data processing and data

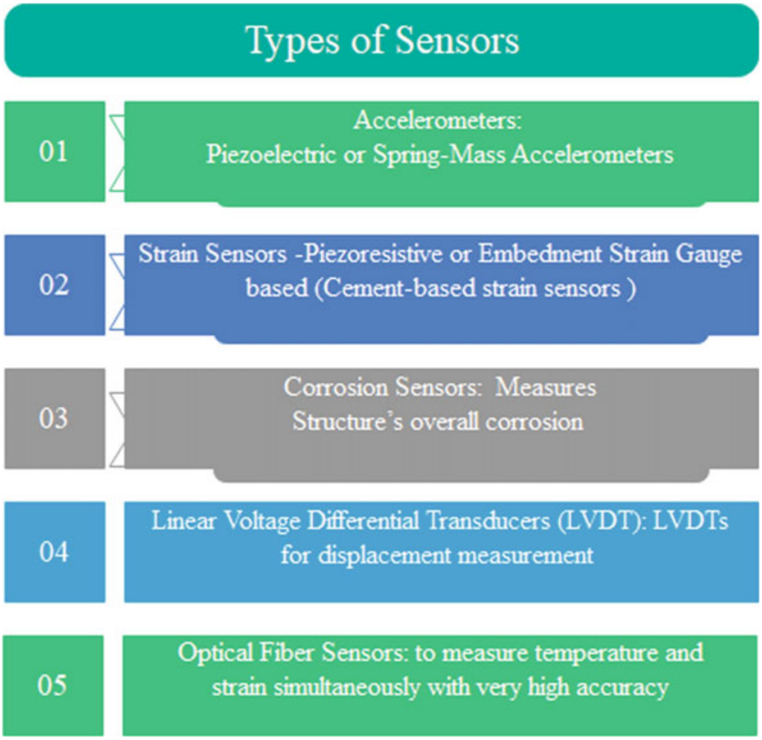


Fig. 2 Different types of sensors for SHM system [29]

manipulation. Structural health monitoring (SHM) system detect and diagnose any damage and perform prediction of future states of the structures. A large amount of data may be produced by sensors embedded in structural system. Since data is obtained in gigabytes or terabytes, the conventional data processing system (storage, processing and handling) is not feasible for the handling of bulk data. Thus, big data-based SHM needs to be employed for the precise prediction. In view of this, MapReduce is used to create data tables and Hadoop for detection method.

Big data techniques are used to analyze voluminous SHM data for damage diagnosis, and to quantify the uncertainty in diagnosis and prognosis [30–32]. To cope with the costly computation, big data techniques such as MapReduce and Spark are explored in SHM. The concept of MapReduce and its implementation in Spark are introduced to ease the burden of computations through big data techniques. MapReduce is a framework designed for processing large datasets, by utilizing multiple nodes (machines) for the computations. MapReduce framework can be split into two steps: map and reduce. Spark is an open-source cluster computing framework. It consists of various steps as first collection of data, diagnosis of available data for prediction of future health, future risk, predicting the remaining useful life, and guide maintenance/repair actions if needed. Electromagnetic testing and ultrasonic

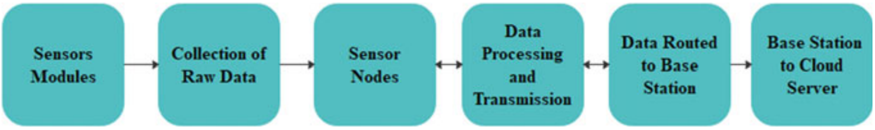


Fig. 3 Illustration of the working principle of SHM [41]

guide wave testing are examples of active experimentation, whereas the passive techniques consist of methods like acoustic emission, digital image co-relation, fiber optic sensing [33–35]. Other techniques of NDE, such as infrared thermography, can be further utilized either inactive or passive modes. There is an urgent need to develop and deploy an orderly system with high reliability and robustness in the system, with an eye toward cost-effectiveness. The system must be for 'real-time' monitoring of infrastructure to protect human lives, saving capital assets, and ultimately, must ensure the stability and quality [36, 37]. Optical fiber sensors have certain special advantages, such as compact scale, light weight, sensitivity to electromagnetic interference (EMI), and embedding capabilities. Hence, it is used worldwide to track infrastructure systems. The function of structural health monitoring is to explore future risk, and thus, calculate the remaining active life by detecting and diagnosing damages in the structure and deploying maintenance/repair actions if needed [38–40]. Figure 3 illustrates the working principle of SHM.

3 Image Processing

In several SHM techniques, digital image formatting such as digital image correlation (DIC) and infra-red thermography is being used. The process involves the primary step of detecting the damage location and quantifying by comparing the image of the damaged structure against that for the intact structure, using image processing techniques [42–44]. The general procedure of image processing is described in Fig. 4.

After obtaining the raw image to prepare for edge detection using the various preprocessing techniques, which can lead to damage detection [46, 47], noise reduction and edge detection are computationally expensive besides the positive aspect of its applicability in the big data techniques. The steps for the big data analytics of image processing in structural health monitoring are as follows:

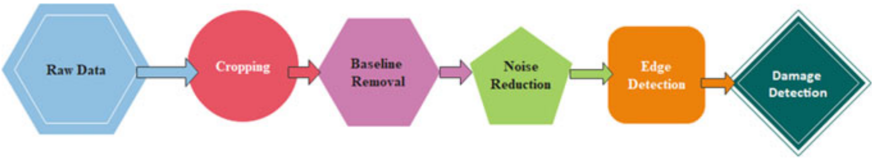


Fig. 4 General procedure for image processing [45]

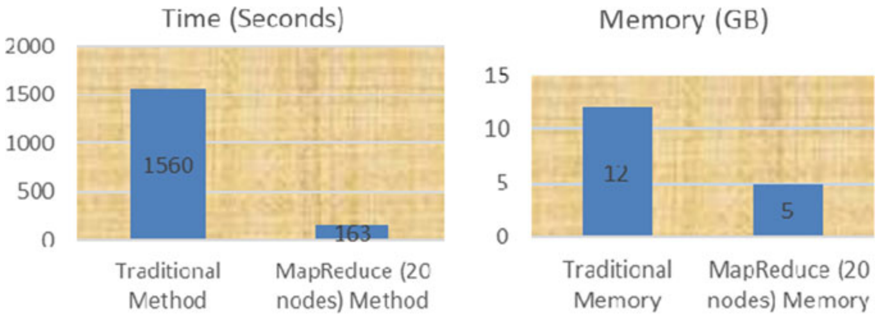


Fig. 5 Comparison of time and memory consumed between traditional method and big data techniques for SHM [50]

1. Data stored gets uploaded
2. Image processing functions get prepared
3. It is further substituted to the Map functions
4. Data files are processed and finally retrieved from the cluster, back to the local computer.

Thus, the edge detection approach could be applied to different situations. To apply big data technique to structural health monitoring, particularly image processing, a framework was developed. The approach was illustrated for the processing of thermal images obtained for a concrete slab. The proposed framework has applied the popular MapReduce approach [48, 49]. MapReduce simultaneous systemic risk estimation by transforming inputs and outputs as primary value pairs. Figure 5 shows the comparative graphs of using traditional and big data techniques to analyze the digital images obtained through optical sensors. For structural health monitoring of the entire infrastructure system, the data may be very large, hence use of MapReduce is substantial in realistic application.

4 Big Data: Overview and Challenges

Big data method is the analysis and investigation of an enormous amount of stored data to extract behavior pattern [51]. It is characterized by the following:

1. High speed by which they are generated
2. A considerable volume that they represent
3. An immense amount of typology they encompass.

Big data analytics are being classified into these categories as based on their working behavior and diagnosis:

1. Descriptive big data analytics represents the data that happened in the past through the graph or reports.

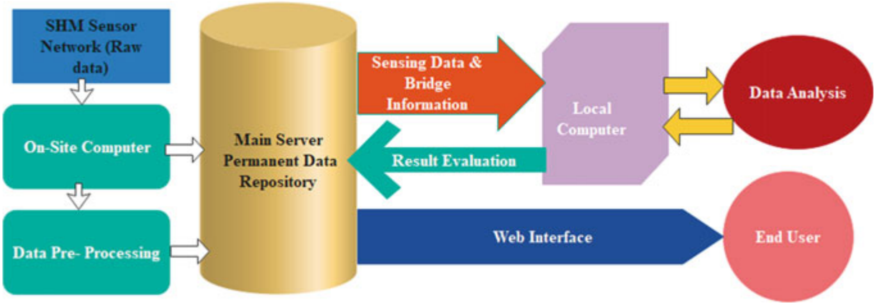


Fig. 6 Sensor data management framework for structural health monitoring [59]

2. Diagnostic big data Analytics: It is closely related to the descriptive one, but it explains why any activity occurred in the past.
3. Predictive big data analytics: It is essential for SHM, which can predict what may happen.
4. Prescriptive big data analytics: An evolution of proceeding approach based on automation processing.

The data which are beyond storage capacity or processing capacity is known as big data. There are different data generators through which the data are generated. The system decides to analyze and predict data, and then it advises how to continue according to requirements [52–54]. Examples of data generators are sensors, webcams, images, etc. In the context of structural health monitoring, sensors are the primary source of data generators. Sensor data management framework for Structural Health Monitoring is explained in Fig. 6. The computation of the data is processor bound [55, 56]. A vast amount of information big data can be is defined as based on.

1. The volume of data rapidly increasingly (Gegabyte/Terabyte/Petabyte)
2. Velocity through which it travels
3. Variety Fetching data and sending velocity problem.

Hadoop is the best solution for the storage of both unstructured and semi-structured big data. Hadoop stores a massive amount of data and processes it. The core concept of functioning of Hadoop is HDFS and MapReduce also. HDFS is a Hadoop distributed file system. MapReduce is the technique of processing the data which we are stored in the HDFS. Hadoop is the system for processing and storing large datasets and a cluster of commodity hardware. Therefore, the data which gets saved by the sensors of structural health monitoring are being analyzed by Hadoop [57, 58].

The stages of big data-based SHM can be classified as follows:

1. Data Acquisition
2. Decision-making software.

Data Acquisition—The sources and working methods of Data acquisition and decision-making software are elaborated in Fig. 7. Data are acquired from the applied

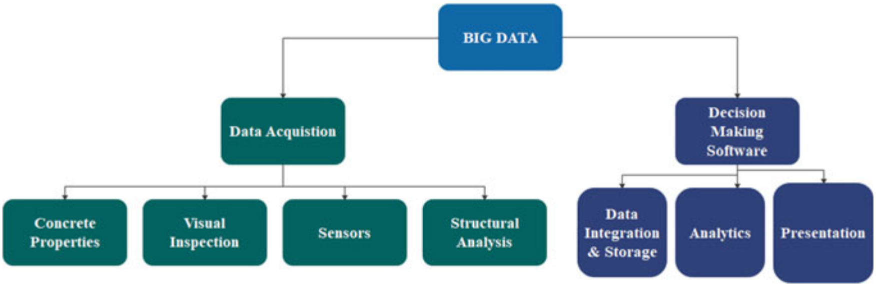


Fig. 7 Process of big data-based SHM system [34]

sensors, to get the details about the properties of concrete, by analyzing the data of the structures. Through sensors, data about the condition of the concrete structures are obtained, and other information about its usability [60–62]. Decision-Making Software—The interpretation of the acquired data is made by the decision-making software, which analyses the data to present predictive models. Presentations in terms of predictive models are made to diagnose the degradation of the structures [63–65].

5 Conclusions

The principle of big data closely matches the requirement of Structural Health Monitoring. Voluminous amount of data is obtained through sensors, which can be analyzed only through the application of big data. Precise and significant results are anticipated through big data in SHM. The observation between the area of SHM and big data demonstrates the existence of various similar aspects and its challenges. The advancement in big data science would definitely boost the field of SHM. Some papers show methodologies have been developed to handle the various steps of data processing in structural health monitoring. MapReduce implementation was proposed to process sensor data of high volume, high velocity, and a wide variety. Data processing tasks were wrapped in 'mappers' to allow the nodes in the cluster to works on the partitions of the data set. Image processing for structural damage detection is channelized. However, the application of high-volume data through big data in structural health monitoring is highly advantageous. The primary purpose of the sensor technologies and sensor strategies is to foster the development of real-time SHM of real-life structures. However, further research is needed for a more precise analysis of data obtained by sensors and to develop an effective future prediction of structural health.

References

1. Law, K.H., Smarsly, K., Wang, Y.: Sensor data management technologies for infrastructure asset management. In: Wang, M.L., Lynch, J.P., Sohn, H. (eds.) Sensor Technologies for Civil Infrastructures: Applications in Structural Health Monitoring, vol. 2, issue 1, pp. 3–32. Woodhead Publishing, Cambridge, UK (2014)
2. Singh, P., Shah, N.D.: Comprehensive study on structural health monitoring of structural system. J. Civil Eng. Environ. Technol. **5**(3), 129–132. p-ISSN 2349-8404; e-ISSN 2349-879X (2018)
3. Liao, Y., Mollineaux, M., Hsu, R., Bartlett, R., Singla, A., Raja, A., Bajwa, R., Rajagopal, R.: Snowfort: an open source wireless sensor network for data analytics in infrastructure and environmental monitoring. IEEE Sens. J. **14**(12), 4253–4263 (2014)
4. Alampalli, S., Alampalli, S., Ettouney, M.: Big data and High-Performance Analytics. In: Krimotat, A., Ettouney, M., Alampalli, S., Ozdemir, T. (eds.) (2016). Overview of a cyber-enabled wireless monitoring system for the protection and management of critical infrastructure systems. In: Proceedings of SPIE, vol. 7294, p. 72940L (2009)
5. Jang, S., Jo, H., Cho, S., Mechitov, K., Rice, J.A., Sim, S., Jung, H., Yun, C., Spencer, B.F., Jr., Agha, G.: Structural health monitoring of a cable-stayed bridge using smart sensor technology: deployment and evaluation. Smart Struct. Syst. **6**(5–6), 439–459 (2010)
6. Kim, S., Pakzad, S., Culler, D., Demmel, J., Fenves, G., Glaser, S., Turon, M.: Healthmonitoring of civil infrastructures using wireless sensor networks. In: Proceedings of 6th International Symposium on Information Processing in Sensor Networks, Cambridge, MA, USA, (2007). https://doi.org/10.1109/IPSN.2007.4379685
7. Jang, S., Jo, H, Cho, S., et al.: Structural health monitoring of a cable-stayed bridge using smart sensor technology: deployment and evaluation. Smart Struct. Syst. **6**(56) 439–459 (2010). https://doi.org/10.12989/sss.2010.6.5_6.439
8. Lynch, J.P., Wang, Y., Loh, K.J., Yi, J.H., Yun, C.B.: Performance monitoring of the Geumdang bridge using a dense network of high-resolution wireless sensors. Smart Mater. Struct. **15**(6), 1561 (2006). https://doi.org/10.1088/0964-1726/15/6/008
9. Pakzad, S.: Statistical Approach to Structural Monitoring Using Scalable Wireless Sensor Networks. University of California, Berkeley (2008)
10. Sohn, H., Farrar, C.R., Hemez, F.M., Shunk, D.D., Stinemates, D.W., Nadler, B.R., Czarnecki, J.J.: A Review of Structural Health Monitoring Literature: 1996–2001. Los Alamos National Laboratory, USA (2003)
11. Wang, T., Alam Bhuiyan, M.Z., Wang, G., Rahman, M.A., Wu, J., Cao. J.: Big data reduction for a smart city's critical infrastructural health monitoring. IEEE Commun. Mag. **56**(3), 128–133 (2018)
12. Kim, S., Pakzad, S., Culler, D., Demmel, J., Fenves, G., Glaser, S., Turon, M.: Wireless sensor networks for structural health monitoring. In: Proceedings of the 4th International Conference on Embedded Networked Sensor Systems, pp. 427–428. ACM (2006)
13. Cho, S., Yun, C.-B., Lynch, J.P., Zimmerman, A.T., Spencer, B.F., Jr, Nagayama, T.: Smart wireless sensor technology for structural health monitoring of civil structures. Steel Struc. **8**(4), 267–275 (2008)
14. Deraemaeker, A., Worden, K. (eds.) New Trends in Vibration Based Structural Health Monitoring, vol. 520. Springer (2012)
15. Ko, J.M., Ni, Y.Q.: Technology developments in structural health monitoring of large-scale bridges. Eng. Struct. **27**(12), 1715–1725 (2005)
16. Ye, X.W., Ni, Y.Q., Wong, K.Y., Ko, J.M.: Statistical analysis of stress spectra for fatigue life assessment of steel bridges with structural health monitoring data. Eng. Struct. **45**, 166–176 (2012)
17. Harms, T., Sedigh, S., Bastianini, F.: Structural health monitoring of bridges using wireless sensor networks. IEEE Instrum. Meas. Mag. **13**(6), 14–18 (2010)
18. Ansari, F. (ed.): Sensing Issues in Civil Structural Health Monitoring. Springer, Dordrecht, The Netherlands (2005)

19. Sohn, H., Farrar, C.R., Hemez, F.M., Czarnecki, J.J.: A review of structural health review of structural health monitoring literature 1996–2001. No. LA-UR-02–2095. Los Alamos National Laboratory (2002)
20. Saafi, M., Sayyah, T.: Health monitoring of concrete structures strengthened with advanced composite materials using piezoelectric transducers. Compos. B Eng. **32**(4), 333–342 (2001)
21. Gulgec, N.S., Shahidi, G.S., Matarazzo, T.J., Pakzad, S.N.: Current challenges with bigdata analytics in structural health monitoring. In: Structural Health Monitoring & Damage Detection, vol. 7, pp. 79–84. Springer, Cham (2017)
22. Grosse, C.U., Krüger, M.: Wireless acoustic emission sensor networks for structural health monitoring in civil engineering. In: Proceedings of European Conference on Non-Destructive Testing (ECNDT), DGZfP BB-103-CD (2006)
23. Chen, Bo., Liu, W.: Mobile agent computing paradigm for building a flexible structural health monitoring sensor network. Comput.-Aided Civil Infra. Eng. **25**(7), 504–516 (2010)
24. Guo, J., Xie, X., Bie, R., Sun, L.: Structural health monitoring by using a sparse coding-based deep learning algorithm with wireless sensor networks. Pers. Ubiquit. Comput. **18**(8), 1977–1987 (2014). https://doi.org/10.1007/s00779-0140800-5
25. Farrar, C.R., Worden, K.: An introduction to structural health monitoring. In: New Trends in Vibration Based Structural Health Monitoring, pp. 1–17. Springer, Vienna (2010)
26. Elgamal, A., Conte, J.P., Masri, S., Fraser, M., Fountain, T., Gupta, A., Trivedi, M., El Zarki, M.: Health monitoring framework for bridges and civil infrastructure. In: Proceedings of the 4th International Workshop on Structural Health Monitoring, pp. 123–130. (2003)
27. Zhao, X., Yuan, S., Zhenhua, Yu., Ye, W., Cao, J.: Designing strategy for multi-agent system based large structural health monitoring. Expert Syst. Appl. **34**(2), 1154–1168 (2008)
28. Bao, Y., Li, H., Sun, X., Yan, Yu., Jinping, Ou.: Compressive sampling–based data loss recovery for wireless sensor networks used in civil structural health monitoring. Struct. Health Monit. **12**(1), 78–95 (2013)
29. Li, A.Q., Ding, Y.L., Wang, H., Guo, T.: Analysis and assessment of bridge health monitoring mass data—Progress in research/development of "Structural Health Monitoring." Sci. China Technol. Sci. **55**(8), 2212–2224 (2012)
30. Catbas, F.N., Shah, M., Burkett, J., Basharat, A.: Challenges in structural health monitoring. In: Proceedings of the 4th International Workshop on Structural Control, pp. 10–11 (2004)
31. Choi, H., Choi, S., Cha. H.: Structural health monitoring system based on strain gauge enabled wireless sensor nodes. In: 2008 5th International Conference on Networked Sensing Systems, pp. 211–214. IEEE (2008)
32. Noel, A.B., Abdaoui, A., Elfouly, T., Ahmed, M.H., Badawy, A., Shehata, M.S.: Structural health monitoring using wireless sensor networks: a comprehensive survey. IEEE Communi. Surv. Tutorials **19**(3), 1403–1423 (2017)
33. Bagavathiappan, S., Lahiri, B.B., Saravanan, T., Philip, J., Jayakumar. T.: Infrared thermography for condition monitoring—A review. Infrared Phys. Technol. **60**, 35–55 (2013)
34. Hiasa, S., Birgul, R., Necati Catbas, F.: Infrared thermography for civil structural assessment: demonstrations with laboratory and field studies. J. Civil Struct. Health Monit. **6**(3), 619–636 (2016)
35. Kobayashi, K., Banthia, N.: Corrosion detection in reinforced concrete using induction heating and infrared thermography. J. Civil Struct. Health Monit. **1**(1–2), 25–35 (2011)
36. Antolis, C., Rajic, N.: Optical lock-in thermography for structural health monitoring–a study into infrared detector performance. Procedia Eng. **188**, 471–478 (2017)
37. Lo, T.Y., Choi. K.T.W.: Building defects diagnosis by infrared thermography. Struct. Surv. **22**(5), 259–263 (2004)
38. Harizi, W., Chaki, S., Bourse, G., Ourak, M.: Mechanical damage assessment of glass fiber-reinforced polymer composites using passive infrared thermography. Compos. B Eng. **59**, 74–79 (2014)
39. Agarwal, V., Neal, K.D., Mahadevan, S., Adams, D.: Concrete Structural Health Monitoring in Nuclear Power Plants. No. INL/CON-17–41433. Idaho National Lab. (INL), Idaho Falls, ID (United States) (2017)

40. Dassios, K.G., Kordatos, E.Z., Aggelis, D.G., Matikas, T.E.: Crack growth monitoring in ceramic matrix composites by combined infrared thermography and acoustic emission. J. Am. Ceram. Soc. **97**(1), 251–257 (2014)
41. Papaelias, M., Cheng, L., Kogia, M., Mohimi, A., Kappatos, V., Selcuk, C., Constantinou, L., Muñoz, C.Q.G., Marquez, F.P.G., Gan, T.H.: Inspection and structural health monitoring techniques for concentrated solar power plants. Renew. Energy **85**, 1178–1191 (2016)
42. Czichos, H. (ed.): Handbook of Technical Diagnostics: Fundamentals and Application to Structures and Systems. Springer (2013)
43. Kilic, G.: Using advanced NDT for historic buildings: towards an integrated multidisciplinary health assessment strategy. J. Cultural Heritage **16**(4), 526–535 (2015)
44. Balaras, Argitiou, C., Argiriou. A.A.: Infrared thermography for building diagnostics. Energy Build. **34**(2), 171–183 (2002)
45. Baxes, G.A. (ed.): Digital Image Processing: Principles and Applications. Wiley, Hoboken, NJ (1994)
46. Tennyson, R.C., Mufti, A.A., Rizkalla, S., Tadros, G., Benmokrane, B.: Structural health monitoring of innovative bridges in Canada with fiber optic sensors. Smart Mater. Struct. **10**(3), 560–573 (2001)
47. Li, H.N., Ren, L., Jia, Z.G., Yi, T.H., Li, D.S.: State-of-the-art in structural health monitoring of large and complex civil infrastructures. J. Civil Struct. Health Monit. **6**(1), 3–16 (2016)
48. Li, X., Yu. W.: Data stream classification for structural health monitoring via on-line support vector machines. In: 2015 IEEE First International Conference on Big Data Computing Service and Applications, pp. 400–405. IEEE (2015)
49. Li, H.N., Li, D.S., Song, G.B.: Recent applications of fiber optic sensors to health monitoring in civil engineering. Eng. Struct. **26**(11), 1647–1657 (2004)
50. Cai, G.: Big data analytics in structural health monitoring. Ph.D. dissertation. Vanderbilt University (2017)
51. Farrar, C.R., Worden, K.: An introduction to structural health monitoring. Philos. Trans. R. Soc. A: Math. Phys. Eng. Sci. **365**(1851), 303–315 (2006)
52. Dey, B., Kundu, M.K.: Efficient foreground extraction from HEVC compressed video for application to real-time analysis of surveillance "big" data. IEEE Trans. Image Process. **24**(11), 3574–3585 (2015)
53. Caffrey, J., Govindan, R., Johnson, E., Krishnamachari, B., Masri, S., Sukhatme, G., Chintalapudi, K., et al.: Networked sensing for structural health monitoring. In Proceedings of the 4th International Workshop on Structural Control, pp. 57–66. Columbia University, NY (2004)
54. Yeum, C.M., Dyke, S.J., Ramirez, J., Benes, B.: Big visual data analytics for damage classification in civil engineering. In: Transforming the Future of Infrastructure through Smarter Information: Proceedings of the International Conference on Smart Infrastructure and Construction, pp. 569–574. ICE Publishing, London, UK (2016)
55. Araujo, A., Garca-Palacios, J., Blesa, J., Tirado, F., Romero, E., Samartn, A., Nieto-Taladriz, O.: Wireless measurement system for structural health monitoring with high time-synchronization accuracy. IEEE Trans. Instrum. Meas. **61**(3), 801–810 (2012)
56. Dean, J., Ghemawat, S.: Mapreduce: simplified data processing on large clusters. Commun. ACM **5**(1), 107–113 (2008)
57. Infrared thermography for condition monitoring 2014 A review Infrared Phys. Technol. 60 35 55
58. Roshandeh 1, A.M., Poormirzaee 2, R., Ansari 3, F.S.: "Systematic Data management for real-time bridge health monitoring using layered big data and cloud computing. Int. J. Innov. Sci. Res. **2**(1), 29–39 (2014).ISSN 2351-8014. Innov. Space Sci. Res. J. https://www.ijisr.issr-journals.org/
59. Kezia, S.P., Mary, A.V.A.: Prediction of rapid floods from big data using map reduce technique. Glob. J. Pure Appl. Math. **12**(1), 369–373 (2016)
60. Jeong, S., Byun, J., Kim, D., Sohn, H., Bae, I.H., Law, K.H.: A data management infrastructure for bridge monitoring. In: Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2015, vol. 9435, p. 94350P. International Society for Optics and Photonics (2015)

61. Gandhi, T., Chang, R., Trivedi, M.M.: Video and seismic sensor-based structural health monitoring: Framework, algorithms, and implementation. IEEE Trans. Intell. Transp. Syst. **8**(2), 169–180 (2007)
62. Wu, J., Yuan, S., Ji, S., Zhou, G., Wang, Y., Wang, Z.: Multi-agent system design and evaluation for collaborative wireless sensor network in large structure health monitoring. Expert Syst. Appl. **37**(3), 2028–2036 (2010)
63. Cai, G., Mahadevan, S.: Big data analytics in structural health monitoring. Int. J. Prognos. Health Manage. **7** (2016)
64. Chakraborty, D., Kovvali, N., Wei, J., PapandreouSuppappola, A., Cochran, D., Chattopadhyay, A.: Damage classification structural health monitoring in bolted structures using time-frequency techniques. J. Intell. Mater. Syst. Struct. **20**(11), 289–305 (2009)
65. Antolis, C., Rajic, N.: Optical lock-in thermography for structural health monitoring—A study into infrared detector performance. In: Desjardins, S.L., Londono, N.A., Lau, D.T., Khoo, H. (eds.) Real-time data processing, analysis and visualization for structural monitoring of the confederation bridge. Adv. Struct. Eng. **9**(1), 141–157. Procedia Eng. **188**, 471–478 (2017)
66. Alampalli, S., Alampalli, S., Ettouney, M.:Big data and high-performance analytics in structural health monitoring for bridge management. In: Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2016, vol. 9803, p. 980315. International Society for Optics and Photonics (2016)

Sustainable Circular Manufacturing in the Digital Era: Analysis of Enablers

Dhairya Garg, Omar A. Mustaqueem, and Ravinder Kumar

Abstract In the digital era, advanced technologies and strategies are required to cope with the changing demands of consumers. "Sustainable circular manufacturing" is the new ray of hope meeting all standards of sustainable manufacturing and circular economy. It focuses on environment friendly production with the philosophy of reuse, remanufacture, and recycle and also endorses a close loop manufacturing pattern. This pattern not only aims to improve the product life cycle but also decrease resource consumption. Authors in this research paper authors identified nine key factors which enable the sustainable circular manufacturing by literature review and expert opinion. To determine a structural link amongst these enablers "Total Interpretive Structural Modelling (TISM)" methodology is used. Authors also derive the most dependent and independent enablers with the help of MICMAC analysis chart.

Keywords Circular economy · Sustainable manufacturing · TISM · Enablers

1 Introduction

"Sustainability" or "sustainable development" are two terms which can be used interchangeably. Their basic explanation is the "ability of a product/process to sustain" [1]. The foremost aim of the concept of sustainability is to fulfil the present market requirements, without putting the needs of future generations at risk. It can also be understood as utilizing the resources in such a fashion that they are sustained for as long as possible [2]. The concept of sustainability also focuses upon the overall welfare of living beings and the society, which means that everyone should have an easy passage to all the necessary resources such as fresh and lively environment, healthful source of food and water, and assuring right style of living [3].

Various authors have defined sustainability in different yet similar ways. R. Sreenivasan et al. defines sustainability as the usage of resources while keeping a factor

D. Garg · O. A. Mustaqueem · R. Kumar (✉)
Amity University Uttar Pradesh, Sector 125, Noida, India
e-mail: rkumar19@amity.edu

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_48

of depletion in mind, and by what means they can sceptically disturb the environment [4]. Man and Strandhagen's defined the term sustainable business models as the model, which simply integrates the environmental, social and economic vision with the neoclassical method [5]. From Stock's and Obenaus's point of view, the concept of sustainability consists of three different aspects, which are named as social, environmental and economic aspects [6]. In developing economies, the ordinary life course of a product is linear (Fig. 1). The traditional linear life course is focused upon the production of a product, introducing it, selling, utilization, service and discarding it as waste at last. In the modern era of depleting natural resources, there is need of shift from linear to circular product cycle (circular economy). The circular economy (henceforth CE) model helps in the reduction of wastage and monitor the consumption of natural resources by rework, recycles, remanufacture, reutilize, renew and reduce [19].

In this research paper, authors have studied enablers of sustainable circular manufacturing by using TISM techniques. Section 2 will discuss related literature and identification of enablers of sustainable circular manufacturing in the Indian scenario. Section 3 will discuss the methodology and its application. Section 4 will discuss the observation and results of the study. Lastly, Sect. 5 will discuss the outcome, shortcomings and future research path.

2 Literature Review

Some important sustainability issues from the manufacturer's point of view consists of energy usage, industrial waste production, water utilization and the toll took from the environment from manufacturing [7]. It has been observed that the carbon footprint of the poor cannot be taken into account and major market players or Multi-National Company (MNC) already are trying to reduce their carbon footprint to an acceptable level. MNCs have adequate funds for that, but SMEs do not. Hence, the main focus of this paper is upon SME [9, 10].

In "Industry 4.0" or "I4.0", sustainability is an important point which the world is focusing upon, and it covers three aspects of manufacturing such as environment, economic and social. Another micro-aspect which is yet to be focused upon is the extension of product life cycle or proper disposal of products. Sustainability has three pillars, i.e. social, economic and environmental, but critical factor of reuse, recycle, remanufacture is missing. In the current scenario, the industry should ideally start moving from "linear economy" to "circular economy" [18]. In this paper, authors have discussed the vital element which concept of sustainability has missed, sustainability talks only about reduce, for an ideal sustainable future "reduce" won't be enough alone, reuse and recycle is also essential. Additionally, it has become highly necessary to adopt I4.0 and circular economy for manufacturing firms, as this will help firms to stay updated, expand to global levels, and let the existing system absorb principles of sustainability [22]. Indian economy highly depends upon the manufacturing sector, especially automobile, and the Indian automobile industry has consistently been one of the largest contributors in GDP [23]. The linear economy was being followed due to the availability of resources in abundance. Soon, shifting to a more sustainable alternative won't be an option, hence for better utilization of resources and to increase the product life cycle, the best choice currently available is circular economy.

In many countries, like USA, Japan and Europe, CE is being used as a tool to make environmental and waste management policies [20]. Sustainable Circular Manufacturing in the words of Ellen MacArthur is "an industrial system that is restorative or regenerative by intention and design" [24]. CE approach creates an enormous amount of information regarding wastage, side-effect, raw substance and so forth. It calls for the supply chain to have digitization to screen and handle the ongoing data. Contextually, I4.0 gives significant advancement in sustainable processes and forms a progressively unique and productive chain. Key enablers identified from the existing literature are compiled within Table 1.

3 Methodology of TISM

From the literature review, authors have identified nine enablers of sustainable circular manufacturing in thse digital era (Table 1). After identifying the enablers, authors have used the TISM methodology for deriving a quantified relationship between these enablers. TISM stands for Total Interpretive Structural Modelling. It can be understood as a methodology that is an advancement of ISM technique. It is a subjective analysis approach to establish as well as quantify relationships, discovering causality flow by determining the dependent and independent variables and defining the changes between them, and summarizing these relationships. It helps in converting unplanned and poorly designed models into clear and well-designed models, making it simpler to deal with complex subjects with the help of directed graphs or digraphs which utilize the variables as mentioned earlier [27].

The methodology has the following steps:

Step 1: Identify Enablers

The identification of enablers has been summarized in Table 1, and the procedure has been explained.

Step 2: Designing SSIM

A matrix is formed in this step (Table 2), indicating the relation between the enablers by using four variables "*V*, *A*, *X*, *O*", the roles of which have been defined. It helps establish a rough idea of the structure of the relationship between them.

E1: Awareness about CE, E2: Knowledge of latest digital technologies, E3: Availability of latest information and manufacturing technologies (Hardware and software), E4: Government rules and customer pressure on CE, E5: Willingness (top

Table 1 Enablers of sustainable circular manufacturing in the digital era

S. No.	Enablers	Description	References
1	Awareness about CE	Analyzing current practices gives an appropriate idea about how CE can help overcome their shortcomings; Technologies like RFID and GPS make traceability simpler	[15, 31, 41–43]; Own contribution
2	Knowledge of latest digital Technologies	Digitalization helps organizations in obtaining, storing, sorting, analyzing and using the data for upgradation; Recyclability and reusability increases with the help of technologies such as additive and flexible manufacturing	[24, 28, 30, 34, 35]; Own contribution
3	Availability of latest technologies (Hardware and Software)	Technologies like IIoT and CPS connect physical and virtual systems, establish a fast connection between organizations, and improve responses of tracking systems	[14, 32, 33, 50]; Own contribution
4	Government rules and customers awareness on CE	Incentive for organizations to inculcate recyclability and reusability in their processes	[11, 16, 37, 38, 44]; Own contribution
5	Willingness (top management) to create CE-inspired products/ brand	Companies establish themselves among organizations and groups that are environment-conscious; Eases implementation of CE in the organization	[8, 39, 40, 45, 48]; Own contribution
6	Environment friendly practices	Conserving natural resources; reducing carbon footprints; less CO2 emissions by reuse in comparison to new product manufacturing; reduced pollution by reuse in comparison to unplanned disposal	[30, 36, 47, 49]; Own contribution

(continued)

Table 1 (continued)

S. No.	Enablers	Description	References
7	Reduction in the overall cost of new products	The overall cost of products gets reduced by recycling, reuse and minimum use of new materials, less governmental fines, and low waste generation	[12, 13, 21, 26, 35]; Own contribution
8	Creation of employment	Added stages in the economic model of the closed-loop supply chain of the circular economy will lead towards increment of workforce required	[29, 46]; Own contribution
9	Availability of investment for CE (Local/ FDI, etc.)	As circular economy has tremendous scope of growth, investors are ready to invest a good amount of money in start-ups and organizations willing to work on it	[17, 25]; Own contribution

Table 2 SSIM of enabling factors

Variable	EN9	EN8	EN7	EN6	EN5	EN4	EN3	EN2	EN1
EN1	*V*	*V*	*V*	*V*	*V*	*A*	*V*	*V*	
EN2	*X*	*V*	*O*	*O*	*X*	*A*	*X*		
EN3	*A*	*V*	*V*	*V*	*X*	*A*			
EN4	*V*	*V*	*V*	*V*	*V*				
EN5	*V*	*V*	*V*	*V*					
EN6	*V*	*V*	*V*						
EN7	*A*	*O*							
EN8	*A*								
EN9									

management) to create CE-inspired products/ brand, E6: Environment friendly practices, E7: Reduction in cost of products, E8: Creation of employment, E9: Availability of investment for CE.

V When there is a direct connection from vertical enabler to horizontal enabler and not vice versa.
A When there is a direct connection from horizontal enabler to vertical enabler but not vice versa.
X When there is a direct connection in enablers from both the directions.
O When there is no direct connection amongst the enablers.

Step 3: Interpretive Logical Knowledge-Based Table

In this step, a Yes/No (Y/N) relation is established between the pairs of enablers which are compared with each other and the reasons for which are given. This information is tabulated in Table 3. Y/N is converted in Binary with the help of Table 4.

Step 4: Basic Reachability Matrix

This step discusses the basic reachability matrix (Table 5) in which each Yes/No relationship from the previous table is interpreted in binary form that is 1 or 0, 1 being true and 0 being false.

Step 5: Ultimate Reachability Matrix (with the Help of Transitivity Rule)

Ultimate reachability matrix (Table 6) is formed with the help of basic matrix, and the binary values are finalized. “DP” in the column depicts Driving Power, “dp” in the row represents Dependent Power.

Step 6: Finding Levels of Enablers Through Partition Leveling

The level of enabler through partitioning technique has been determined. The level one of partitioning is shown in Table 7. Due to the space constraint, level 2, 3, and 4 are not shown here. The final level is shown in Table 8.

Step 7: MICMAC Analysis

MICMAC Analysis is a graph which helps categorize factors into four categories, i.e. Independent, Linkage, Autonomous, Dependent enabler. Figure 1 shows the MICMAC analysis for the above data.

Both leveling technique and MICMAC analysis show that E7 and E8 are dependent/driven enablers, and E4 and E1 are independent/driving enablers.

4 Result and Discussion

The authors identified nine factors that enable circular economy in Industry 4.0, namely Awareness about CE; Knowledge of latest digital technologies (hardware and software); Government rules and customers pressure on CE; Willingness of top management to create CE-inspired products/brand; Environment friendly practices; Reduction in cost of products; Creation of employment and Availability of investment for CE. Further, they quantifiably derived the relation between them using TISM methodology in seven steps, namely identifying the enablers; forming SSIM; interpretive knowledge-based chart; forming basic reachability matrix; forming ultimate reachability matrix; finding levels of enablers through partition leveling and finally, MICMAC analysis, which shows the graphical representation of findings. From partition leveling and MICMAC analysis, the authors observed that reduction in the cost of products as well as the creation of employment is the most dependent/driven enablers. At the same time, awareness about CE as well as government rules and customer pressure on CE are the most independent/driving enablers. Authors’ observed that

Table 3 Interpretive logical knowledge-based table

S. No.	Enabler relationship	Y/N	Reason
1	E1–E9, E9–E1	Y, N	Awareness about CE influences availability of investment for CE
2	E1–E 8, E8–E 1	Y, N	Creation of employment gets influenced by awareness about CE
3	E1–E7, E7–E1	Y, N	Awareness about CE influences reduction in the cost of products as reusability and recyclability bring down the cost of raw materials
4	E1–E6, E6–E1	Y, N	Awareness about CE increases environment friendliness of an organization, hence influencing it
5	E1–E5, E5–E1	Y, N	Awareness about CE influences top management to create CE-inspired products
6	E1–E4, E4–E1	N, Y	Govt rules and customer pressure on CE influences awareness about CE
7	E1–E3, E3–E1	Y, N	Awareness about CE influences the availability of the latest information and manufacturing technologies
8	E1–E2, E2–E1	Y, N	Awareness about CE influences knowledge about latest digital technologies
9	E2–E9, E9–E2	Y, Y	Knowledge of latest digital technologies affects the availability of investment for CE and vice versa
10	E2–E8, E8–E2	Y, N	Knowledge of latest digital technologies influences the creation of employment by equipping the organization better for the future
11	E2–E7, E7–E2	N, N	No influence of knowledge of latest digital technologies and reduction in the cost of products on each other
12	E2–E6, E6–E2	N, N	No influence of knowledge of latest digital technologies and environment friendly practices on each other
13	E2–E5, E5–E2	Y, Y	Latest technologies help develop a circular system, while the need to implement circular economy needs constant learning about latest technologies
14	E2–E4, E4–E2	N, Y	Government rules and customer pressure greatly influence knowledge of latest digital technologies as industry experts start looking into them, hence gaining knowledge about it
15	E2–E3, E3–E2	Y, Y	Knowledge about latest technologies and availability of latest hardware and software are factors that enable each other
16	E3–E9, E9–E3	N, Y	If an organization has latest hardware and software, getting investments is easy
17	E3–E8, E8–E3	Y, N	When new technologies are introduced specialized workers are required to operate them which results in employment creation, while the reverse isn't possible
18	E3–E7, E7–E3	Y, N	Latest technologies simplify the processes and help in product cost reduction. It might reduce the lead time too

(continued)

Table 3 (continued)

S. No.	Enabler relationship	Y/N	Reason
19	E3–E6, E6–E3	Y, N	While designing new automation, the environment is kept in mind. Therefore, it makes practices environment friendly
20	E3–E5, E5–E3	Y, Y	With the availability of advanced machinery top management will be ready to promote CE inspired products, and vice versa
21	E3–E4, E4–E3	N, Y	No factor can affect government rules, but they can affect the availability of new manufacturing techniques
22	E4–E9, E9–E4	Y, N	Changes in government policies can enable or restrict the investors to invest in projects, but investors can never change the government policies
23	E4–E8, E8–E4	Y, N	To create a balance in economy employment creating is essential and only government policies can enable them
24	E4–E7, E7–E4	Y, N	When the government and customers are aware of CE, they can support and help the industry reduce the cost of the product
25	E4–E6, E6–E4	Y, N	Government rules and customer pressure influences environment friendly practices
26	E4–E5, E5–E4	Y, N	Rules made by the government highly enable or challenges the willingness of management to create CE-inspired products
27	E5–E9, E9–E5	Y, N	The willingness of making a new product influences availability of investment from an investor
28	E5–E8, E8–E5	Y, N	If an organization decides to create CE-inspired products, they need new employs to work upon new project and machinery
29	E5–E7, E7–E5	Y, N	The willingness of top management to implement CE positively influences reduction in the cost of products
30	E5–E6, E6–E5	Y, N	The willingness of top management to create CE-inspired products directly influences environment friendly practices
31	E6–E9, E9–E6	Y, N	Environment friendly practices enable the availability of investment for CE as they provide good prospects
32	E6–E8, E8–E6	Y, N	Environment friendly practices influence the creation of employment as a greater number of people are inclining towards environment friendly organizations
33	E6–E7, E7–E6	Y, N	Environment friendly practices influence the reduction in the cost of products
34	E7–E9, E9–E7	N, Y	Increased availability of investment influences reduction in the cost of products
35	E7–E8, E8–E7	N, N	No influence of reduction in cost of products and the creation of employment on each other
36	E8–E9, E9–E8	N, Y	Availability of investment for CE influences the creation of employment, whereas vice versa isn’t true

Table 4 Cheatsheet for the conversion of SSIM to Initial reachability matrix

Y	1
N	0

Table 5 Basic reachability matrix

Variable	EN1	EN2	EN3	EN4	EN5	EN6	EN7	EN8	EN9
EN1	1	1	1	0	1	1	1	1	1
EN2	0	1	1	0	1	0	0	1	1
EN3	0	1	1	0	1	1	1	1	0
EN4	1	1	1	1	1	1	1	1	1
EN5	0	1	1	0	1	1	1	1	1
EN6	0	0	0	0	0	1	1	1	1
EN7	0	0	0	0	0	0	1	0	0
EN8	0	0	0	0	0	0	0	1	0
EN9	0	1	1	0	0	0	1	1	1

Table 6 Ultimate reachability matrix

Variable	EN1	EN2	EN3	EN4	EN5	EN6	EN7	EN8	EN9	DP
EN1	1	1	1	0	1	1	1	1	1	8
EN2	0	1	1	0	1	1*	1*	1	1	7
EN3	0	1	1	0	1	1	1	1	0	6
EN4	1	1	1	1	1	1	1	1	1	9
EN5	0	1	1	0	1	1	1	1	1	7
EN6	0	1*	1*	0	1*	1	1	1	1	7
EN7	0	0	0	0	0	0	1	0	0	1
EN8	0	0	0	0	0	0	0	1	0	1
EN9	0	1	1	0	1*	1*	1	1	1	7
dp	2	7	7	1	7	7	8	8	6	

To develop the final reachability matrix, transitivity check is applied on the initial reachability matrix following the transitivity (*) rule as mentioned in methodology. In this final reachability matrix dependence power and driving power are obtained for each challenge represented by row and column respectively

the finding of this study will help organizations in implementing CE. Below is the TISM Model (flowchart) derived from the level of enablers.

Table 7 Level 1

S. No.	Reachability set	Antecedent set	Intervention set	Level
1	1, 2, 3, 5, 6, 7, 8, 9	1, 4	1	
2	2, 3, 5, 6, 7, 8, 9	1, 2, 3, 4, 5, 6, 9	2, 3, 5, 6, 9	
3	2, 3, 5, 6, 7, 8	1, 2, 3, 4, 5, 6, 9	2, 3, 5, 6	
4	1, 2, 3, 4, 5, 6, 7, 8, 9	4	4	
5	2, 3, 5, 6, 7, 8, 9	1, 2, 3, 4, 5, 6, 9	2, 3, 5, 6, 9	
6	2, 3, 5, 6, 7, 8, 9	1, 2, 3, 4, 5, 6, 9	2, 3, 5, 6, 9	
7	7	1, 2, 3, 4, 5, 6, 7, 9	7	1
8	8	1, 2, 3, 4, 5, 6, 8, 9	8	1
9	2, 3, 5, 6, 7, 8, 9	1, 2, 4, 5, 6, 9	2, 5, 6, 9	

Table 8 Final levels from partition leveling

S. No.	Enabler	Level
1	Awareness about CE	4
2	Knowledge of latest digital Technologies	2
3	Availability of latest Information and manufacturing technologies (Hardware and Software)	2
4	Government rules and customers awareness on CE	5
5	Willingness (top management) to create CE-inspired products/ brand	2
6	Environment friendly practices	2
7	Reduction in the overall cost of new products	1
8	Creation of employment	1
9	Availability of investment for CE (Local/ FDI, etc.)	3

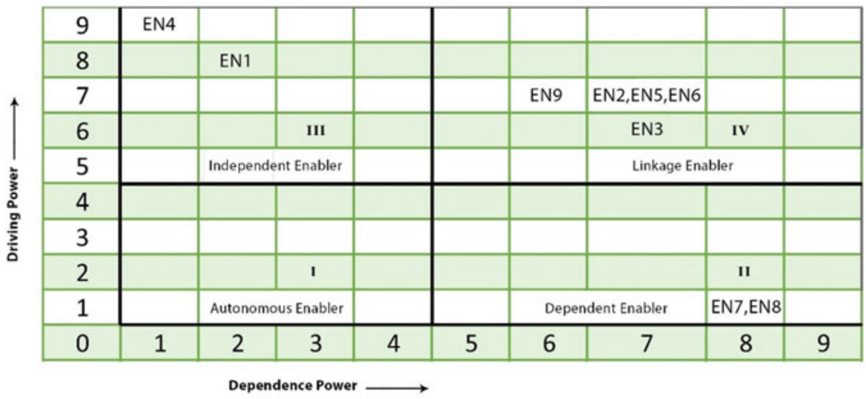


Fig. 1 MICMAC analysis

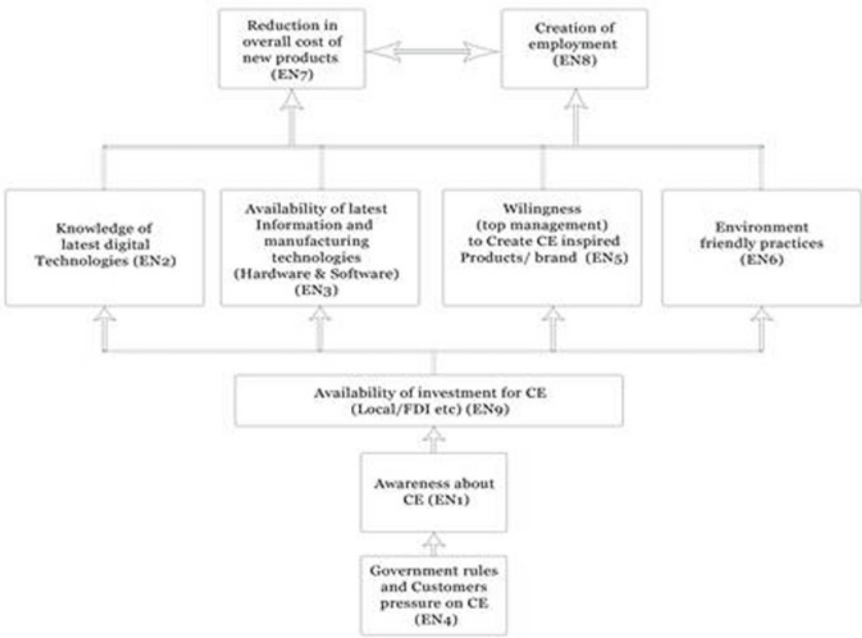


Fig. 2 Digraph showing the enablers connect

5 Conclusion, Limitations and Future Research Directions

In this study, authors have identified and analyzed the enablers of sustainable circular manufacturing by using TISM methodology. From the finding of the study, authors observed that the enabler (EN4), i.e. "Government rules and customer pressure on CE", and "EN1, i.e. "Awareness about CE" are the most independent factors while EN8, i.e. "Creation of employment", and EN7, i.e. "Reduction in overall cost of new products" are the most dependent factors. The above-used methodology is executed based on the feedbacks of experts. Higher dependency on expert opinion maybe its limitation too. Therefore, these results cannot be used as (the only) concrete base to be used for future research. In another context or some other circumstances, the results might vary. A tremendous research scope is present in this field. As the field of research is very niche and yet to be discovered by the researchers. There is a lot of scope of study that how an industry can increase the sustainability of its manufacturing practices in CE-inspired environment.

References

1. Lee, J., Kao, H.A., Yang, S.: Service innovation and smart analytics for industry 4.0 and big data environment. Procedia CIRP **16**, 3–8 (2014)
2. Ibarra, D., Ganzarain, J., Igartua, J.I.: Business model innovation through Industry 4.0: A review. Procedia Manuf. **22**, 4–10 (2018)
3. Vaidya, S., Ambad, P., Bhosle, S.: Industry 4.0—A glimpse. Procedia Manuf. **20**, 233–238 (2018)
4. Sreenivasan, R., Goel, A., Bourell, D.L.: Sustainability issues in laser-based additive manufacturing. Phys. Procedia **5**, 81–90 (2010)
5. de Man, J. C., Strandhagen, J.O.: An Industry 4.0 research agenda for sustainable business models. Procedia CIRP, **63**, 721–726 (2017)
6. Stock, T., Obenaus, M., Kunz, S., Kohl, H.: Industry 4.0 as enabler for a sustainable development: A qualitative assessment of its ecological and social potential. Process Saf. Environ. Protect. **118**, 254–267 (2018)
7. Stock, T., Seliger, G.: Opportunities of sustainable manufacturing in industry 4.0. Procedia CIRP, **40**, 536–541 (2016)
8. Boccella, A.R., Piera, C., Cerchione, R., Murino, T.: Evaluating centralized and heterarchical control of smart manufacturing systems in the era of Industry 4.0. Appl. Sci. **10**(3), 755 (2020)
9. Sukkasi, S., Chollacoop, N., Ellis, W., Grimley, S., Jai-In, S.: Challenges and considerations for planning toward sustainable biodiesel development in developing countries: lessons from the Greater Mekong Subregion. Renew. Sustain. Energy Rev. **14**(9), 3100–3107 (2010)
10. Alcacer, V., Cruz-Machlado, V.: Scanning the Industry 4.0: a literature review on technologies for manufacturing systems. Eng. Sci. Technol. Int. J. **22**, 899–919 (2019)
11. Ghobakhloo, M.: The future of manufacturing industry: a strategic roadmap toward Industry 4.0. J. Manuf. Techn. Manage. (2018)
12. Knieke, C., Lawrenz, S., Fröhling, M., Goldmann, D., Rausch, A.: Predictive and flexible Circular Economy approaches for highly integrated products and their materials as given in E-mobility and ICT. In: Materials Science Forum, vol. 959, pp. 22–31. Trans Tech Publications Ltd. (2019)
13. Bassi, L.: Industry 4.0: Hope, hype or revolution? In: 2017 IEEE 3rd International Forum on Research and Technologies for Society and Industry (RTSI), pp. 1–6. IEEE (2017)
14. Wits, W.W., García, J.R.R., Becker, J.M.J.: How additive manufacturing enables more sustainable end-user maintenance, repair and overhaul (MRO) strategies. Procedia CIRP **40**, 693–698 (2016)
15. Garrido-Hidalgo, C., Olivares, T., Ramirez, F.J., Roda-Sanchez, L.: An end-to-end Internet of Things solution for reverse supply chain management in Industry 4.0. Comput. Ind. **112**, 103127 (2019)
16. Bressanelli, G., Adrodegari, F., Perona, M., Saccani, N.: The role of digital technologies to overcome circular economy challenges in PSS business models: an exploratory case study. Procedia CIRP **73**(2018), 216–221 (2018)
17. Preston, F., Lehne, J., Wellesley, L.: An Inclusive Circular Economy. Priorities for Developing Countries (2019)
18. Mishra, S., Singh, S.P., Johansen, J., Cheng, Y., Farooq, S.: Evaluating indicators for international manufacturing network under circular economy. Manage. Decis. (2019)
19. Ghisellini, P., Cialani, C., Ulgiati, S.: A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. J. Clean. Prod. **114**, 11–32 (2016)
20. Breau, S.C., Samuel, K.L.H.: Research Handbook on Disasters and International Law. Elgar, UK (2016)
21. Ghisellini, P., Ripa, M., Ulgiati, S.: Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review. J. Clean. Prod. **178**, 618–643 (2018)

22. Yadav, G., Luthra, S., Huisingh, D., Mangla, S.K., Narkhede, B.E., Liu, Y.: Development of a lean manufacturing framework to enhance its adoption within manufacturing companies in developing economies. J. Clean. Prod. 118726. https://doi.org/10.1016/J.JCLEPRO.2019.118726 (2019)
23. Haupt, M., Hellweg, S.: Measuring the environmental sustainability of a circular economy. Environ. Sustain. Indicat. **1**, 100005 (2019)
24. Rajput, S., Singh, S.P.: Industry 4.0—challenges to implement circular economy. Benchmark.: In. J. (2019)
25. Rizos, V., Behrens, A., Van der Gaast, W., Hofman, E., Ioannou, A., Kafyeke, T., Flamos, A., Rinaldi, R., Papadelis, S., Hirschnitz-Garbers, M., Topi, C.: Implementation of circular economy business models by small and medium-sized enterprises (SMEs): Barriers and enablers. Sustainability, **8**(11), 1212 (2016)
26. Agyemang, M., Kusi-Sarpong, S., Khan, S.A., Mani, V., Rehman, S.T., Kusi-Sarpong, H. Drivers and barriers to circular economy implementation. Manage. Decis. (2019)
27. Yadav, N.: Total interpretive structural modelling (TISM) of strategic performance management for Indian telecom service providers. Int. J. Prod. Perform. Manage. (2014)
28. Antikainen, M., Uusitalo, T., Kivikytö-Reponen, P.: Digitalisation as an enabler of circular economy. Procedia CIRP **73**, 45–49 (2018)
29. Economic Times: Circular economy can generate 1.4 crore jobs in 5–7 years: NITI Aayog CEO. https://economictimes.indiatimes.com/news/economy/circular-economy-can-generate-1-4-crore-jobs-in-5-7-years-niti-aayog-ceo/articleshow/69836073.cms. Last assessed 15 Feb 2020 (2019)
30. Nascimento, D.L.M., Alencastro, V., Quelhas, O.L.G., Caiado, R.G.G., Garza-Reyes, J.A., Rocha-Lona, L., Tortorella, G.: Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context. J. Manuf. Technol. Manage. (2019)
31. Moktadir, M.A., Rahman, T., Rahman, M.H., Ali, S.M., Paul, S.K.: Drivers to sustainable manufacturing practices and circular economy: a perspective of leather industries in Bangladesh. J. Clean. Prod. **174**, 1366–1380 (2018)
32. Fatorachian, H., Kazemi, H.: A critical investigation of Industry 4.0 in manufacturing: theoretical operationalization framework. Prod. Plan. Control **29**(8), 633–644 (2018)
33. Zhong, R.Y., Xu, X., Klotz, E., Newman, S.T.: Intelligent manufacturing in the context of industry 4.0: a review. Engineering, **3**(5), 616–630 (2017)
34. Batista, L., Bourlakis, M., Smart, P., Maull, R.: In search of a circular supply chain archetype–a content-analysis-based literature review. Prod. Plan. Control **29**(6), 438–451 (2018)
35. Kumar, V., Sezersan, I., Garza-Reyes, J.A., Gonzalez, E.D., Moh'd Anwer, A.S.: Circular economy in the manufacturing sector: benefits, opportunities and barriers. Manage. Decis. (2019)
36. Hofmann, E., Rüsch, M.: Industry 4.0 and the current status as well as future prospects on logistics. Comput. Ind. **89**, 23–34 (2017)
37. Bocken, N., Boons, F., Baldassarre, B.: Sustainable business model experimentation by understanding ecologies of business models. J. Clean. Prod. **208**, 1498–1512 (2019)
38. Caldera, H.T.S., Desha, C., Dawes, L.: Evaluating the enablers and barriers for successful implementation of sustainable business practice in 'lean'SMEs. J. Clean. Prod. **218**, 575–590 (2019)
39. Wang, S., Wan, J., Zhang, D., Li, D., Zhang, C.: Towards smart factory for industry 4.0: a self-organized multi-agent system with big data based feedback and coordination. Comput. Netw. **101**, 158–168 (2016)
40. Ranta, V., Keränen, J., Aarikka-Stenroos, L.: How B2B suppliers articulate customer value propositions in the circular economy: Four innovation-driven value creation logics. Ind. Mark. Manage. (2019)
41. de Sousa Jabbour, A.B.L., Jabbour, C.J.C., Godinho Filho, M., Roubaud, D.: Industry 4.0 and the circular economy: a proposed research agenda and original roadmap for sustainable operations. Ann. Oper. Res. **270**(1–2), 273–286 (2018)

42. Blunck, E., Werthmann, H.: Industry 4.0–an opportunity to realize sustainable manufacturing and its potential for a circular economy. In: DIEM: Dubrovnik International Economic Meeting, vol. 3, No. 1, pp. 644–666. Sveučilište u Dubrovniku (2017)
43. Pagoropoulos, A., Pigosso, D.C., McAloone, T.C.: The emergent role of digital technologies in the circular economy: a review. Procedia CIRP **64**, 19–24 (2017)
44. Ruiz-Salmón, I., Margallo, M., Laso, J., Villanueva-Rey, P., Mariño, D., Quinteiro, P., Dias, A.C., Nunes, M.L., Marques, A., Feijoo, G., Moreira, M.T.: Addressing challenges and opportunities of the European seafood sector under a circular economy framework. Curr. Opin. Environ. Sci. Health (2020)
45. Zinck, S., Ayed, A.C., Niero, M., Head, M., Wellmer, F.W., Scholz, R.W., Morel, S.: Life cycle management approaches to support circular economy. In: Designing Sustainable Technologies, Products and Policies, pp. 3–9). Springer, Cham (2018)
46. European Commission: Report from the commission to the European parliament, the council. The European Economic and Social Committee and the Committee of the Regions on the implementation of the Circular Economy Action Plan, European Commission, Brussels. https://ec.europa.eu/environment/circular-economy/implementation_report.pdf. Last assessed 22 Feb 2020 (2017)
47. Geissdoerfer, M., Savaget, P., Bocken, N.M., Hultink, E.J.: The circular economy–A new sustainability paradigm? J. Clean. Prod. **143**, 757–768 (2017)
48. Svensson, N., Funck, E.K.: Management control in circular economy. Exploring and theorizing the adaptation of management control to circular business models. J. Clean. Prod. **233**, 390–398 (2019)
49. Priyadarshini, P., Abhilash, P.C.: Circular economy practices within energy and waste management sectors of india: a meta-analysis. Bioresour. Technol. 123018 (2020)
50. Tseng, M.L., Tan, R.R., Chiu, A.S., Chien, C.F., Kuo, T.C.: Circular economy meets industry 4.0: can big data drive industrial symbiosis? Resour. Conserv. Recycl. **131**, 146–147 (2018)

A Business Process Modeling Approach in Human Resource Management for Small and Medium-Sized Enterprises

T. Ramadas

Abstract The primary objective of this research paper to highlight the research work carried out in the area of human resource management for SMEs using a business process modeling approach. This paper provides a method of developing a human resource management model from the perspective of business process modeling that has not to be investigated before to the best of our knowledge. Hence, the aim of this paper is to design the human resource management model for SMEs, and to do that business process modeling instruments were employed. The proposed conceptual model represents the workflow regarding human resource activities in small and medium-sized enterprises. The presented human resource business process model is expected to help researchers, business modelers, and analysts, as well as for real professionals for further studies in the domain of human resources management in the SME context.

Keywords SMEs · Human resource management · Business process modeling · Exploratory modeling technique

1 Introduction

Human resources play a significant role in the organizational development and growth. Human resources only live in all aspects of production, and they have unlimited capabilities and potentials. By applying appropriate strategies, this person's capabilities and potential can be developed for the benefit of the organization. Human beings are not only an active factor in production but also enable other inactive and passive components of production, such as money, machines, and methods [7]. The term human resource management involves multiple concepts. In many cases, the success of an organization, group, or even a country depends on the ability of the leader to manage human resources [8]. Although research has shown that employees of SMEs tend to have less sophisticated human resource management than that of

T. Ramadas (✉)
Postgraduate School of Engineering Management, University of Johannesburg, Johannesburg, South Africa
e-mail: tramadas@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_49

large companies, they are still satisfied and engaged [6, 9]. To make sense of the contradictory evidence, it is necessary to go beyond universalistic stances to explore how to properly conceptualize and operate human resource management in a SME environment. This implies greater adaptation to contextual conditions, by examining what organizations actually do in practice for effective HR practices in a SME environment [10, 12, 16]. Several studies have been conducted to analyze the human resource management system in small and medium-sized enterprises, however, there are a few reference models available in application of HR in SMEs, but there is no standard representation of human resource management strategic model using business process modeling technique. So, Hence the aim of this paper to develop business process models in HR activities for SMEs.

2 Methodology

This article examined BPMN language with real-world practical examples for SME to recognize and highlight the problems and provide the requirements and solutions. To do this two-type method was followed (1) literature research to investigate the theoretical part of language (2) followed by explanatory development of workflow design human resource business process model using BPMN for SME.

3 Characteristic of Human Resource Management in SMEs

Human resources management deals with the administrative and strategic human resources processes. It should be noted that small and medium-sized organization involves the human resource management with aspects of globalization and is more dynamic, dealing with intercultural problems, problems of merging subsidiaries, and problems of global transfer of resource processes issues [21]. Human process management classified into two, one is the primary HR process, and the second is the administrative Process [13]. Main HR Process that includes recruitment, performance management, strategic planning, and exit interview. Administrative HR process includes leave and absence data management, costing, payroll. By integrating global aspects, including cross-cultural, national and international law, international knowledge management, and the transfer of human resource processes from multinational companies, human resource processes can be extrapolated to design the business process model. From here, we can easily use a business process model to capture all the effects of changes in HR, so we can design and deploy HR in a direction that can change and change, leading to strategic human resources management for international competitive advantage. The business process model may also include designing an HR system with the following requirements:

1. Process coordination based On HR process, labor and union legislation and, subsidiary and parent company strategies.
2. Interactive integration by dynamically updating different stakeholders (for example, using government policies and corporate procedures and new laws in the global environment).

Compared to large companies, the number of Small and Medium-sized Enterprises (SMEs) is much larger, but the research on SMEs is relatively small [14]. Compared to multidisciplinary results, we know more about the success factors of large enterprises than small businesses [22]. The management of human resources in a commercial environment must be understood as a strategic attitude toward the recruitment, selection, hiring and development and training of employees, the workforce [15]. The socio-economic importance of Small and Medium-sized Enterprises (SMEs) cannot be underestimated. Worldwide, SMEs account for over 95% of businesses and 60% of jobs in the private sector. SMEs are constrained by limited resources and to reduce themselves hierarchically, which makes the potential impact of human resources management more transparent and revealing. Therefore, the successful management of employees is critical to determining the survival and development of a small business [4].

4 Business Process Modeling

The term business process has it appeared in the twentieth century and has matured through plans that involve activities from flow diagram to functional block diagrams. The American Center for Productivity and Quality (APQC) has established a good practice format for business process definitions. According to APQC definition Business processes are the capturing of the sequence of activity as performed by the business. Business Process Modelling (PPM) is a method of integrating an organization into the needs and wants of its customers [23]. It is a comprehensive management approach that improves business efficiency and efficiency while striving for innovation, flexibility, and integration with technology. As companies seek to achieve their goals, BPM continuously seeks to improve processes—define, measure, and improve processes—and optimize processes [5, 27]. Business Process Modeling (PPM) is the central focus of business process management. It is an activity that describes the process of organization of current state or what they should become. However, in recent years, an expressive and understandable business process modeling language is suitable for all users. Currently, several modeling languages define the basics of creating business process models, for example, Petri Nets (PN) [25], UML Activity Diagrams [20], Business Process Execution Language (BPEL) for web services [18], and Business Process Modeling Notation (BPMN) [19]. There is a lot of research on the importance, quality, and applicability of modeling languages. Due to the complexity and error-prone tasks of modeling and designing business processes, many methods have emerged for modeling and analyzing business processes [26].

Many of these methods provide a rich design environment that lacks accurate conceptual awareness, and the others have a clear conceptual basis but lack graphic expressiveness. Both business engineering and information technology experts conclude that successful systems start with an understanding of an organization's business processes [3]. In addition, business processes are a key element in enterprise integration [1]. Conceptual modeling of business processes has been implemented on a large scale to develop software that supports business processes, improve analytics, and re-engineer on a daily basis [2]. There are many suggested techniques and patterns that are useful to follow. Mendling et al. [17] advocate a set of seven guidelines for developing a quality business process model. Gunasekaran and Kubo [11] provide guidelines for selecting modeling tools and techniques associated with the areas in which reengineering is to be performed. A lot of research has been carried out to assess the suitability and the capacities of modeling languages. Strembeck and Mentling [24] report the lack of modeling language elements related to the integration of processes and role-based access control. For the purposes of this paper, we have not been able to provide a complete list of several papers on the suitability of using BPMN in recent years, but to our knowledge, there is no active example of investigation to highlight the semantic flow problems of objects in the use of BPMN.

5 Development of Business Process Modeling of Human Resource Management—Exploratory Modeling Technique

The term modeling is a type of simulation where a sequence of related phases constitutes a process, and these processes are analyzed, studied, and executed repeatedly to improve the performance of the business process. Therefore, the purpose of Business Process Modeling (BPM) is to optimize the efficiency of executing business processes and activities related to the production of products and services. Traditionally, human resource development has been essential to maintaining a quality human resource and setting them up for future work. Figure 1 represents the basic HR activities in SMEs and workflow of basic HR activities described in the below section.

5.1 Development of Business Process Model for Human Resource Strategy

The development of human resource strategy comprises the following subprocess represented in Fig. 2. Human Resource Development (HRD) has focused on developing the human resource capabilities of any organization. HRD plays an essential

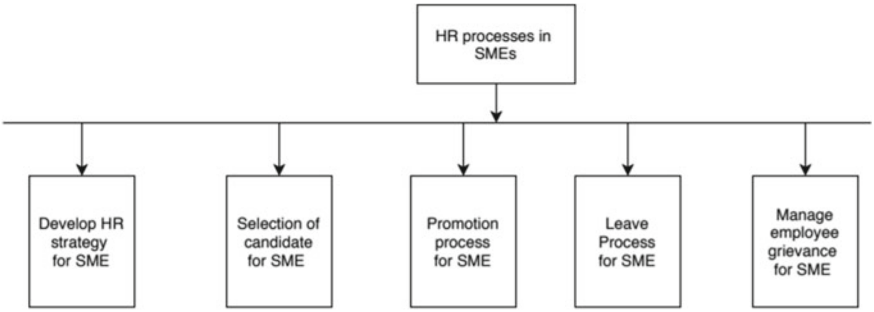


Fig. 1 HR business process model for SMEs

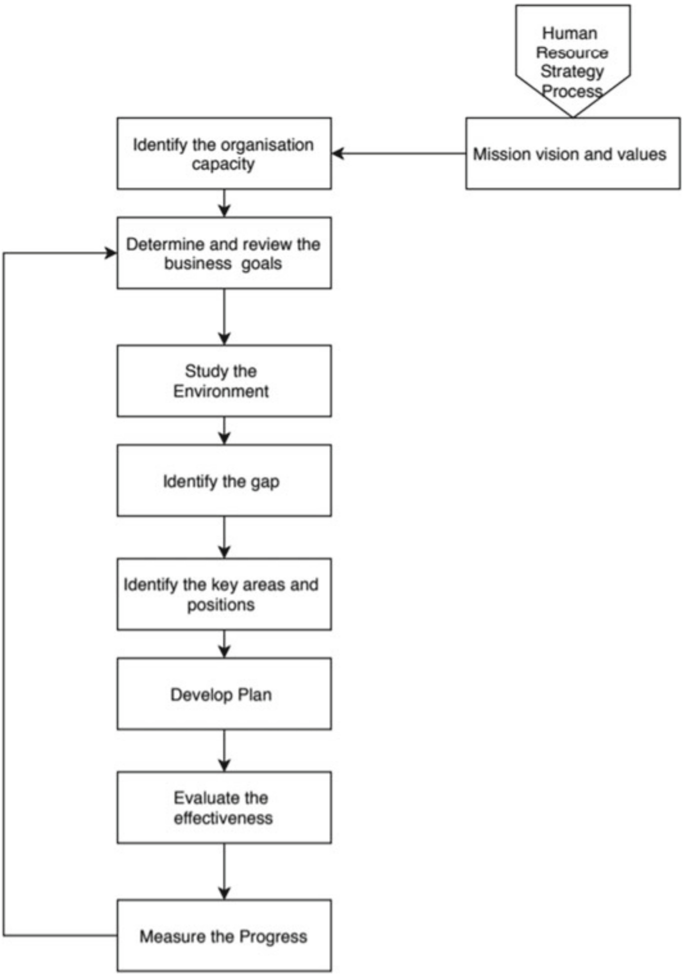


Fig. 2 Human resource business strategy process model

role in retaining employees and in obtaining and maintaining a competitive advantage in the market. A human resource development program requires proper planning and implementation to achieve efficiency and effectiveness. The planning and implementation process begin with the formulation of the human resources development strategy and ends with the evaluation.

HRD is a continuous process and will never be completed because, in terms of feedback, the training needs to be redesigned or modified to meet the company's production needs. The human resource process strategy formulation is in line with company goals and objectives of SMEs. The SWOT analysis was performed to identify internal and external factors. Then the organization should do the budgeting. Budgeting will conclude the strategy formulation step in the HRD process. The last stage is of Evaluation to measure the effectiveness of the plan.

5.2 Development of Business Process Model for Selection of Candidate

Recruitment involves face-to-face procedures and activities between the job seeker and the recruiter. It is a means of attracting and securing a position for the candidate. Recruitment consists of following steps and stages as described in Fig. 3.

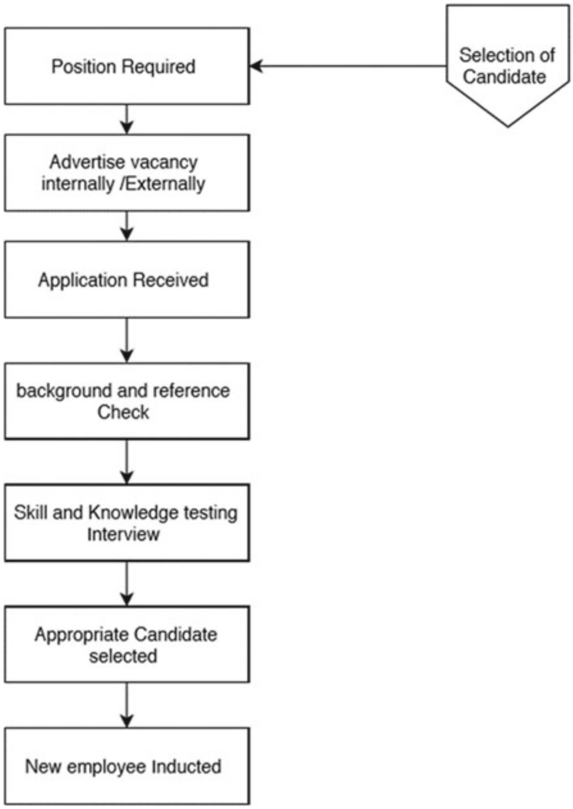
Here, the first organization provides information on the job offer (Internally/Externally). Then candidate submits the resume to the organization. After filtering the candidate resume organization finalizes the list of authorized candidates for the next procedure, as there will be a knowledge test, a technical interview. After completing the process, if the candidate agreed with the terms and conditions and salary negotiation, then the organization gives him/her an appointment letter.

5.3 Development Business Process Model for Promotion

The human resource department in the small and medium-sized organization determined which of your employees promoted. The HR department should have a reliable procedure for making the promotion decision. Promotion process consists of the following steps as explained in Fig. 4.

The organization provides information about the promotion process through the human resource department. Then the candidate fills employee performance appraisal form after the HR department evaluates the appraisal form of the candidate. Next process as there will be an interview with the top authority of the organization. Later completing this process HR department will take the decision which employee should promote and which employee shouldn't promote. Finally, the organization will give a promotion letter with feedback. The policies of promotion must be communicated with the employee. It will avoid confusion and misconceptions in the minds

Fig. 3 Business process Model for Recruitment and selection of candidate



of employees. Once they know the criteria to be followed for promotion, they can decide for themselves against those criteria. The possibility of reaching higher positions within an organization allows staff to use their skills fully. Promotion, therefore, means that the transfer of the staff member to another position with a higher qualification, another title, more responsibility, and a higher salary.

5.4 Development of Business Process Model for Leave

Leave management is the process of managing employee leave in time demand. Hence, it should be in a fair, accurate, and effective manner. Responsibility for processing employee leave requests rests on human resources personnel and employee managers. Figure 5 represents the business process modeling leave request for SMEs.

Whole leave requests have recorded through the leave application form. Prior applying for leave, worker must check the leave balance. At least two weeks before the

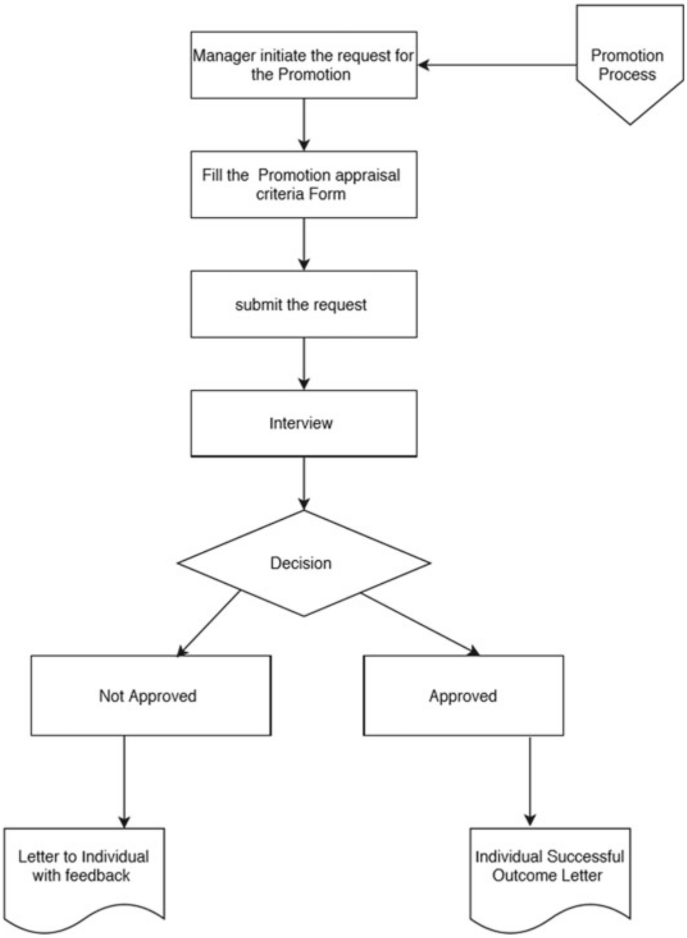


Fig. 4 Business process model for promotion process

leave date should be requested to assist with planning and operational requirements. In case the leave is unexpected, fill out the leave form and submit it to the HR department when the employee returns. Employee must fill in leave request to indicate the type of leave required. The completed leave request form is sent to HR through the supervisor for approval. HR department reviews the number of leave available for the employee before approving leave applications. Once the human resources department has confirmed the leave, the human resources staff will return a copy of the approved leave request to the employee. If leave is not confirmed human resources person returns a copy of the form to the employee explaining why leave was not permitted.

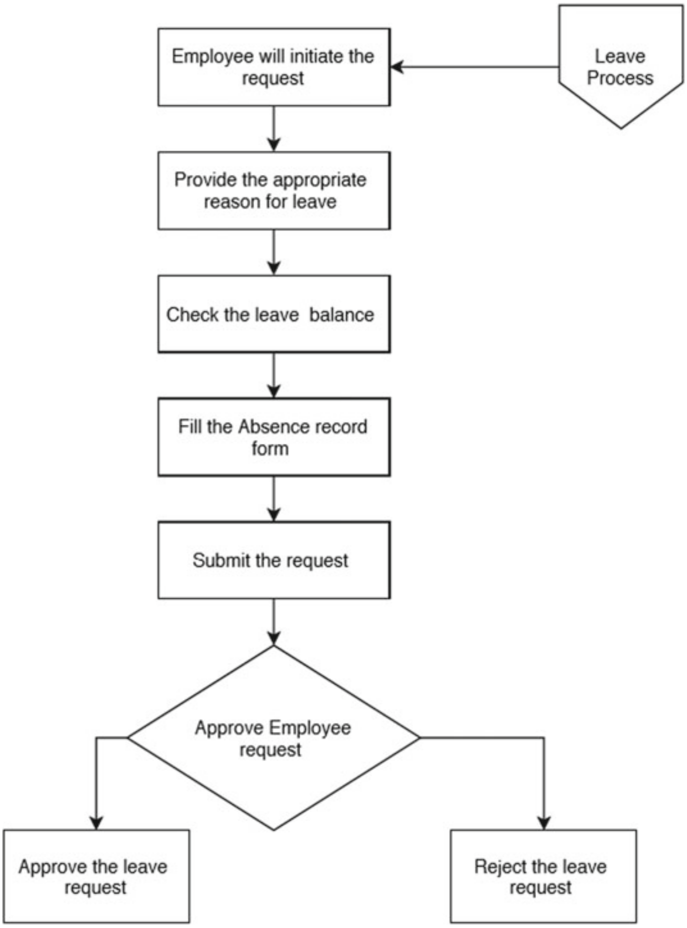


Fig. 5 Business process model for leave request

5.5 Development of Business Process Model for Employee Grievance

Staff complaints should be dealt with carefully and appropriately. A complaint may refer to the role of an employee, his workplace, or even another member of staff. The role of an HR professional in handling the complaint should be to resolve the problem quickly and efficiently. Figure 6 represents the business process modeling approach for handling the employee grievance.

Firstly, the HR department should tell the employee whom to contact if employee having the dissatisfaction. The next HR department takes some time to investigate the grievance. Then necessary action to hold the formal meeting with the employee to set out their grievance and provide the evidence to prove their grievance. After

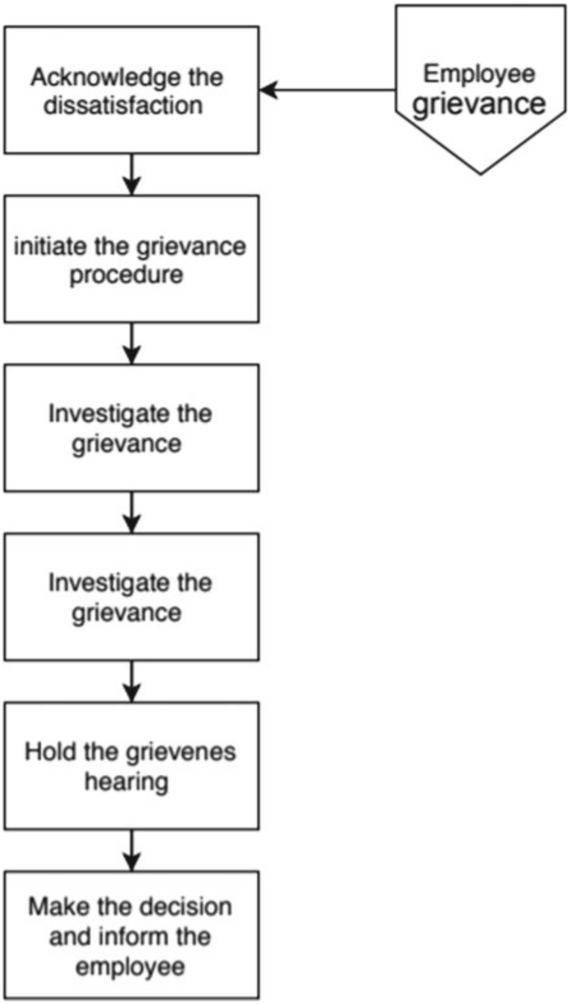


Fig. 6 Employee grievance management business process model

meeting with the employee, the HR professional will decide to accept or reject the grievance and inform the employee.

6 Result and Discussion

The human resource department plays an important role in the development of an organization. With economic globalization, markets have become more complex, competitive, and uncertain. Managing people is a difficult task. The most significant resources in the world are human resources. The business process modeling method is one of the latest techniques for managing human resources effectively. The human resource business modeling approach always helps to understand the overall human resource process of different activities. In the proposed human resource modeling approach, the human resource process language is converted into representation, such as a business process modeling symbol. Generally, BPMN is used to convey different information about business processes to different audiences. Functional diagram is used for explaining the human resource process in SMEs to describe the entire scenario through a series of activities. The developed HR business process model for SME, which helps to understand not only how it works even to a non-technical user but also it supports system architecture software developers in a better way.

This paper focused on the applicability of BPM on capturing the human resource activities in SMEs. All the HR activity's roles and flows level have been identified and represented in the graphical representation. In addition, the proposed business process model provides general and empirical guidelines for the data modeling requirements steps of the human resource management system. Another important feature of this paper is easy-to-understand strategies and techniques at modeling the business processes that can be used to model the same cases with more HR activities in SMEs.

7 Conclusion and Future Work

This paper provides a method of enabling human resource management strategies for SMEs from the perspective of business process modeling that has not been investigated before to the best of our knowledge. Our proposed BPM model refers to (1) Design the HR business process model for Small and Medium-sized Enterprises (SMEs). (2) Identify the HR process and its subprocess in SMEs. Future work includes the expansion of the proposed model by identification more HR activities in SMEs and its implementation.

References

1. Aguilar-Savén, R.S., Olhager, J.: Integration of product, process and functional orientations principles and a case study, pp. 375–389. APMS Kluwer (2002)
2. Aytuluna, S.K., Gunerib, A.F.: Business process modeling with stochastic networks. Int. J. Prod. Res. **46**(10), 2743–2764 (2008)
3. Barjis, J.: The importance of business process 28. Gunasekaran, A., Kubo, B. Modelling and modeling in software systems design. Science of analysis of business process reengineering. Comput. Program. **71**, 73–87 (2002)
4. Barrett, R., Mayson, S.: The formality and informality of HRM practices in small firms. In: International Handbook of Entrepreneurship and HRM, pp. 111–136 (2008)
5. Brocke, J., Rosemann, M.: Handbook on Business Process Management 1: Introduction, Methods, and Information Systems. Springer (2010)

6. Bryson, A., White, M.: HRM and small-firm employee motivation: before and after the great recession. ILR Rev. **72**(3), 749–773 (2019)
7. Cha, Y.: Global transfer of HR processes. Int. J. Digit. Content Technol. Appl. **7**(11), 422–428 (2013)
8. Ferner, A., et al.: Power, institutions and the crossnational transfer of employment practices in multinationals. Human Relat. **65**(2), 163–187 (2012)
9. Forth, J., Bewley, H., Bryson, A.: Small and Medium-sized Enterprises. Department of Trade and Industry (2006)
10. Gilman, M., Raby, S., Pyman, A.: The contours of employee voice in SMEs: the importance of context. Hum. Resour. Manage. J. **25**(4), 563–579 (2015)
11. Gunasekaran, A., Kubo, B.: Modelling and analysis of business process reengineering. Int. J. Prod. Res. **40**(11), 2521–3254 (2002)
12. Harney, B., Dundon, T.: Capturing complexity: developing an integrated approach to analysing HRM in SMEs. Hum. Resour. Manage. J. **16**(1), 48–73 (2006)
13. KPMG Insight into HRM Systems. https://www.kpmg.nl (2012)
14. Katz, J., Aldrich, H., Welbourne, T., Williams, P.: Human resource management and the SME: toward a new synthesis. Entrepreneur. Theory Pract. **25**, 7–10 (2000)
15. Ladislav, M., Ključnikov, A., Tvaronavičienė, M., Androniceanu, A.: Conceptual modelling of human resource evaluation process. Acta Polytechnica Hungarica **14**(7) (2017)
16. Lai, Y., Saridakis, G., Blackburn, R., Johnstone, S.: Are the HR responses of small firms different from large firms in times of recession? J. Bus. Ventur. **31**(1), 113–131 (2016)
17. Mendling, J.H., Reijers, A., Van der Aalst, W.M.P.: Seven process modeling guidelines (7PMG). Inf. Softw. Technol. **52**, 127–136 (2010)
18. OASIS: Web Services Business Process Execution Language Version 2.0. Committee Specification (2007)
19. OMG(b): Business process model and notation (BPMN 2.0), formal/2011–01–03. https://www.omg.org/spec/BPMN/2.0 (2011)
20. OMG: Unified Modeling Language: Superstructure, Technical Report Version 2.1.1 (2007)
21. Ozbilgin, M.F.: International Human Resource Management. Cambridge University Press (2014)
22. Sisodia, P., Wolfe, D.B., Sheth, J.: Firms of Endearment: How World Class Companies Profit from Passion and Purpose. Wharton School Publishing, Upper Saddle River, NJ (2007)
23. Smith, H., Fingar, P.: Business Process Management the Third Wave. Meghan-Kiffer Press (2002)
24. Strembeck, M., Mendling, J.: Modeling process-related RBAC models with extended UML activity models. Inf. Softw. Technol. **53**, 456–548 (2011)
25. Theiben, M., Hai, R., Marquardt, W.: A framework for work process modeling in the chemical industries. Comput. Chem. Eng. **35**(4), 679–691 (2011)
26. Van Dongen, B.F., van der Aalst, W.M.P., Verbeek, H.M.W.: Verification of EPCs using reduction rules and Petri nets. In: 17th Conference on Advanced Information Systems Engineering (2005)
27. Verma, N.: Business Process Management: Profiting from Process. Global India Publcations (2009)

Capability Enhancement in the Manufacturing Industry to Achieve Zero Defect

Narottam, K. Mathiyazhagan, and Pramod Bhatia

Abstract Manufacturing industries are continually facing the challenge of operating their production processes and systems to achieve the required production levels of high-quality goods while maximizing resource utilization. Zero Defects Manufacturing (ZDM) aims to go further than traditional six-sigma approaches. Traditional Six Sigma techniques have limitations in highly variable production contexts, characterized by small batch productions, customized or even product mix. Manufacturing and design capabilities are essential pillars of the organization. These consist of quality, cost, delivery, flexibility, process capability, and inspection capability. The inspection system plays an important role in achieving zero-defect in the process. Inspection capability and inspector certification are the resultant of an inspection system. Environment health and safety, people development, measurement systems, and continuous improvement systems are also important to achieve zero-defect. In this paper, we plan to improve the existing system to control defect flow-out to the customer end.

Keywords Zero-defect · Inspection capability · Quality · Cost · Delivery · MSA · Six sigma · Manufacturing

1 Introduction

In the technological world of new customer needs, new markets, innovation, and social change, there is a strong need to improve existing processes, serve existing customers, and develop new processes to meet customer satisfaction. Zero Defect and Zero Effect is the requirement of the customer. It generates a lot of pressure on the supplier and the Original Equipment Manufacturer (OEM) to meet the customer

Narottam · P. Bhatia
Department of Mechanical Engineering, The NorthCap University, Sec 23A, Gurugram, Haryana 122017, India

K. Mathiyazhagan (✉)
Department of Mechanical Engineering, Amity University Uttar Pradesh, Sec 125, Noida, UP, India
e-mail: kmathiyazhagan@amity.edu

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_50

requirement and remain competitive. The capability shows the strengths of the organization to compete in the global market. These are organization-specific and developed internally by the management approach towards customer satisfaction and competitiveness. People, training, and education, organizational focus, and Management Information System (MIS) are the major for manufacturing infrastructure [36]. Manufacturing outcomes and capabilities are cost, quality, dependability, and flexibility [39]. In this paper, various capability enhancement techniques are discussed to achieve zero defects in the manufacturing industry.

2 Literature Review

Oh and Rhee highlighted the manufacturer-supplier relationship for capability and technology development. Communication, new model development, problem-solving, strategic purchasing, supplier development are the five distinct categories for capability enhancement. Anand et al. study continuous improvement capability as a dynamic capability to improve the organization context and customer satisfaction. Manufacturing capability builds over time sequentially. It consists of quality, delivery, low cost, and manufacturing flexibility [23]. Competitiveness improves the cost capability to reduce manufacturing costs. New technology helps the manufacturer to focus on flexibility to meet customer requirements.

Szalavetz discussed the production, technological, innovation, and research & development capabilities. Production capability is defined as the capability of operation at a given level of technology [11]. Technological capability significantly improves the product and process than routine production activities [29]. Innovation and R&D capability improve new design features of products or processes and create new technology for production processes [7].

European commission discussed in the "factories of the future" work program 2019–20 about the capability development to achieve industry 4.0 and beyond. Flexible production, human capital, and customer–worker collaboration capability are essential for connecting humans, machines, and customers. Robust manufacturing methods are needed to support production and efficient working for novel products and many applications. Sharma and Chetiya discussed capability assessment and design capability for supplier development. These goals can be achieved by implementing Lean Six Sigma (LSS), and it would be a win-win situation for the supplier and customer [26]. The capability assessment must be done before starting the LSS project to know the potential of the project [4]. Sethi et al., using advanced manufacturing technology to improve the performance of a manufacturing firm. Technological capability building is one of the critical capability features of the organization. It includes the procurement of equipment, planning, plant start-up, improvement of production processes, product specification, and new design study.

Supplier development is focused through OEM engineers by visiting the supplier facilities to solve the critical issues and ensure product quality. Capability development activities are replicated on various suppliers through a hierarchy of practiced routines [30].

3 Parameters for Capability Enhancement in Indian Manufacturing Industries

Based on the above discussion and literature review, various types of capability were collected for improving manufacturing performance in the Indian industries. Six types of capabilities are selected for improving the manufacturing performance of the organization. These are Manufacturing, Design, Safety, Health, and Environment (SHE), people development and engagement system, a measurement system for quality and standardization, and continuous improvement capabilities.

The detailed analysis of types of capability study based on the literature review is explained below:

3.1 Manufacturing Capabilities

1. *Quality capability*: The definition of Quality is the ability of a product to meet customer requirements. The product must be conformance with the specification as per customer expectations. It should include aesthetics, durability, reliability, serviceability, and perceived quality. It can directly affect the performance of the organization. In a competitive environment, the customer is more focused on the quality and durability of the product. It also includes the performance of the product. The capability to produce high quality significantly depends on the product's design and process that fulfill customer expectations [17]. Quality capability serves as the base for all other capabilities, i.e.; if we work to improve quality abnormality, all other capabilities start behaving within specifications [16]. It also reduces rework generation, and the process becomes more stable and reliable. A quality improvement strategy can be beneficial for improvement in cost performance [34].
2. *Cost capability*: Cost is mainly the expenditures involved in the part of manufacturing. It involves raw material receiving to the dispatch of the product to the customer. Fixed overheads and variable overheads are also part of the cost. The manufacturing cost of the product can be reduced by controlling the defect and waste generation in a process. For remaining in the competition, we must focus on low-cost products [23]. If we reduce manufacturing costs without planning, it impacts other capabilities also. We can control cost capability from the development stage of the new product or process.

3. Delivery capability: Delivery of the product is time-based. It is an essential parameter in providing customer service. Manufacturing lead time and speed of delivery are important parameters of delivery capability [39]. By improving the product quality, we can reduce lead time, set-up time, and enhances delivery. So, manufacturing capabilities are interlinked, and one improves by improving the other capability. Reducing the cycle time of the process helps in higher productivity and fewer inventory levels. Thus, improving delivery capability gives direct benefits in cost and flexibility.
4. *Flexibility capability*: It is the ability to adopt changes. It consists of the manufacturing capability to offer high product and variant mix at a time to fulfill all volumes of the order. It serves each customer's unique needs by a flexible production operating system to handle specific customer needs and design variation [19]. Product and Volume flexibility is the need of the day. Cost and flexible capability are opposite to each other as they do not seem to support each other.

3.2 Design Capability

1. Process capacity (C_p): The statistical calculation of a process is the output of parts within a given time limit. A process capability diagram shows both the customer's voice as well as the process's voice. The process capability (C_p and C_{pk}) and process performance indices (P_p, P_{pk}, and C_{pm}) describe the process's current performance and provide statistical evidence to compare the post-adjustment results to the starting point [15]. C_p gives the ratio between USL-LSL tolerance and process spread, as shown in Fig. 1. If the distribution is ±3 standard deviations, a process that is distributed normally and exactly halfway between the specification limits will yield a C_p of 1. The commonly accepted minimum value for C_p is 1.33—this varies from one industry to another, but the greater the number, the better the capability. C_{pk} calculates the absolute distance between the mean and the nearest specified limit. The C_{pk} value over 1.33 is needed, but

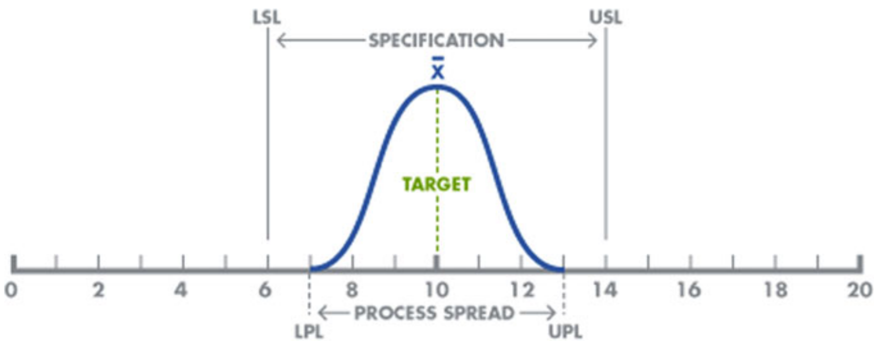


Fig. 1 Capability analysis representation of a normally distributed process

this differs for industries. C_{pk} considers the centering of the process, unlike C_p. C_{pk} offers a standard measurement along with C_p for assigning an initial process capability to center on specification limits.

2. Inspection capability:

   (a) Kappa analysis: It is a measure used to test the interrater agreement between the categorical variable.

   Let $P_0 =$ Sum of observed proportion in the diagonal cell
   $P_e =$ the sum of expected proportion in the diagonal cell.
   Then
   Kappa $= \frac{P_0 - P_e}{1 - p_e}$, Kappa is a measure rather than a test.
   This analysis determines the differences between appraises decisions about the good parts as good and bad parts as bad. But, it does not tell how the measurement system selected good parts from bad parts. For comparing the appraiser's decision, reference value or known value is taken as master value.

   (b) *Gauge R&R*: Gage Repeatability and Reproducibility (R&R) tools are part of measurement systems analysis (MSA); used to ensure that team members and equipment can accurately collect process and physical item data required to perform computations. Gage precision and accuracy and gage/survey operator training is tested. Additionally, survey/form/test questions that tend to produce inaccurate results are highlighted. A Gage R&R study's primary objective is to calculate variability in the measurement. A secondary purpose of the Gage R&R analysis is to isolate the variability contributions from different sources—what or who is causing the problems.
   (c) Inspector certification: Inspection certification is done based on the poison test, in which some defective and good parts are mixed and checked by the inspectors. Based on the inspector's decision, pass/fail criteria matched, and the passing candidate becomes a certified inspector.
   (d) Operator by the part matrix: In this technique also the different parts and operators mixed to make the decision of good and reject part.

3.3 Environment, Health, and Safety Systems

The environment, health, and safety are the general guidelines to work in a healthy and safe environment. These ensure proper analysis of risk during operation and hazard identification. There are general guidelines and industry-specific guidelines available based upon which we can work in a risk-free environment. OHSAS 18001 and ISO 14001 are the central management systems for EHS. They highlighted the company's systematic approach, discipline, and dedication towards a safe workplace.

This management system helps the process of producing zero-defect in the following ways:

- Identifies hazards and associated risks as early as possible in the project cycle or facility development. It can also improve the site selection process, product design process, the layout of workstations, facility modification, etc.
- Activity specific plans for improving and carry out a specialized work environment.
- Understand the magnitude and likelihood of the risk.
- Preparing workers and nearby community for any type of accident and health attack to provide first-aid.
- Prioritization of risk management with the objective of zero accident and zero impact on the environment.
- Elimination of the cause of the hazard at its source. The elimination is not feasible, then provides engineering and management control to minimize the possibility and magnitude of risk.

3.4 People Development and Engagement System

Work dynamics have altered, and many organizations are beginning a drastic shift from mechanistic working models to more knowledge-intensive communities [3, 9]; Employees are more likely to engage in organizational decision-making, seek diverse participation in organizational activities and regularly identify job contexts where they feel and treated with dignity [8]. As a result, conventional models of hierarchical and valid authority practices are questioned, as a new era of employees enters the shop floor [6, 8, 28].

Employee engagement is the process of boosting the morale of employees to achieve organizational outcomes in a cognitive, emotional, and behavioral manner [33], promising to maintain and even enhance competitive advantages across multiple organizational levels [10]; this type of competitive advantage is important for the success of the organization.

Trahant states that "highly-engaged employees are twice as likely as less-engaged person to be top performers in their organizations; three-quarters of highly engaged employees exceed or far exceed job performance expectations". New skills and competencies are not predominantly guided by industrial systems but are built through interaction [24].

3.5 Measurement Systems for Quality and Standardization

For a quality measurement system and standardization, Total Quality Management (TQM) principles are used by the organization. These are the basic principles for quality management and customer satisfaction. Total employee involvement, customer focus, and continuous improvement are vital pillars of the organization's top management approach. The eight principles of TQM are explained below.

1. *Customer Focus*: This is the basic principle of TQM in which the objective is taken to satisfy the customer. The abnormality and consequences happening at the customer end must close on a priority basis, and the customer also takes care of the supplier's concerns.
2. *Leadership*: Top management involvement and their guidelines for quality management are essential. They lead the organization to build internal capability to satisfy customer needs. Strong management and leadership will result in zero defects.
3. *Involvement of People*: All departments have an equal role in quality management and suggestions to improve quality. The material and production department has a similar function as a quality department to satisfy the customer.
4. *Process Approach*: Quality audits should be the process-centric to solve the problem. The process must be appropriately analyzed to eliminate the bottlenecks to improve quality and to achieve zero-defect.
5. *System Approach to Management*: The identification and selection of the problem will be based on customer concerns. The standard operating procedures and work instructions must be followed. Their revision and new technology up-gradation should be taken care of timely by the concerned department.
6. *Continual Improvement*: It is a continuous journey of the firm to satisfy the customer and sustain profitability. The Plan-Do-Check-Act (PDCA) cycle should be running continuously by taken the small changes to improve the process.
7. *Factual Approach to Decision Making*: The management's decision should be based on the information gathered through the data. The process behavior and abnormality are interrelated and must be encountered based on the data information.
8. *Mutually Beneficial Supplier Relationships*: The customer and suppliers are interdependent. Both have to improve the organization's value in terms of customer satisfaction and profitability. Their mutual understanding gives an excellent result to satisfy the customer and the end-user.

3.6 Continuous Improvement Capability

LSS is an expansion of the applicability of the Six Sigma. It is a set of procedures and techniques whose primary purposes are to minimize variance, eradicate duplication, and improve efficiency. It consists of five phases to complete the project, i.e., DMAIC (define, measure, analyze, improve, and control). Other continuous improvement tools and techniques are also used for enhancing the capability of the organization. These are explained in Fig. 2. These are the essential tools used in the manufacturing industries for improving the competitiveness and capability of the organization.

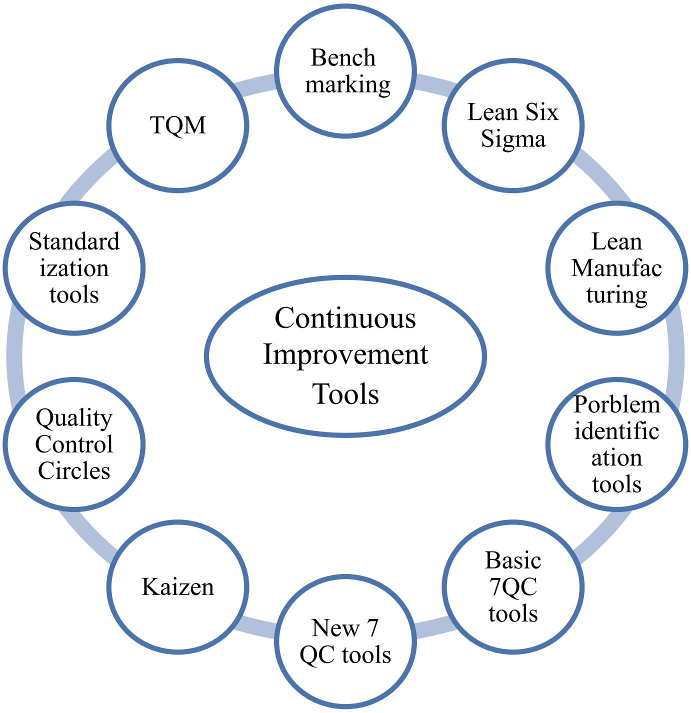


Fig. 2 Tools used for continuous improvement

4 Conclusion

Manufacturing capabilities and their links to other capabilities play an important role in the growth of the organization. This helps in reducing cost and improving quality to remain competitive in the global environment. Customer–supplier relations also improve through close coordination on the improvement process and ensuring zero-defect product. Flexibility capability improves customer faith due to product mix demand and fixes infrastructure at the supplier end.

Process capability study is the basis for improving the design of the product or process. The capability index value highlights the scope of improvement in the process. The analysis of the capability index shows the voice of the customer and the voice of the process. Measurement system analysis and gauge repeatability and reproducibility study improve the inspection capability by reducing the measurement system's error. The poison test improves the attribute inspection system through the training of the operators through the certification process.

Environment, health, and safety system are also essential for a customer–supplier relationship. Various quality management standards (OHSMS 45001, ISO 14001) support and upgrade this as a pillar for the organization towards a safe workplace. Training and education, employee engagement, and other organizational activities keep improving the employees' knowledge and skills. Leadership improves productivity, organizational behavior, and job performance by engaging people. Highly engaged employees are giving a good performance as compared to less engaged employees.

Quality measurement and standardization are also crucial for improving and maintaining the process performance. Total quality management principles improve customer–supplier relation and top management approach towards building the capability of the organization. Eight principles of TQM are discussed in the quality management system. Continuous improvement tools and techniques also strengthen the organization's capability for problem analysis and solving. The potential of the problem must be calculated before starting the LSS project. It will improve the continuous improvement capability of the organization.

The capabilities enhancement of Indian organizations discussed in this paper are as follows: manufacturing capability, design capability, people engagement, and development system, a measurement system for quality, standardization, and continuous improvement. These are the key capability for customer–supplier relations and improving profitability and market share in the Indian industries.

5 Limitations and Future Scope

The capabilities discussed above are selected through a detailed literature review and tested in various organizations through a survey questionnaire. The author wants to summarize these capabilities for Indian manufacturing industries. These methodologies can be implemented in Indian organizations to improve customer–supplier relationships to achieve zero-defect at the customer end. These capabilities can be implemented combined with the customer for better results.

References

1. Anand, G., Ward, P.T., Tatikonda, M.V., Schilling, D.A.: Dynamic capabilities through continuous improvement infrastructure. J. Oper. Manage. **27**(6), 444–461 (2009)
2. Antony, J.: Six sigma for service processes. Bus. Process Manag. J. (2006)
3. Adler, P.S.: Market, hierarchy, and trust: the knowledge economy and the future of capitalism. Organ. Sci. **12**(2), 215–234 (2001)
4. Albliwi, S., Antony, J., Lim, S.A.H., van der Wiele, T.: Critical failure factors of Lean Six Sigma: a systematic literature review. Int. J. Qual. Reliab. Manage. (2014)
5. Aydarov, D., Klochkov, Y., Ushanova, N., Frolova, E., Ostapenko, M.: Developing plans for QFD-based quality enhancement. In: Syst. Perform. Manage. Anal, pp. 241–249. Springer, Singapore (2019)
6. Beck, J.: Independent workforce theory: Implications for HRD. Hum. Resour. Dev. Int. **6**(1), 21–41 (2003)
7. Bell, M., Figueiredo, P.N.: Innovation capability building and learning mechanisms in latecomer firms: recent empirical contributions and implications for research. Can. J. Dev. Stud. **33**(1), 14–40 (2012)

8. Burke, R.J., Ng, E.: The changing nature of work and organizations: Implications for human resource management. Hum. Resour. Manage. Rev. **16**(2), 86–94 (2006)
9. Cho, Y., Cho, E., McLean, G.N.: HRD's role in knowledge management. Adv. Dev. Hum. Resour. **11**(3), 263–272 (2009)
10. Christian, M.S., Garza, A.S., Slaughter, J.E.: Work engagement: a quantitative review and test of its relations with task and contextual performance. Pers. Psychol. **64**(1), 89–136 (2011)
11. Cohen, W.M., Levinthal, D.A.: Absorptive capacity: a new perspective on learning and innovation. Adm. Sci. Q. **35**(1), 128–152 (1990)
12. Creswell, J., Plano Clark, V.: The foundations of mixed methods research. In: Creswell, J., Plano Clark, V. (eds.) Designing and Conducting Mixed Methods Research, pp. 19–52. Sage, London (2011)
13. Eger, F., Coupek, D., Caputo, D., Colledani, M., Penalva, M., Ortiz, J.A., Freiberger, H., Kollegger, G.: Zero defect manufacturing strategies for reduction of scrap and inspection effort in multi-stage production systems. Procedia CIRP (2018)
14. El Souri, M., Gao, J., Owodunni, O., Simmonds, C., Martin, N.: Improving design for manufacturing implementation in knowledge intensive collaborative environments: An analysis of organisational factors in aerospace manufacturing. In: 2017 IEEE Technology & Engineering Management Conference (TEMSCON), pp. 448–454. IEEE (2017)
15. Erdogan, A., Canatan, H.: Literature Search Consisting of the Areas of Six Sigma's Usage (2015)
16. Ferdows, K., De Meyer, A.: Lasting improvements in manufacturing performance: in search of a new theory. J. Oper. Manage. **9**(2), 168–184 (1990)
17. Größler, A., Grübner, A.: An empirical model of the relationships between manufacturing capabilities. Int. J. Oper. Prod. Manage. (2006)
18. Hallowell, R.: The relationships of customer satisfaction, customer loyalty, and profitability: an empirical study. Int. J. Serv. Ind. Manage. (1996)
19. Hill, T., Portioli staudacher, A.: Trade-off scenarios within the context of a manufacturing strategy. In: ONE WORLD? ONE WIEW OF OM? The Challenges of Integrating Research and Practice, vol. 1, pp. 129–139. SGE Editoriali (2003)
20. Hoe, L.C., Mansori, S.: The effects of product quality on customer satisfaction and loyalty: Evidence from Malaysian engineering industry. Int. J. Ind. Mark. **3**(1), 20–35 (2018)
21. Kasiri, L.A., Cheng, K.T.G., Sambasivan, M., Sidin, S.M.: Integration of standardization and customization: impact on service quality, customer satisfaction, and loyalty. J. Retail. Consumer Serv. **35**, 91–97 (2017)
22. Korkala, M., Maurer, F.: Waste identification as the means for improving communication in globally distributed agile software development. J. Syst. Softw. **95**, 122–140 (2014)
23. Li, L.L.X.: Manufacturing capability development in a changing business environment. Ind. Manage. Data Syst. (2000)
24. Lucas, R.: On the mechanics of development planning. J. Monetary Econ. **22**(1), 3–42 (1988)
25. Mcmillan, J.H.: Educational Research: Fundamentals for the Consumer, 6th edn. Pearson, USA (2012)
26. Nicholas, M.D.: Six Sigma and the media. ASQ Six Sigma Forum Mag. **7**(2), 10–12 (2008)
27. Oh, J., Rhee, S.K.: The influence of supplier capabilities and technology uncertainty on manufacturer-supplier collaboration. Int. J. Oper. Prod. Manage. (2008)
28. Pink, D.H.: Free Agent Nation: How America's New Independent Workers are Transforming the Way We Live. Warner Books, New York, NY (2001)
29. Radosevic, S., Yoruk, E.: Why do we need a theory and metrics of technology upgrading? Asian J. Technol. Innov. **24**(sup1), 8–32 (2016)
30. Sako, M.: Supplier development at Honda, Nissan and Toyota: comparative case studies of organizational capability enhancement. Ind. Corp. Change **13**(2), 281–308 (2004). https://doi.org/10.1093/icc/dth012https://doi.org/10.1093/icc/dth012
31. Sethi, A.P.S., Khamba, J.S., Kiran, R.: Technological capability building in Indian manufacturing industry: an empirical study on the role of technology adoption and adaptation process. Int. J. Serv. Oper. Manage. **7**(2), 252–274 (2010)

32. Shuck, B., Reio, T.G., Jr.: The employee engagement landscape and HRD: how do we link theory and scholarship to current practice? Adv. Dev. Hum. Resour. **13**(4), 419–428 (2011)
33. Shuck, B., Wollard, K.: Employee engagement and HRD: a seminal review of the foundations. Hum. Resour. Dev. Rev. **9**(1), 89–110 (2010)
34. Skinner, W.: The productivity paradox. Harvard Bus. Rev. **64**(4), 55–59 (1986)
35. Snee, R.D.: Lean Six Sigma—Getting better all the time. Int. J. Lean Six Sigma (2010)
36. Swink, et al.: An exploratory study of manufacturing practice and performance interrelationships. Int. J. Oper. Prod. Manage. (2005)
37. Szalavetz, A.: Industry 4.0 and capability development in manufacturing subsidiaries. Technol. Forecast. Soc. Change **145**(May), 384–95 (2019). https://doi.org/10.1016/j.techfore.2018.06.027
38. Thienhirun, S., Chung, S.: Influence of list of values on customer needs, satisfaction, and return intention in ethnic restaurants. J. Hospital. Mark. Manage. **26**(8), 868–888 (2017)
39. White, G.P.: A meta-analysis model of manufacturing capabilities. J. Oper. Manage. **14**(4), 315–331 (1996)

Analysis of the Challenges of Industry 4.0-Enabled Sustainable Manufacturing Through DEMATEL Approach

Bala Sai Prathipati, Anbesh Jamwal, Rajeev Agrawal, and Sumit Gupta

Abstract In the present conditions, Industry 4.0-enabled sustainable manufacturing practices can affect whole business system by methods for changing the techniques the things are organized, made, passed on and discarded. Industry 4.0 is reasonably novel to making nations, especially in India and necessities an obvious definition for fitting understanding and practice in business. This paper intends to analyse the key challenges to Industry 4.0-enabled sustainable manufacturing. Decision-making trail & evaluation laboratory (DEMATEL) Process is used to analyse challenges of Industry 4.0-enabled sustainable manufacturing. This work is exceptionally valuable for experts, approach producers, administrative bodies and directors to build up an inside and out comprehension of Industry 4.0 activities and destroy the potential difficulties in receiving Industry 4.0 activities for sustainability.

Keywords Industry 4.0 challenges · Sustainable manufacturing · DEMATEL

1 Introduction

The modern computerization level in assembling division is additionally similarly lower in India. From administrative perspectives, the selection of Industry 4.0 based ideas in assembling is in its early stage in India when contrasted with different areas like car, administration the executives, food, vitality and force [1]. Indian government trying to build up the economy and create business openings so as utilizing Industry 4.0 and present-day data innovations in assembling condition, brilliant urban community's advancement and Digital India activity. For growing best class producing foundation in India, the "Make in India" activity must be combined with "Industry 4.0". Along these lines, it is significant for assembling area in India as a rising economy to manage the different difficulties to Industry 4.0 activities in creating environmental,

B. S. Prathipati · S. Gupta (✉)
Department of Mechanical Engineering, ASET, Amity University, Noida, UP 201313, India
e-mail: sumitgupta2007@gmail.com

A. Jamwal · R. Agrawal
Department of Mechanical Engineering, Malaviya National Institute of Technology, Jaipur, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_51

social, monetary supportability of flexible chain. The principal goal of this work is to perceive key difficulties in Industry 4.0 activities for achieving maintainability direction in flexibly chains.

2 Literature

In the course of recent years, modern frameworks are affected incredibly by the presentation of the Internet-of-Things (IoT) and Cyber Physical systems [2]. The idea of Industry 4.0 was presented by Hanover Messe in 2011. Industry 4.0 can be comprehended as the "shrewd assembling" or "incorporated industry" has the capacity to impact the entire business regarding items are structured, make and conveyed and so on [3]. Sustainable production philosophy is developed in the twentieth century, which considers no longer simplest the environment like inexperienced manufacturing; but all different factors together with social and economic. Garbie [4], Garetti and Taisch[5] explicitly nation that the 3 pillars of sustainability consist of social, surroundings and monetary. Molamohamadi and Ismail [6] advise to feature generation, schooling, ethic and accountability alongside side the precept 3 pillars of social, surroundings and financial (Table 1).

3 Evaluation of the Industry 4.0 Adoption Challenges in the Indian Industry to Determine Their Relative Importance Using DEMATEL

The finalized industry 4.0 adoption barriers were evaluated using DEMATEL, whose relative importance was invaluably identified through expert input. A simplified classification is formed using expert inputs. This classification has three different levels: Evaluating the industry 4.0 adoption challenges for relative importance (Class-1), the three categories of challenges (Class-2) and ten specific challenges (Class-3) as shown Fig. 1.

Pairwise interrelation is defined for both categories of challenges and the specific challenging factors using expert's input through DEMATEL Scale. This way of Interrelation matrix for categories of challenges are summarized below from Tables 2, 3, 4 and 5. This gives the inter-relation between categories of challenges Pairwise Analysis matrix for "Economical Challenger" categories of Industry 4.0 challenges. This is the direct relation matrix.

Now normalized matrix is calculated from direct relation matrix by dividing each term with maximum value of Sum of a_{ij}, this is shown in Table 3.

Each term of this normalized matrix is undergone by this formula, $T = X(X - 1)^{-1}$ which is calculated through MATLAB to get total relation matrix. This is shown in Table 4.

Table 1 Challenges of Industry 4.0-enabled Sustainable manufacturing

S. No.	Challenges	Description	References
1	High introductory expense for ecological inviting bundling (A1)	The significant expense for bundling of items limits its appropriation among the association	[7, 8, 11]
2	Poor administration duty for appropriation of maintainability (A2)	The insignificant contribution of top administration specialists towards maintainability selection prompts SSCM execution disappointments	[9, 10]
3	Ineffectual linkage of maintainability with existing procedure structure (A3)	By and large, the administration can't connect manageability inside the current store network process structure	[9, 11, 12]
4	Struggle among item supportability arrangement and organized commerce arrangements (A4)	There exists irreconcilable circumstance between the item manageability strategy and organized commerce arrangements which impacts supportability appropriation	[9, 13, 14]
5	Inaccessibility of variable structure for SSCM appropriation (B1)	Absence of accessibility of proper SSCM structure goes amiss the association from accomplishing supportability in production network	[7, 14–16]
6	Absence of attention to economical gauges for crude materials (B2)	It is very basic to know about existing manageable measures of crude material in setting to the providers	[9, 17, 18]
7	High establishment cost (B3)	The high removal costs confine the association from receiving manageability in production network	[9, 18–20]
8	Absence of successful correspondence with providers (C1)	It is critical to have solid and continuous correspondence with the provider by following authoritative exercises to wipe out the generation delay	[6, 20, 23]
9	Absence of powerful worker commitment and strengthening (C2)	Characterized inclusion of worker in administrative exercises and offering strengthening improves their effectiveness and supports SSCM appropriation	[20, 23, 24, 25]
10	Ineffectual provider choice techniques (C3)	Determination of proper provider is important to create wanted manageable items	[7, 11, 21, 22]

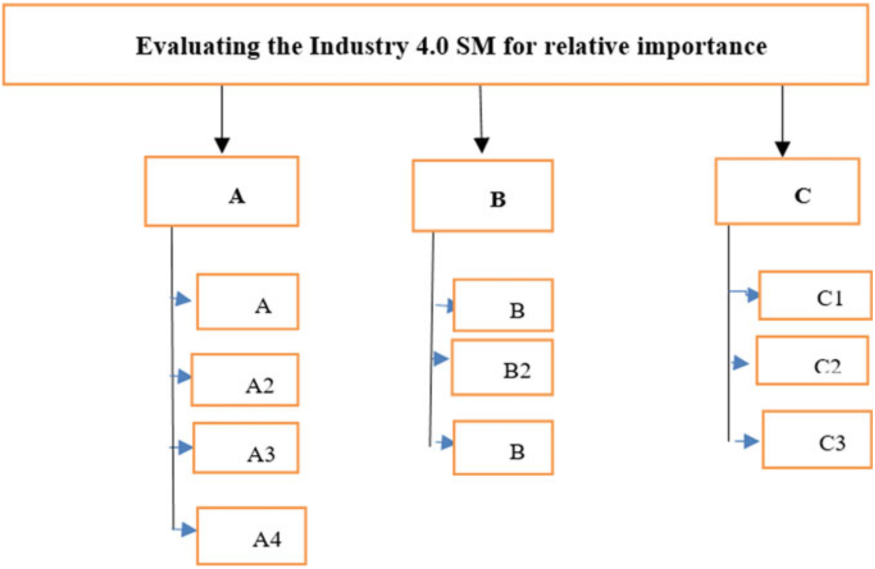


Fig. 1 The developed decision hierarchy of barriers to adopting industry 4.0

Table 2 Direct relation matrix

Challenges	A1	A2	A3	A4	Sum of a_{ij}
A1	0	4	3	2	9
A2	1	0	3	2	6
A3	4	1	0	3	8
A4	4	1	2	0	7

Table 3 Normalized matrix

Challenges	A1	A2	A3	A4
A1	0	0.44	0.33	0.22
A2	0.11	0	0.33	0.22
A3	0.44	0.11	0	0.33
A4	0.44	0.11	0.22	0

Table 4 Total relation matrix

Challenges	A1	A2	A3	A4	*D*
A1	1.4413	1.3961	1.5658	1.3609	5.7641
A2	1.1874	0.7706	1.2069	1.0491	4.214
A3	1.7278	1.1603	1.2567	1.3801	5.5249
A4	1.5849	1.0643	1.3182	1.0178	4.9852
R	5.9414	4.3919	5.3478	4.8079	

Table 5 Inter-relation matrix

Challenges	D	R	$D-R$	$D+R$	Rank
A1	5.7641	5.9414	−0.1773	11.7055	1
A2	4.214	4.3919	−0.1779	8.6059	4
A3	5.5249	5.3476	0.1773	10.8725	2
A4	4.9852	4.8079	0.1773	9.7931	3

Now the inter-relation matrix if formed to determine the inter-relationship and there ranking for the challenges (Table 5).

The maximum value in $D+R$ column gives the most interrelated challenges hence are ranked accordingly. The negative value in $D-R$ tells the enabler is dependent on other challenges which are represented by positive sign. Pairwise analysis matrix for "Social Challenger" category challenges to the implementation of Industry 4.0 is shown in Tables 6, 7, 8 and 9. Pairwise Analysis matrix for categories of industry 4.0, This is the direct relation matrix.

Now normalized matrix is calculated from direct relation matrix by dividing each term with maximum value of Sum of a_{ij}, this is shown in Table 7

Each term of this normalized matrix is undergone by this formula, $T = X(X-1)^{-1}$. which is calculated through MATLAB to get total relation matrix. This is shown in Table 8.

Table 6 Direct relation matrix

Challenges	B1	B2	B3	a_{ij}
B1	0	2	3	5
B2	1	0	3	4
B3	1	2	0	3

Table 7 Normalized matrix

Challenges	B1	B2	B3
B1	0	0.4	0.6
B2	0.2	0	0.6
B3	0.2	0.4	0

Table 8 Total relation matrix

Challenges	B1	B2	B3	D
B1	0.6379	1.3793	1.8103	3.8275
B2	0.6897	0.8966	1.5517	3.138
B3	0.6034	1.0345	0.9828	2.6207
R	1.931	3.3104	4.3448	

Table 9 Inter-relation matrix

Challenges	D	R	$D - R$	$D + R$	Rank
B1	3.8275	1.931	1.8965	5.7585	3
B2	3.138	3.3104	−0.1724	6.4484	2
B3	2.6207	4.3448	−1.7241	6.4655	1

Now the inter-relation matrix is formed to determine the inter-relationship and there ranking for the challenges (Table 9).

The maximum value in $D + R$ column gives the most interrelated challenges hence is ranked accordingly. The negative value in $D - R$ tells the challenges are dependent on other factors which are represented by positive sign. Pairwise analysis matrix for "Environmental Challenger" category of challenges to the implementation of Industry 4.0 is shown in Table 10. Pairwise Analysis matrix for categories of Industry 4.0 challenges: This is the direct relation matrix.

Now normalized matrix is calculated from direct relation matrix by dividing each term with maximum value of Sum of a_{ij}, this is shown in Table 11.

Each term of this normalized matrix is undergone by this formula, $T = X(X - 1)^{-1}$ which is calculated through MATLAB to get total relation matrix. This is shown in Table 12.

Now the inter-relation matrix is formed to determine the inter-relationship and their ranking for the challenge as shown in Table 13.

The maximum value in $D + R$ column gives the most interrelated challenges hence are ranked accordingly. The negative value in $D - R$ tells the challenges is dependent on other challenges which are represented by the positive sign (Table 14).

This study shows that empowering agents and hindrances have been gathered through on the web and introduced in the wake of approving the information by factual investigation for vital usage of Industry 4.0 sustainable manufacturing. Although it isn't to give equivalent consideration to all the empowering influences and boundaries simultaneously, it will be valuable to recognize causal connections

Table 10 Direct relation matrix

Challenges	C1	C2	C3	a_{ij}
C1	0	3	2	5
C2	3	0	2	5
C3	3	3	0	6

Table 11 Normalized matrix

Challenges	C1	C2	C3
C1	0	0.6	0.4
C2	0.6	0	0.4
C3	0.6	0.6	0

Table 12 Total relation matrix

Challenges	C1	C2	C3	*D*
C1	−6.9375	−6.5625	−5.0000	−18.5
C2	−6.5625	−6.9375	−5.0000	−18.5
C3	−7.5000	−7.5000	−6.0000	−21
R	−21	−21	−16	

Table 13 Inter-relation matrix

Challenges	*D*	*R*	$D - R$	$D + R$	Rank
C1	−18.5	−21	2.5	−39.5	1
C2	−18.5	−21	2.5	−39.5	2
C3	−21	−16	−5	−37	3

Table 14 Global ranking of Industry 4.0 challenges

Categories of challenges	Specific challenges	$D + R$ value	Relative rank	Global ranking
Economical	A1	11.7055	1	1
	A2	8.6059	4	4
	A3	10.8725	2	2
	A4	9.7931	3	3
Social	B1	5.7585	3	7
	B2	6.4484	2	6
	B3	6.4655	1	5
Environmental	C1	−39.5	1	8
	C2	−39.5	2	9
	C3	−37	3	10

in every one of the empowering agents and hindrances separately as it will help in distinguishing and concentrating on basic empowering agents and obstructions. There is a need to think of appropriate models as contextual investigations executing manageability with respect to how the issues rose at the appointed time of time and how they were reasonably handled. Identification of basic empowering influences and boundaries to supportable fabricating is a pivotal advance towards supportability execution in the assembling area.

4 Conclusion

Sustainable product layout is ready to create merchandise which, despite the fact that maximizing their monetary and social influences, limit any harmful results they will have on the environment. As SM technology keep to progress from fast prototyping to production, more new substances emerge as to be had, and more than one cloth technologies are evolved to the point where complicated multi-fabric production great assemblies may be made, the field of product layout desires to evolve in parallel in order to meet higher the needs of rising sustainable layout trends. This research is limited to the automobile sector. Similar study can be done in machinery, process and electrical manufacturing companies. Survey-based research is also be performed in various manufacturing companies.

References

1. Council, B.B.: Skill development for Industry 4.0. In: A White Paper by BRICS Skill Development Working Group (2017)
2. Wollschlaeger, M., Sauter, T., Jasperneite, J.: The future of industrial communication: automation networks in the era of the internet of things and industry 4.0. IEEE Ind. Electron. Mag. **11**(1), 17–27 (2017)
3. Askary, Z., Singh, A., Gupta, S., Shukla, R.K., Jaiswal, P.: Development of AHP framework of sustainable product design and manufacturing of electric vehicle. In: Advances in Engineering Design, pp. 415–422. Springer, Singapore (2019).
4. Garbie, I.H.: An analytical technique to model and assess sustainable development index in manufacturing enterprises. Int. J. Prod. Res. **52**(16), 4876–4915 (2014)
5. Garetti, M., Taisch, M.: Sustainable manufacturing: trends and research challenges. Prod. Plan. Control **23**(2–3), 83–104 (2012)
6. Molamohamadi, Z., Ismail, N.: Developing a new scheme for sustainable manufacturing. Int. J. Mater. Mech. Manuf. **1**(1), 1–5 (2013)
7. Eltayeb, T.K., Zailani, S., Ramayah, T.: Green supply chain initiatives among certified companies in Malaysia and environmental sustainability: investigating the outcomes. Resour. Conserv. Recycl. **55**, 495–506 (2011). https://doi.org/10.1016/j.resconrec.2010.09.003https://doi.org/10.1016/j.resconrec.2010.09.003
8. Singh, A., Askary, Z., Gupta, S., Sharma, A.K., Shrivastava, P.: AHP Based model for evaluation of sustainable manufacturing enablers in Indian Manufacturing Companies. In: Advances in Industrial and Production Engineering, pp. 397–403. Springer, Singapore (2019)
9. Ghisellini, P., Cialani, C., Ulgiati, S.: A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. J. Clean. Prod. **114**, 11–32 (2016). https://doi.org/10.1016/j.jclepro.2015.09.007https://doi.org/10.1016/j.jclepro.2015.09.007
10. Gupta, S.: Some issues in sustainable manufacturing: a select study of Indian manufacturing companies, Doctoral dissertation, MNIT, Jaipur (2016)
11. Lee, J., Kao, H.A., Yang, S.: Service innovation and smart analytics for industry 4.0 and big data environment. Procedia CIRP **16**, 3–8 (2014)
12. Gupta, S., Dangayach, G.S., Singh, A.K., Meena, M.L., Rao, P.N.: Adoption of sustainable supply operation quality practices and their impact on stakeholder's performance and sustainable performance for sustainable competitiveness in Indian manufacturing companies. Int. J. Intel. Enterp. **5**(1–2), 108–124 (2018)

13. Valiaveetil, J.J., Singh, S., Jain, A., Gupta, S.: Design and development of an online process measurement system for zero defect production. In Advances in Industrial and Production Engineering, pp. 791–800. Springer, Singapore (2019)
14. Basl, J.: Pilot study of readiness of Czech companies to implement the principles of Industry 4.0. Manage. Prod. Eng. Rev. **8**(2), 3–8 (2017)
15. Gupta, S., Dangayach, G.S., Singh, A.K., Rao, P.N.: Analytic hierarchy process (AHP) model for evaluating sustainable manufacturing practices in Indian electrical panel industries. Procedia-Soc. Behav. Sci. **189**, 208–216 (2015)
16. Mathur, B., Gupta, S., Meena, M.L., Dangayach, G.S.: Impact of supply chain practices on organizational performance with moderating effect of supply chain performance in Indian Health Care industry. Int. J Sup. Chain. Mgt **7**(4), 30 (2018a)
17. Gupta, S., Dangayach, G.S., Singh, A.K., Meena, M.L. Rao, P.N.: Implementation of sustainable manufacturing practices in Indian manufacturing companies. Benchmark.: Int. J. **25**(7), 2441–2459 (2018b)
18. Kiel, D., Müller, J., Arnold, C., Voigt, K.I.: Sustainable industrial value creation: benefits and challenges of Industry 4.0. In ISPIM Innovation Symposium, p. 1. The International Society for Professional Innovation Management (ISPIM) (2017)
19. Jaiswal, P., Kumar, A., Gupta, S.: Prioritization of green manufacturing drivers in Indian SMEs through if-TOPSIS approach. U.P.B. Sci. Bull. Ser. D **V80**(2), 277–292 (2018)
20. Khan, M., Wu, X., Xu, X., Dou, W.: Big data challenges and opportunities in the hype of Industry 4.0. In: 2017 IEEE International Conference on Communications (ICC), pp. 1–6. IEEE (2017).
21. Mathur, B., Gupta, S., Meena, M.L., Dangayach, G.S.: Healthcare supply chain management: literature review and some issues. J. Adv. Manage. Res. **15**(3), 265–287 (2018b)
22. Aggarwal, A., Gupta, S., Ojha, M.K.: Evaluation of key challenges to Industry 4.0 in Indian context: a DEMATEL approach. In: Advances in Industrial and Production Engineering, pp. 387–396. Springer, Singapore (2019)
23. Almada-Lobo, F.: The Industry 4.0 revolution and the future of manufacturing execution systems (MES). J. Innov. Manage. **3**(4), 16–21 (2016)
24. Singh, M., Arora, R., Ojha, A., Sharma, D., Gupta, S.: Solid waste management through plasma arc gasification in Delhi: a step towards Swachh Bharat. In: Advances in Industrial and Production Engineering, pp. 431–440. Springer, Singapore (2019)
25. Dawson, T.: Industry 4.0—Opportunities and challenges for smart manufacturing. https://blog.ihs.com/q13-industry-40-opportunities-and-challenges-for-smart-manufacturing. Last accessed 14 Nov 2017 (2014)

Six Sigma in Piston Manufacturing

A. Vamsikrishna, Medha Shruti, and S. G. Divya Sharma

Abstract Process improvement is a key for any company to make profits and improve their quality standards. One of the widely used techniques to do process improvement is by implementation of Six Sigma. In this paper, a Six Sigma analysis was done to reduce the scrap and rework of pistons which are rejected in order to improve the quality and decrease the wastage from money invested. The process variations of skirt diameter and pinhole diameter were controlled by changing a few manufacturing parameters which produced good results.

Keywords Lean manufacturing · Six sigma · Fishbone diagram · Control charts

1 Introduction

Process improvement stands for identifying, analyzing and improving the existing manufacturing processes so as to fulfil the criteria of new standards of quality and also to carry out the optimization techniques for increasing the profit of the organization's Process improvement is very necessary in every company as it identifies the bottlenecks in all the processes in production, reduces completion time of the projects, wastage, scrap production and thereby improves quality and efficiency. There are many process improvement techniques out of which one of the most widely used techniques is the Six Sigma (DMAIC) approach. J. P. C Tong et al. have applied the Six Sigma techniques for process improvement of production of Printed circuit boards and have received positive results [1]. Chin Hung et al. have implemented six sigma in a food manufacturing industry and have reduced defect rate by 70% from baseline for small custard buns [2]. Antony et al. have mentioned the different ingredients of six sigma for understanding the DMAIC process in a good manner [3]. Antony et al. have also implemented six sigma in an automotive industry and improved the first pass yield from 85 to 99.4% [4]. Evans et al. have highlighted the importance of six sigma and how it is used in general electric company [5]. Valles

A. Vamsikrishna · M. Shruti · S. G. Divya Sharma (✉)
Department of Mechanical Engineering, Amrita School of Engineering, Amrita Vishwa Vidyapeetham, Bengaluru, India
e-mail: sg_divya@blr.amrita.edu

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_52

et al. have studied the rejections of inkjet printer cartridges then applied six sigma for process improvement and reduced the rejections by 50% [6]. Gijo et al. have applied six sigma techniques in the honing process in an automobile industry and have proved to improve the first pass yield from 88 to 100% [7]. Kumar et al. have applied the DMAIC process and reduced production of leaking gloves by 50% [8]. Prabhu et al. implemented DMAIC on manufacturing of submersible pumps and improved sigma level quality from 3.90 to 3.97 [9]. Kumar et al. have implemented DMAIC in the piston manufacturing industry and have proved to reduce scrap and save around Rupees 52 lakhs/annum [10]. Priya et al. applied Six sigma and eliminated few non-value-added activities in the automotive manufacturing industries [11].

As said by Kumar et al. [10], even in industries such as piston manufacturing industries, Six Sigma concepts are implemented. Pistons are used in many engines such as automobile engines, marine engines, aircraft engines, etc. Hence it becomes very necessary to produce good quality pistons for good performance. The factors that can result in low-quality pistons are improper machining, improper casting, improper finishing, improper material selection, etc. Many pistons that are manufactured have multiple defects where a lot of scraps are produced and reworks are done. Pistons may be rejected due to improper skirt diameter, improper pinhole diameter, presence of blowholes, improper crown finish, cavity, skirt quality, etc. Hence, data from leading piston manufacturing MNC was taken for performing Six Sigma analysis to improve the quality. The Six Sigma process consists of basically five steps, i.e., Define, Measure, Analyze, Improve and Control [DMAIC].

1.1 Define

In this step the actual problem, scope of a project, scope of improvement, goal, etc., are defined. Identifying the problem plays a vital role in improving the process. Techniques like critical path analysis, SIPOC (Supplier-Input-Process-Output-Customers), risk assessment, cost of quality, etc., are used to carry out this step.

1.2 Measure

This step basically aims to gather data about some process which will be considered as a metric for comparison with the results obtained after implementing certain changes. In this step, we should make sure that the data collected are relevant to the defined purpose, the correct CTQs (Critical to quality) are considered, the data collected must be accurate and precise and the right data sampling technique is chosen.

1.3 Analyze

In this step, the major root causes of the problem are to be found for elimination. A Fishbone diagram is initially drawn to understand the various influencing factors and tools like Pareto charts are used to figure out the highly influencing factors, i.e., potential causes for the problems are found. Further, detailed process maps are created to magnify on where exactly the root causes stay.

1.4 Improve

In this step, ideas are implemented in order to eliminate the root causes as analyzed from the previous step. The easiest and simplest solutions are considered at first and if the complexity of the root cause is high, then complex solutions like implementation of Design of Experiments (DOE) are done to overcome the problem.

1.5 Control

In this step, tools like control charts are used to check whether the processes are within the control limit. This is to ensure that the new ideas implemented have produced results on the processes and also is used to compare the results after implementation of new ideas before the implementation of new ideas.

2 Problem Statement

Time and money invested in rework of rejected pistons and eliminated piston scrap is too high. There are a lot of variations found in that control charts considered for the analysis which is not a good sign for any process.

3 Methodology

There are many lines in the piston manufacturing, hence a Pareto chart was plotted in order to check for the line with the highest number of rejections. Further another Pareto chart was plotted to figure out what are the reasons for which the highest number of rejections happened in that particular line. If the reason was found related to dimensions, then a control chart (Mostly X-bar and R chart is used) was plotted to look for the points out of control. Then, a fish-bone diagram is drawn for that particular reason of rejection and the potential cause is targeted and improved. Then again control charts are drawn to verify that all the points are in control. The above steps include all the steps of Six Sigma, i.e., DMAIC.

4 Results and Discussions

There were around 15 different lines in which the pistons were manufactured. It was necessary to know the line in which the highest number of pistons were rejected. If this information can be found, then this particular line could be further targeted for the process improvement. Hence, with the data, a Pareto chart was plotted.

From the graph, it was found that the line '11-5c' had the highest number of rejections. But this line can't be chosen for analysis because it was an automated manufacturing line and more involved in casting. The programming involved for the automation must be revised for analysis on this line and much scope for process improvement was not found here. Hence the line '13-MLVD' was considered for further analysis as this has the highest number of rejections after '11-5c'. In the line '13-MLVD', pistons were rejected for various reasons. Improper skirt diameter, improper pinhole diameter, improper surface finish, improper crown finish, etc., are few reasons for which the pistons were rejected. So, it was necessary to find the defect for which the highest number of pistons were rejected. Hence, a Pareto analysis was done again to find the potential defect for rejections.

From this graph, it was found that skirt diameter variation and improper pinhole diameters are major defects as they are the reasons for the highest number of rejections. So, these parameters were considered for further analysis. Hence, fishbone diagrams were drawn for each case to understand the root causes (Fig. 1).

For further analysis, variable control charts become very important as only these charts can show us clearly how the process variation happens. Most prominently used variable control charts are X-bar and R charts and X-bar and S charts. When the number of sample measurements are less, X-bar and R chart is preferred while X-bar and S chart is preferred when the number of samples are more. Since the number of sample measurements were less, we used X-bar and R chart for checking process variations.

Generally, pistons are not round in shape, but are oval and are not parallel sided, but tapered. They are manufactured in oval shape in order to cope up with the thermal expansions and side loads on the skirt. Pistons have tapered sides such that the crown end will have a lesser diameter. This is because an allowance must be given to the crown end of the piston for thermal expansions. Also, it is to be noted that the tolerance limit will be around 20 microns which is very critical. Hence, these make it hard for a piston to have proper skirt diameter. Hence, an X-bar and R chart was plotted to study the process variations of skirt diameter as shown in Fig. 2.

It can be seen from the graph that there is a point out of control limit in the R chart. Hence, a fishbone diagram was drawn to find the potential cause for having such kind of process variations. Looking at the different causes, DOE was performed

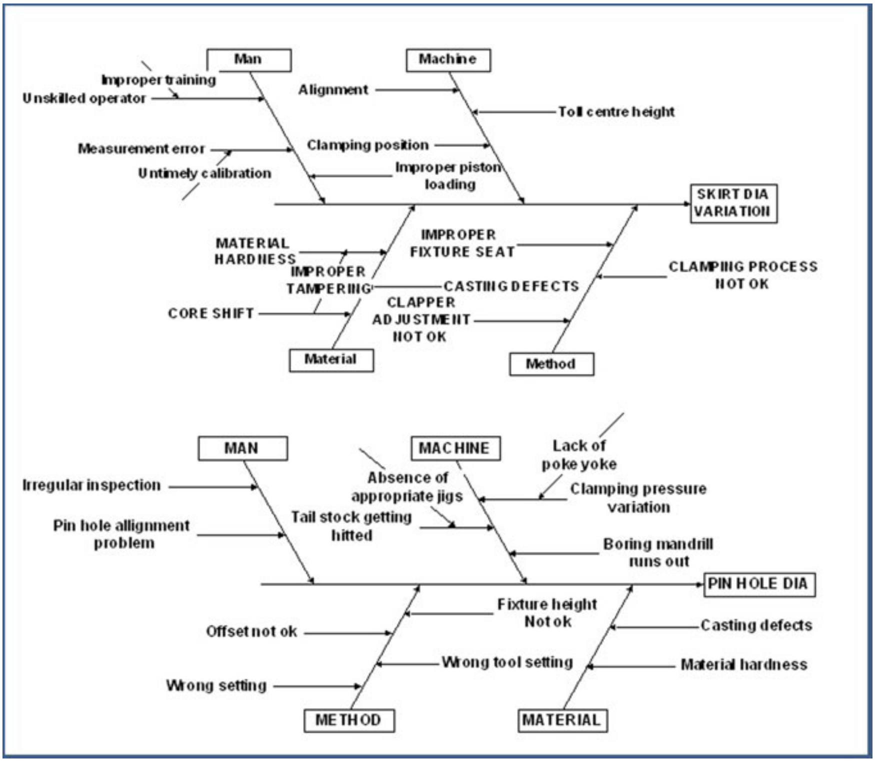


Fig. 1 Fishbone diagrams for skirt and pinhole diameter variations

and it was decided to check for the results at 0.26 mm/rev but there were no positive results found. Further, it was decided to change the feed rate to 0.29 mm/rev. The respective control chart is shown in Fig. 3.

It can be noted that we use WECO rules to determine if the control charts are in control. WECO stands for Western Electric Company, who set out some rules in order to analyze the control charts. According to these rules, dots out of control limit, 2 out of 3 dots that are 2 sigmas away from control line, 4 out of 5 dots between 1 and 2 sigmas away from control line, 8 consecutive dots between control line and 1 sigma away from it, 6 continuous dots upward or downward and 14 dots in a row alternating up and down shows that the given control chart is not in control. It is necessary to consider all the rules of WECO to tell if a given chart is in control or not.

Hence the process variations are in control with respect to the skirt diameter. So, a feed rate of 0.29 mm/rev is an appropriate one for the skirt diameter variation to be in control. Other factors of the fishbone diagram can be neglected as a change in feed rate has caused a significant improvement in scrap reduction.

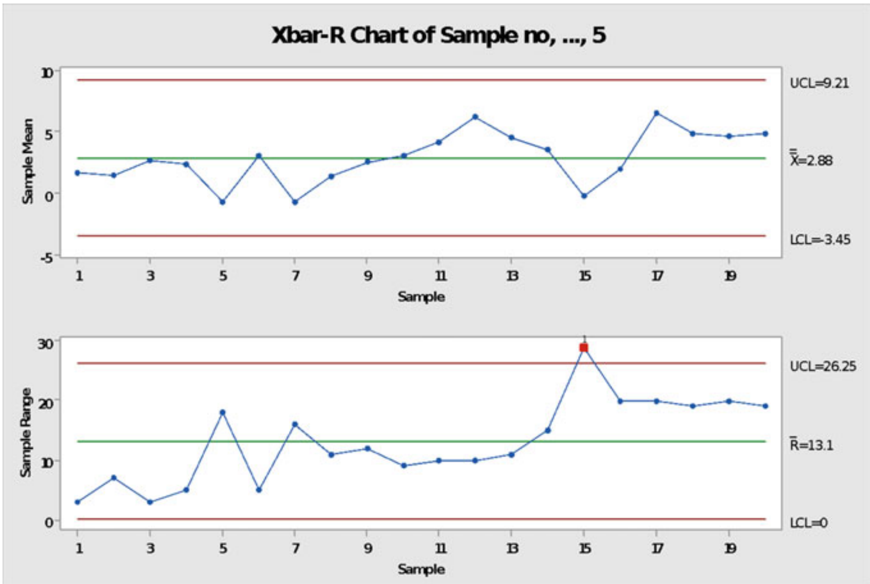


Fig. 2 X-bar and R chart of skirt diameter variations

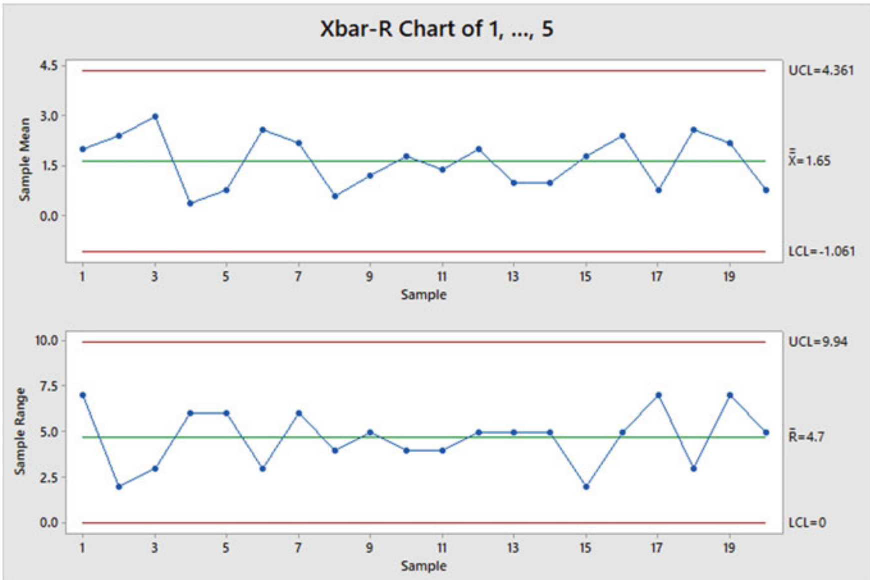


Fig. 3 X-bar and R chart for skirt diameter variation at a feed rate of 0.29 mm/rev

The process variations of pinhole diameter analysis were continued. Rejections due to improper pinhole diameter are due to inner diameter variations, pinhole not being a perfect circle, i.e., the hole being oval in shape, high roughness, etc. The number of rejections found due to this reason was second highest in the MLVD line. So, process optimization is very necessary for this aspect. Hence, an X-bar and R chart was plotted for the same as shown in Fig. 4.

It can be inferred from the R chart of the X-bar and R chart that pinhole diameter variations are out of the control limits. Hence, a fishbone diagram was drawn to understand the various reasons for the same. Having discussions with industry experts on the fishbone diagram, DOE was performed and it was concluded that usage of old mandrel for manufacturing is the major cause for these rejections. Hence it was decided to change the mandrel and proceed further. After changing the mandrel, an X-bar and R chart was again plotted to study the process variations due to pinhole diameter. It is shown in Fig. 5.

It is clearly visible from the graph that the process is completely in control as per WECO rules. Hence, changing the mandrel has produced good results in controlling the process variations due to pinhole diameter.

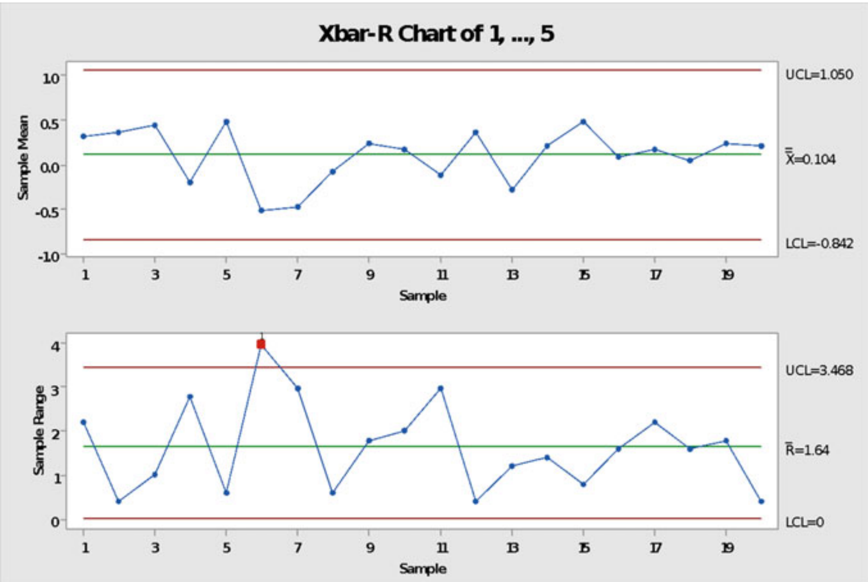


Fig. 4 X-bar and R chart for pinhole diameter variations without changing mandrel

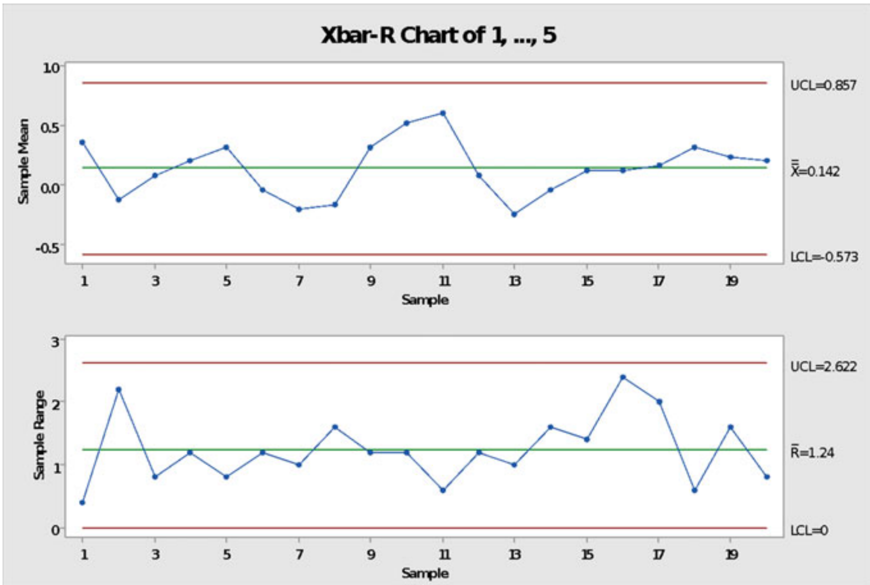


Fig. 5 X-bar and R chart for pinhole diameter variations after changing the mandrel

5 Conclusions

Therefore, implementation of DMAIC has proven to be helpful and productive. Feed rate was a potential factor that influenced the production of pistons with proper skirt diameter. Optimum feed rate was hence very necessary for the production of good pistons. Changing of mandrel in regular intervals was also necessary to produce pistons with tolerable pinhole diameter. Also, further research on other parameters mentioned in the root cause analysis may help in further reduction of scrap and rework of pistons which can be considered as further scope of research for this work.

References

1. Tong, J.P.C., Tsung, F., Yen, B.P.C.: A DMAIC approach to printed circuit board quality improvement. Int. J. Adv. Manuf. Technol. **23**(7–8), 523–531 (2004)
2. Hung, H.C., Sung, M.H.: Applying six sigma to manufacturing processes in the food industry to reduce quality cost. Sci. Res. Essays **6**(3), 580–591 (2011)
3. Antony, J., Banuelas, R.: Key ingredients for the effective implementation of Six Sigma program. Measur. Bus. Excell. **6**(4), 20–27 (2002)
4. Antony, J., Gijo, E.V., Childe, S.J.: Case study in Six Sigma methodology: manufacturing quality improvement and guidance for managers. Prod. Plann. Control **23**(8), 624–640 (2012)
5. Henderson, K.M., Evans, J.R.: Successful implementation of Six Sigma: benchmarking general electric company. Benchmarking Int. J. (2000)

6. Valles, A., Sanchez, J., Noriega, S., Nuñez, B.G.: Implementation of Six Sigma in a manufacturing process: a case study. Int. J. Indus. Eng. **16**(3), 171–181 (2009)
7. Gijo, E.V., Scaria, J.: Reducing rejection and rework by application of Six Sigma methodology in manufacturing process. Int. J. Six Sigma Compet. Adv. **6**(1–2), 77–90 (2010)
8. Jirasukprasert, P., Garza-Reyes, J.A., Kumar, V., Lim, M.K.: A Six Sigma and DMAIC application for the reduction of defects in a rubber gloves manufacturing process. Int. J. Lean Six Sigma **5**(1), 2–21 (2014)
9. Prabu, K., Makesh, J., Raj, K.N., Devadasan, S.R., Murugesh, R.: Six Sigma implementation through DMAIC: a case study. Int. J. Process Manage. Benchmark. **3**(3), 386–400 (2013)
10. Kumar, D., Kaushish, D.: Scrap reduction in a piston manufacturing industry: an analysis using six sigma and DMAIC methodology. IUP J. Operat. Manage. **14**(2), 7 (2015)
11. Priya, S.K., Jayakumar, V., Kumar, S.S.: Defect analysis and lean six sigma implementation experience in an automotive assembly line. Mater. Today Proc. **22**, 948–958 (2020)

Adopting Shop Floor Digitalization in Indian Manufacturing SMEs—A Transformational Study

Gautam Dutta, Ravinder Kumar, Rahul Sindhwani, and Rajesh Kumar Singh

Abstract The objective of this paper is to enumerate a study of the transformation of a brownfield manufacturing facility producing Electro-Mechanical Devices (EMD). Essentially this study can be termed as a testimonial for "Digitalize and Transform" initiative. A Production Digital Twin was developed leveraging the IIoT ready shop floor and adopting appropriate digital technologies. The proven DES model and digital twin methodology can be leveraged for future simulations to support market variability. Discrete Event Simulation (DES) method was deployed to create digital models of the shop floor resources and their interplay to help explore the plant characteristics and optimize its performance. The digital simulation model was integrated with the shop floor IIoT framework in a closed-loop, to run experiments and what-if scenarios with variable input parameters. Using this setup, physical shop floor and the digital simulation model share operational data in a continuous closed-loop to provide decision support for improving plant operations. EDM manufacturer's target was to set up a re-usable DES model to arrive at actionable insights those can help them improve assembly line performance and get ready for the variable demand and product variants that subsequently would help them in driving business and profitability. Significant improvements were realized across all operational indicators—efficiency, quality, productivity and flexibility. Manufacturing SMEs across India are implementing IIoT and data analytics with the objective of acquiring real-time data thus enabling quick and accurate decision making. The closed-loop discrete event simulation methodology has the potential of enhancing IIoT investments further. Especially in the post-COVID scenario, when manufacturers are challenged with disrupted supply-chain, inconsistent demand and manpower shortages, this methodology can help execute shop-floor plans efficiently with optimum resources.

Keywords Simulation · Digital · IIoT

G. Dutta (✉) · R. Kumar · R. Sindhwani
Department of Mechanical Engineering, Amity University Uttar Pradesh, Sector 125, Noida, Uttar Pradesh, India
e-mail: dutta.gautam4@googlemail.com

R. K. Singh
Management Development Institute, Gurgaon, Haryana, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_53

1 Introduction

India's manufacturing SMEs are striving to find its place in the new global order. In its transformational journey, Industry 4.0 is playing a pivotal role. Manufacturing SMEs equipped are aspiring to update their existing older generation assets with IIOT [8] and take advantage of digital technologies like simulation, cloud and data analytics [9]. It is also significant to note that mass customization needs are increasing across industry verticals and the advantage of scale is constantly eroding [34] Thus, manufacturing SMEs have an opportunity to compete with their larger counterparts, provided they achieve productivity gains, innovate with smarter offerings at competitive cost structure, gain market share and achieve profitability. With digitalization, these gains are not one time, the resulting integration across entire value chains facilitates continuous optimization of processes, resulting in sustainable, lean practices.

The objective of this paper is to enumerate a study of digitalizing an old manufacturing facility producing Electro-Mechanical Devices (EMD) used for controlling electrical transmission. The EMD manufacturing facility that once used to produce industrial control products for the local market has been transformed into a highly efficient digital factory, by implementing a combination of digital technologies, catering to local and global demand of electromechanical devices. This EMD facility emulates two major objectives—firstly, localizing global devices and making them available locally and secondly, to leverage innovation opportunities and deliver low-cost innovative devices for the developing countries to fulfill their electrification needs. Adoption of digitalization helped the manufacturer engage with customers globally and integrate with its supplier value chain more efficiently. In the digitalized manufacturing facility, the products and machines communicate with each other and most processes are IT optimized, resulting in high-quality and reliable output [33].

Essentially, this study can be termed as a testimonial for "Digitalize and Transform" initiative. Adoption of appropriate digital technologies in shop floor processes enables advanced capabilities like production digital twin [24]. This in turn enables EMD facility assets & resources to be connected to the virtual twin of physical assets and systems to help perform variety of simulations in the "what if" scenarios (see Fig. 1). Based on the learnings from this transformational study, this research paper studies how the Industry 4.0 technologies like IIOT, simulation, system integration and methodologies like discrete event, closed-loop and digital twin can be combined to help manufacturers meet their emerging business needs of efficiency, productivity, quality and mass customization.

1.1 EMD Manufacturing—Organizational Brief

EMD Manufacturing (henceforth called EMD) produces low voltage electrical switching devices. Their product portfolio includes protection devices such as circuit

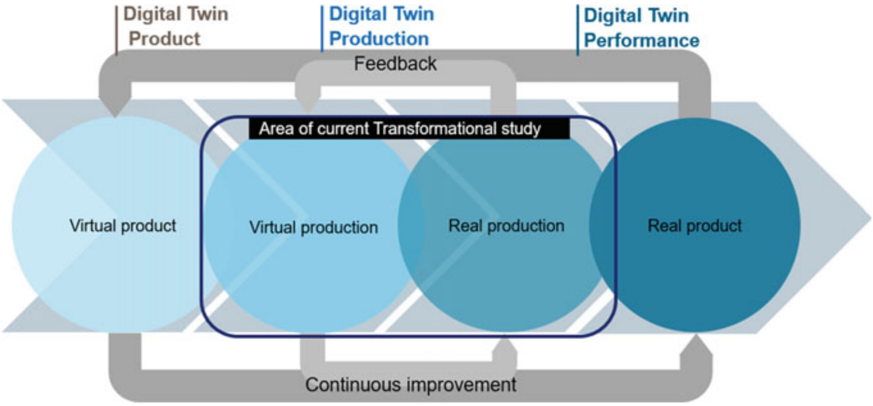


Fig. 1 Production digital twin—virtual twin of physical production assets and simulated model

breakers, miniature circuit breakers, residual current protection devices, fuse systems and overvoltage protection devices, switching devices and switch disconnectors. A typical device of this nature provides over and under-voltage protection, safe isolation and local and remote switching. These devices are deployed from homes to industrial installations and therefore, diverse variants of different ratings and sizes are required to fulfill the breadth of demand. A typical device of this nature consists of several static and moving parts, electronic controls, all encompassed in molded casings. A logical flow of assembly sequences based on individual device designs need to be followed to manufacture these devices. Varying batch sizes of device variants are assembled in a defined sequence with assembly operations allocated to automatic, semi-automatic and manual-assisted assembly stations in a line which is equipped with computer-controlled conveyor.

Most stations of the assembly line are automated and equipped with Programmable Logic Controllers (PLC). These PLCs are preprogrammed to carry out specific operations allocated to the workstation of the assembly line. It continuously monitors and receives information from input devices or sensors, processes the information and triggers the connected automation devices to complete the task designated for the specific assembly station in the EMD assembly line. The line PLCs have been integrated to IIOT systems to upgrade legacy automation and allow remote access, data streaming and monitoring. Before digitalization, the EMD line had the capacity to produce more than 70 variants of switchgears manufactured across 3 separate production lines and the intent of the transformation project was to enhance it substantially in order to cater to the increasing market demand for variants.

2 Relevance, Objectives and Challenges

2.1 Literature Survey to Establish Relevance and Gaps

A literature survey was undertaken to understand the practical aspects of adopting digital technologies to upgrade brownfield manufacturing facilities [13], essentially to address the market demands of [32] mass-customized [23] goods, establishing global quality standards and regulations, while continuing to be profitable. This literature survey intended to further understand interventions that can be undertaken in a shop floor, based on data and analytics [4]. Continuous interventions are facilitated by acquisition of real-time manufacturing data [7] from production equipment and workstations, outfitted with IIoT sensors [27] and data gateways [5]. Insights from various simulations [17] can help identify workstations prone to cause bottlenecks [18].

Surveyed research papers established that implementation of IIOT helps data-based [28] decisions [16], especially to address shop-floor issues. There are observations of reluctance on the part of manufacturers to invest [2], as they are not clear how to use insights to intervene and improve the operational metrics [15] of speed, efficiency, quality and flexibility [6]. The literature survey also targeted subjects like closed-loop methodology involving data and analytics driving simulation, validation, optimization and automation [19]. Digital twin is an emerging technology [29] which is changing the way products and processes are continuously validated and optimized. Literature survey included this subject matter to understand both the product digital twin and production digital twin [20] and its elements.

A manufacturing-related research cannot overlook today's special circumstance of COVID-19. While the operations across geographies are reopening, they need to adapt to a new normal in the post-COVID world [14]. Three focus areas can help navigate their transition from the crisis point to this new normal—employee safety, managing risk and managing performance while ensuring physical distancing [10]. The literature survey highlighted the scarce understanding related to adoption of digital technologies by manufacturing SMEs in the post-COVID scenario to manage this transition and face the new normal.

The literature survey indicates that while past research has extensively addressed benefits and challenges of implementing various digital technologies in companies of different sizes, studies addressing the inter-dependence of technology and processes are few [26]. One area where more research will help the manufacturing fraternity, especially those belonging to small and medium business segment, is to establish how a typical manufacturing facility can leverage digital technologies like IIOT analytics and closed-loop simulation to improve and optimize operations.

2.2 Objectives of Digitalizing the EMD Facility

This study establishes the following set of new digital capabilities for the EMD facility. IIoT and machine networking was implemented in its shop floor complemented with digital product definition in its engineering function. To build upon this investment further, need was to develop an efficient digital factory.

Digital capabilities of the EMD facility are expected to integrate the virtual model of the assembly line with real production assets thus establishing a digital twin framework and perform operational simulations. The data streaming is expected to be bi-directional. In one direction, to acquire feedback from physical EMD assembly line into its virtual model to fine-tune the digital twin using real production data and machine downtimes, i.e., MTTR & MTBF and improve performance using a calibrated digital twin of production with higher level of confidence. In the other direction, to get insights as inputs from virtual model to real assembly line to analyze constraints and critical assets, run simulations for alternative scenarios, perform diagnostics, identify defective assets, perform root-cause triggering predictive maintenance and undertake performance monitoring to continuously improve.

2.3 Identified Improvement Areas

EMD proposed an enhanced digitalization plan to leverage its existing investments of IIoT implementation in its factory floor and digital product definition capability in its engineering function. It was expected that digitalization will help EMD to engage with customers globally and integrate with supplier value chain more efficiently [22]. It was expected that digitalization will make EMD facility scalable and be agile with its capacity to manufacture more device variants and be in tune with dynamic market needs. The improvements to be realized included improved efficiency, quality, flexibility and reduced time-to-market.

3 Digital Twin of the EMD Assembly Line

3.1 Step 1: Discrete Event Simulation (DES)

Discrete-Event Simulation (DES) helps model the functioning of a system as a sequence of discrete events in time. Each event occurs at an instant in time and marks a change of state in the system [30]. It is assumed that between consecutive events, no change in the system state occurs, thus, the simulation time can switch to the time the next event occurs, which is also called next-event time progression, while in real world, time is continuous. For instance, when a component moves along a conveyor, no leaps in time are observed in real world. On the other hand, a DES model only takes into consideration those events and corresponding points in time that are critical during further course of simulation. For example, it could be a part reaching a station in an assembly line, exiting it, and progressing to the next stage. One major advantage of DES is its speed of simulating performance. Since the simulation model can skip all those moments in time that are not of interest for the experiment, it is possible to simulate years of factory operation in just minutes. This is particularly useful when different configurations of the same system need to be simulated and compared or simulating "what-if" scenarios.

DES was deployed to create digital models of EMD assembly line resources and their interplay to help explore system characteristics and optimize their performance. The digital simulation model enables to run experiments and "what-if" scenarios without disturbing an existing production system [25]. Analysis tools, statistics and dashboards enable evaluation of different manufacturing scenarios and help make fast, reliable decisions in the early stages of production planning [21].

3.1.1 Input Data

In the initial steps, DES captured information like workstation sequence, station-wise operations, conveyor layout, control locations, control logic, routing logics, shift details, failure rates, maintenance schedules, conveyor capacities and buffer strategies [3]. While preparing for the simulation, following operational data was input in the DES program—parts details, sub-assembly details, variants handled in the line, production schedule, batch sizes, number of stations per the variant and station-wise cycle times, conveyor speed, line-side and station buffer sizes, station-wise process and activity times, material flow details with routing and transfer dependencies, routing rules and restrictions including in-process quality checks and station MTBF and MTTR.

3.1.2 DES Deliverables

A DES model was developed by capturing the data points stated above. In addition to the 2D view (see Fig. 2) of DES, models were also created in a 3D virtual environment using computer-aided design (CAD) data of the assembly machines (see Fig. 3). This was done keeping in mind the future automation experiments on the performance digital twin. The result is a 3D virtual model that is synchronized with its 2D counterpart [1] allowing the flexibility to choose the appropriate method of visualization without compromising simulation and analysis needs.

The simulated output of the production line helped validate the station-wise cycle times, current bottlenecks, stage-wise utilizations, line balancing effect, utilization of operators, sequencing and scheduling of variants and impact of layout [21]. It also provided reports like total distance travelled by product and total waiting time of a product. The simulation was performed for varying input parameters like batch size,

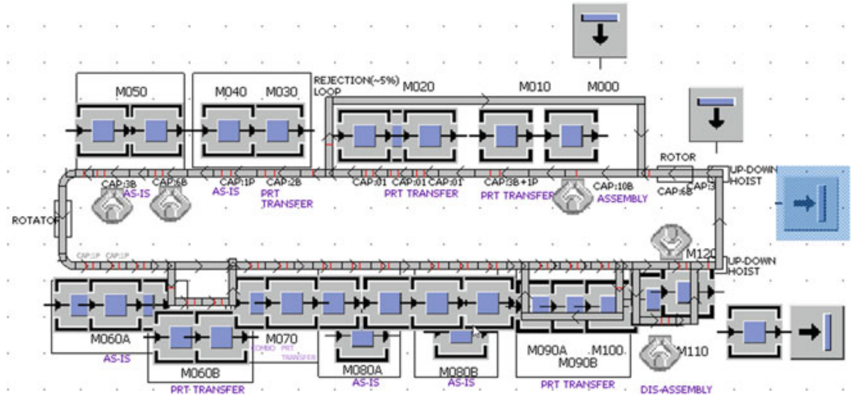


Fig. 2 2D view of EMD line simulation model

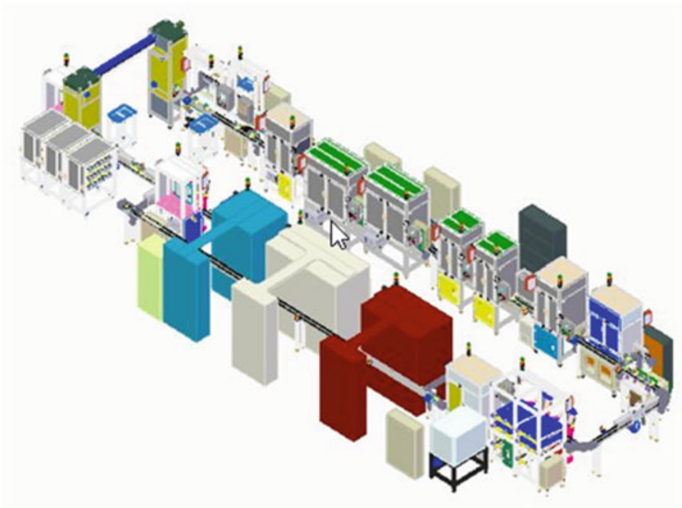


Fig. 3 3D view of simulation model

cycle time, rejections and tests and results were obtained for resources, throughput, bottleneck locations, machine-wise failure and part sequence times (see Fig. 4).

3.2 Step 2: Closed-Loop Discrete Events Simulation

Closed-loop discrete events simulation together with the digital twin help create, manage and run the simulation between an IIOT ready physical production line [11]

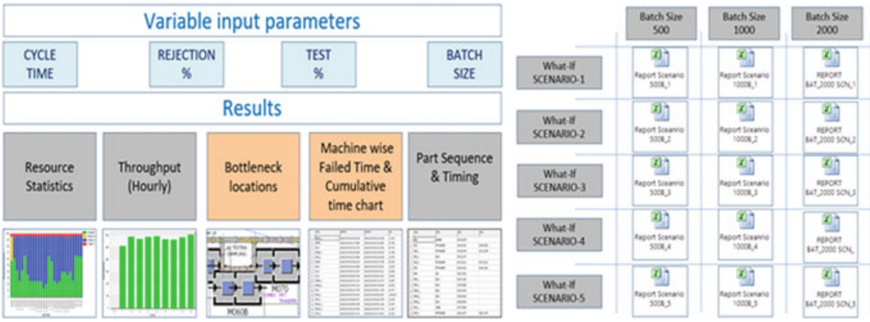


Fig. 4 Simulation and bottleneck results for various scenarios and batch sizes

and its DES model created in step 1. This connected setup consisting of simulation software, assembly line PLCs on IIOT network and data gateways was used to interface the actual EMD assembly line with the DES model (see Fig. 5):

- to map physical assets and variables of the assets in EMD assembly line to the simulation models thus enabling to define digital twin prototype [21].
- to define experiments for the digital twin prototype of EMD facility. Experiments include all the required settings for the closed-loop discrete event simulation.
- to select and import time-slotted data files from the IIOT ready physical assets through digital twin framework and run the DES model with that data to bring models to life [19].
- to run the model with real asset data to transform the model into a digital twin and all existing DES analytical tools into diagnostic tools for the real production line.

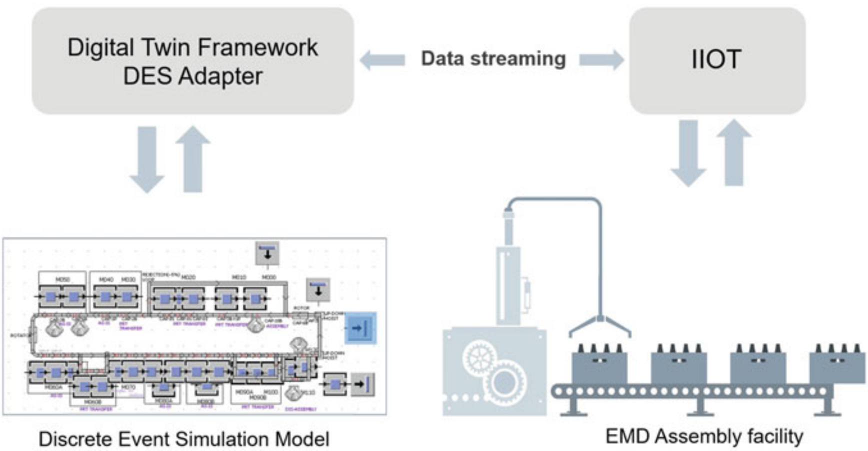


Fig. 5 Integrated digital twin network between assembly line PLCs & simulation tool

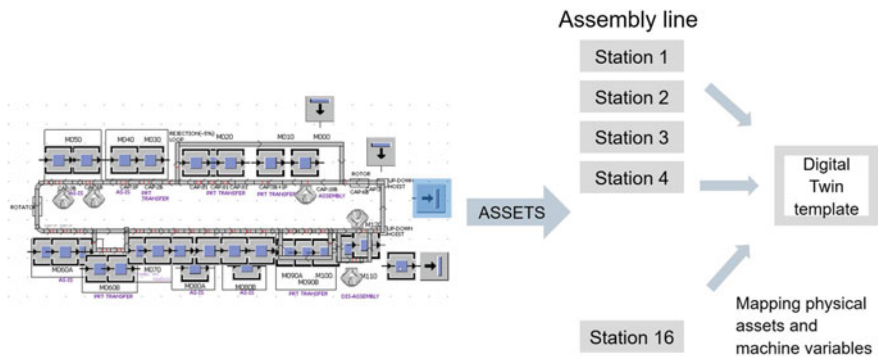


Fig. 6 Closed loop between DES model and assets

- thus, insights from the analysis of the closed-loop simulation results can be applied in different use cases, for example, model calibration, design improvement, bottleneck analysis, condition monitoring, diagnostics and predictive maintenance.

3.2.1 Creating the Closed-Loop Between Simulation Model and Physical Facility

Closed-loop is established by creating asset types with similar hierarchy as the DES model built in step 1 (see Fig. 6). The machine properties and its variable information are exported from the simulation model to IIOT ready digital twin framework. The framework is populated with information regarding physical machines constituting the EMD Assembly line [12]. Once the closed-loop is established, feedback is received from physical plant assembly line to DES model to improve production design model accuracy, and feedback from DES model is sent to real production line to replay optimized scenarios, using plant floor data thus creating a bridge between the physical and virtual world [35]. Various analysis and experiments are then performed for the assembly line to help operate at the highest level of efficiencies as explained in the following scenarios.

Scenario 1: Bottleneck Analysis, Using Digital Twin of a Production-Line
Production engineer opens DES model of the EMD assembly line, uploads physical plant data into the model and runs bottleneck analysis. Critical equipment causing the bottleneck is identified and is serviced at a higher priority and gets flagged for the next plant equipment upgrade. This ensures the assembly line is operating at an optimum efficiency and productivity level. The same procedure is followed to validate the next production lot which could be of different variant mix and quantity thus establishing flexibility.

Scenario 2: Diagnostics and Root-Cause Analysis for Reduced Line Throughput
Upon encountering diminished throughput on the EMD assembly line, individual throughputs of each machine in the digital twin is checked to identify the machine responsible and the OEM is informed. OEM analyses and identifies the machine upgrade requirement which delivers the required reliability.

Scenario 3: Preventive Maintenance Followed by Diagnostics Activities
As per the preventive maintenance schedule, OEM sets up a service call with EMD to maintain the target machine and replaces the impacted subsystem. As per service level agreement, OEM also replaces similar sub-systems on other machines as a predictive maintenance measure thus ensuring continuous improvement in asset efficiency and productivity.

4 Results and Discussions

EMD's organizational target was to set up a re-usable DES model to arrive at actionable insights that can help them improve assembly line performance and get ready for the variable demand and large number of variants that subsequently would help them in driving business and profitability.

Based on DES studies performed, the following listed areas were identified as opportunities for improvement (1) Capacity simulation in the light of varying batch sizes and variant mixes (2) Digital twin methodology supporting input of validated machine parameters to the physical assembly line thus saving precious downtimes (2) Logistics and material flow simulation to reduce shop-floor conflicts arising from material handling (3) Predicting assembly line bottlenecks arising from unbalanced station loads or underperforming machines. (4) Predictive maintenance of stations and machines thus improving machine availability. The model developed, tested and closed-loop with production assembly line is currently used in production planning and forecasting.

4.1 Improvements Achieved

- 3 EMD assembly lines reduced to 1.
- 233% increase in variant types manufactured.
- 43% reduction in average cycle time per variant.
- 3 × improvement in number of quality parameters checked in 1/6th of time.
- 3 × improvement in line performance owing to improved machine availability.
- Local manufacturing of high-tech devices for global markets.

5 Conclusion and Future Scope

India is currently transitioning to an efficiency-driven economy from factor-driven economy. Aspiration would be to elevate to an innovation-driven economy [31]. This indicates that efficiency and innovation are the key drivers for the manufacturing to be a significant contributor to the economy.

Digital twin framework is fast becoming a widely used methodology to simulate, validate, iterate and optimize product, process and performance with the objective of improving efficiency throughout the value chain across various industry verticals. Further, for innovation to be a way of life for a manufacturing organization, continuous experimentation is crucial. It helps in identifying potential faults early while acquiring new knowledge and achieve exponential improvements. Experimentation or using physical prototyping may not be viable owing to economic considerations or paucity of time. Simulating the various scenarios and experimenting with numerous alternatives can quickly give us results and save expensive prototyping.

The transformational study of EMD assembly plant enumerated in this research paper demonstrates how closed-loop discrete event simulation can be deployed to develop a production digital twin. Subsequently, combining simulation studies and continuous feedback data from physical assembly line facilitates real time, operational decision making. These simulation-based decisions have resulted in significant improvements realized across all operational indicators efficiency, quality, productivity and flexibility as demonstrated.

This research paper being based on a transformational study of a manufacturing facility has limitations regarding effects of evolving product designs, its variants and/or upgrades on shop floor operations. Also, automation of lines and workstations has not been included in this research whereas, automation has considerable influence on shop-floor operations. Hence, it is recommended that future research work should include product digital twin methodology in conjunction with production digital twin, to establish deeper understanding of end-to-end value chain consisting of all stages of product design, manufacturing planning, factory automation and customer servicing.

References

1. Akpan, I.J., Brooks, R.J.: Experimental evaluation of user performance on two-dimensional and three-dimensional perspective displays in discrete-event simulation. Decis. Support Syst. **64**, 14–30 (2014)
2. Arcidiacono, F., Ancarani, A., Di Mauro, C., Schupp, F.: Where the rubber meets the road. Industry 4.0 among SMEs in the automotive sector. IEEE Eng. Manag. Rev. **47**(4), 86–93 (2019)
3. Barlas, P., Heavey, C.: Automation of input data to discrete event simulation for manufacturing: a review. Int. J. Model. Simul. Sci. Comput. **7**(01), 1630001 (2016)
4. Boyes, H., Hallaq, B., Cunningham, J., Watson, T.: The industrial internet of things (IIoT): an analysis framework. Comput. Ind. **101**, 1–12 (2018)
5. Chen, Y.: Integrated and intelligent manufacturing: perspectives and enablers. Engineering **3**(5), 588–595 (2017)

6. Dalenogare, L.S., Benitez, G.B., Ayala, N.F., Frank, A.G.: The expected contribution of Industry 4.0 technologies for industrial performance. Int. J. Prod. Econ. **204**, 383–394 (2018)
7. Davis, J., Edgar, T., Porter, J., Bernaden, J., Sarli, M.: Smart manufacturing, manufacturing intelligence and demand-dynamic performance. Comput. Chem. Eng. **47**, 145–156 (2012)
8. Durocher, D.B., Sprinkle, L.: Experiences of a global electrical manufacturing enterprise: the journey to become industry 4.0 ready (2000)
9. Dutta, G., Kumar, R., Sindhwani, R., Singh, R.K.: Digital transformation priorities of India's discrete manufacturing SMEs–a conceptual study in perspective of Industry 4.0. Competitive. Rev. Int. Bus. J. (2020)
10. Furtado, V., Kolaja, T., Mueller, C., Salguero, J.: Managing a Manufacturing Plant Through the Coronavirus Crisis. Mckinsey & Company Operations Practice article (2020)
11. Gehrke, I., Schauss, M., Küsters, D., Gries, T.: Experiencing the potential of closed-loop PLM systems enabled by industrial internet of things. Procedia Manuf. **45**, 177–182 (2020)
12. Guo, J., Zhao, N., Sun, L., Zhang, S.: Modular based flexible digital twin for factory design. J. Amb. Intell. Human. Comput. **10**(3), 1189–1200 (2019)
13. Iiotworld article, 3 Practical Ways to Transform Brownfield Plants into Digital Factories. Available at: https://iiot-world.com/industrial-iot/connected-industry/3-practical-ways-to-transform-brownfield-plants-into-digital-factories/. Accessed at 4th July, 2020 2:09 PM IST
14. Ivanov, D., Sokolov, B., Dolgui, A.: Introduction to scheduling in industry 4.0 and cloud manufacturing systems. In: Scheduling in Industry 4.0 and Cloud Manufacturing, pp. 1–9. Springer, Cham (2020)
15. Jung, K., Morris, K.C., Lyons, K.W., Leong, S., Cho, H.: Mapping strategic goals and operational performance metrics for smart manufacturing systems (2015)
16. Kim, S., Park, S.: CPS (cyber physical system) based manufacturing system optimization. Procedia Comput. Sci. **122**, 518–524 (2017)
17. Lee, Y.T.T., Riddick, F.H., Johansson, B.J.I.: Core manufacturing simulation data–a manufacturing simulation integration standard: overview and case studies. Int. J. Comput. Integr. Manuf. **24**(8), 689–709 (2011)
18. Li, L., Chang, Q., Ni, J.: Data driven bottleneck detection of manufacturing systems. Int. J. Prod. Res. **47**(18), 5019–5036 (2009)
19. Monek, G., Szántó, N., Jósvai, J., István, S.: The role of simulation in a cyber-physical production environment. Simulation in Produktion und Logistik (2019)
20. Negri, E., Fumagalli, L., Macchi, M.: A review of the roles of digital twin in cps-based production systems. Procedia Manuf. **11**, 939–948 (2017)
21. Prajapat, N., Tiwari, A.: A review of assembly optimisation applications using discrete event simulation. Int. J. Comput. Integr. Manuf. **30**(2–3), 215–228 (2017)
22. Pundir, A.K., Devpriya, J., Chakraborty, M., Ganpathy, L.: Technology integration for improved performance: a case study in digitization of supply chain with integration of Internet of Things and blockchain technology. In: 2019 IEEE 9th Annual Computing and Communication Workshop and Conference (CCWC), pp. 0170–0176. IEEE (2019)
23. Rungtusanatham, M.J., Salvador, F.: From mass production to mass customization: hindrance factors, structural inertia, and transition hazard. Prod. Oper. Manage. **17**(3), 385–396 (2008)
24. Schleich, B., Anwer, N., Mathieu, L., Wartzack, S.: Shaping the digital twin for design and production engineering. CIRP Ann. **66**(1), 141–144 (2017)
25. Semini, M., Fauske, H., Strandhagen, J.O.: Applications of discrete-event simulation to support manufacturing logistics decision-making: a survey. In: Proceedings of the 2006 Winter Simulation Conference, pp. 1946–1953. IEEE (2006)
26. Sjödin, D.R., Parida, V., Leksell, M., Petrovic, A.: Smart factory implementation and process innovation: a preliminary maturity model for leveraging digitalization in manufacturing moving to smart factories presents specific challenges that can be addressed through a structured approach focused on people, processes, and technologies. Res. Technol. Manag. **61**(5), 22–31 (2018)
27. Strauß, P., Schmitz, M., Wöstmann, R., Deuse, J.: Enabling of predictive maintenance in the brownfield through low-cost sensors, an IIoT-architecture and machine learning. In: 2018 IEEE International Conference on Big Data (Big Data), pp. 1474–1483. IEEE (2018)

28. Uden, L., He, W.: How the Internet of Things can help knowledge management: a case study from the automotive domain. J. Knowl. Manag. (2017)
29. Uhlemann, T.H.J., Lehmann, C., Steinhilper, R.: The digital twin: realizing the cyber-physical production system for industry 4.0. Procedia Cirp **61**, 335–340 (2017)
30. van Beek, D.A., Gordijn, S.H.F., Rooda, J.E.: Integrating continuous-time and discrete-event concepts in modelling and simulation of manufacturing machines. Simul. Pract. Theory **5**(7–8), 653–669 (1997)
31. Vares, H., Parvandi, Y., Ghasemi, R., Abdullahi, B.: Transition from an efficiency-driven economy to innovation-driven: a secondary analysis of countries global competitiveness. Eur. J. Econ. Finan. Admin. Sci. **31**, 124–132 (2011)
32. Wang, Y., Ma, H.S., Yang, J.H., Wang, K.S.: Industry 4.0: a way from mass customization to mass personalization production. Adv. Manuf. **5**(4), 311–320 (2017)
33. Xu, L.D., Xu, E.L., Li, L.: Industry 4.0: state of the art and future trends. Int. J. Prod. Res. **56**(8), 2941–2962 (2018)
34. Zawadzki, P., Żywicki, K.: Smart product design and production control for effective mass customization in the Industry 4.0 concept. Manag. Prod. Eng. Rev. (2016)
35. Zhuang, C., Liu, J., Xiong, H.: Digital twin-based smart production management and control framework for the complex product assembly shop-floor. Int. J. Adv. Manuf. Technol. **96**(1–4), 1149–1163 (2018)

Using Hybrid AHP-ISM Technique for Modelling of Lean Management Enablers in MSMEs

Vivek Prabhakar and Ankit Sagar

Abstract The following article explores the use of a hybrid model of Analytic Hierarchy Process (AHP) & Interpretive Structure Modelling (ISM) technique for identification, ranking and modelling of various enablers in Micro Small and Medium Enterprises (MSMEs). The first step involves the identification of various enablers which was accomplished by rigorous literature survey of the available literature and consultation from a panel consisting of experts from academia as well as industry working specifically in MSME industry. The process was further accentuated by the ranking of the various enablers identified earlier, using results of survey sheets circulated amongst the panel members depicting a subjective opinion of rankings by them. The cumulative results of the survey sheets were quantified in the final form using AHP technique depicting final ranking of the enablers. Furthermore, the complex interrelationship amongst the various enablers is represented in a comprehensive manner using ISM technique. The hybrid AHP-ISM model can be used by the industry to identify the key techniques to be focused while adapting the lean manufacturing methods in their operations.

Keywords Leanness index · Decision-making · Analytical hierarchy process · Interpretive structural modelling

1 Introduction

AHP technique involves building a hierarchy of decision by identifying the relative priorities of criteria with respect to one another. The priorities are defined by obtaining relative weights of each criteria and checking their consistency, after which the criteria with the highest rating is given the utmost priority and so on [1, 2]. The first step hence is to select the enablers for the study and subsequently obtaining their relative weights using data from survey sheets. Management Process Leanness ($E1$) which is the ability of the manager to adopt to lean management technique and

V. Prabhakar (✉) · A. Sagar
Department of Production Engineering, Birla Institute of Technology Mesra, Ranchi 835215, India
e-mail: vprabhakar.teqip@bitmesra.ac.in

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_54

Process Leanness ($E2$) identified as increasing productivity and increasing customer value by curtailing waste [1] were identified amongst the key enablers. Ravikumar et al. [4] state that adoption of new technologies and automation in the process (Technological Management $E3$) and Customer based feedback along with supplier relations (Customer and Supplier Management $E4$) are vital for efficient lean practices implementation. The literature review shows that adequate training and motivating workforce towards lean practices (Efficient Workforce $E5$) is also a key enabler [4].

Vidyadhar et al. [6] states that proper machine and facility utilization coupled with proper socio-economic development classify under the umbrella of Manufacturing Management ($E6$). But merely ranking the enablers is not sufficient and hence ISM technique is being used to define the complex interrelationships between the various enablers. This study will hence provide the managers with a comprehensive method of implementing the lean technique by targeting the key enablers and their effect on the whole process. For this study Micro, Small and Medium Enterprises (MSMEs) are targeted because of their existing low usage of lean management tools and huge potential for efficiency increase. Hence this study will act as a blueprint for lean implementation in the said industries [6–9].

2 Methodology

2.1 Formulation of AHP Matrix

The first and foremost step for the study was identification of various enablers subsumed in the lean management of MSMEs. For the aforementioned task two strategies were used, first being rigorous literature survey of available literature and second, using inputs from a panel consisting of 3 members of academia and 5 members of industry actively involved with production and planning related work in MSMEs. 2 blank survey sheets each depicting relative ranking of all the enablers and interrelationship amongst the various enablers were distributed to each member. The inputs from the first survey sheets were further accumulated and after using AHP technique, the concluding results were quantified as shown in Table 1.

The above matrix is normalized further and using the results of normalized matrix, a final weighted matrix is obtained depicting the weighted sum values, priority and lambda values as shown in Table 2 for each factor and the consistency for the given matrix is checked.

The consistency of the given matrix is checked by obtaining the final λ values and obtaining the consistency ratio given by $\text{CR} = (\lambda - n)/(n - 1)$, that is, 0.169811483. $\text{CI} = \text{CR/RI} = 0.099889$, which is below the acceptable CI (consistency index = 0.1) hence the matrix is consistent.

The results of AHP merely indicate the priority of various enablers with respect to each other without any dialogue on interrelationship between the enablers.

Table 1 Relative weight of enablers

Leanness Enablers	Enabler 1	Enabler 2	Enabler 3	Enabler 4	Enabler 5	Enabler 6
Enabler 1	1	2	3	4	5	6
Enabler 2	1/5	1	1/5	3	1/4	4
Enabler 3	7	5	1	8	3	9
Enabler 4	1/4	1/3	1/8	1	1/8	2
Enabler 5	2	4	1/3	8	1	6
Enabler 6	1/9	1/4	1/9	1/2	1/6	1

Table 2 Weighted matrix

$E1$	$E2$	$E3$	$E4$	$E5$	$E6$	Weighted sum	Priority	Lambda λ
0.18	0.68	0.07	0.13	0.11	0.20	1.37	0.18	7.66
0.04	0.14	0.10	0.10	0.05	0.09	0.52	0.14	3.79
1.25	0.68	0.52	0.27	0.64	0.20	3.56	0.52	6.84
0.04	0.05	0.07	0.03	0.03	0.04	0.26	0.03	7.75
0.36	0.55	0.17	0.27	0.21	0.13	1.69	0.21	7.91
0.02	0.03	0.06	0.02	0.04	0.02	0.19	0.03	7.15

2.2 ISM Formulation

Interpretive Structural Modelling (ISM) is a technique which uses the transitivity principle to convert large number of complex relationships between a number of factors into a well-structured, easy to translate visual model which can be used by managers to identify the intricacies amongst the enablers [1]. For constructing the ISM, the previously dis survey sheets depicting Structured Self Intersection Matrix (SSIM) were circulated amongst the industrial experts and their results were collected to form a final SSIM as shown in Table 3.

Table 3 Structured self intersection matrix

Leanness Enablers	Enabler 1	Enabler 2	Enabler 3	Enabler 4	Enabler 5	Enabler 6
Enabler 1	*V*	*A*	*V*	*A*	*O*	*X*
Enabler 2	*A*	*X*	*O*	*A*	*X*	
Enabler 3	*V*	*X*	*V*	*X*		
Enabler 4	*O*	*X*	*X*			
Enabler 5	*A*	*X*				
Enabler 6	*X*					

Table 4 Final reachability matrix

Leanness Enablers	Enabler 1	Enabler 2	Enabler 3	Enabler 4	Enabler 5	Enabler 6
Enabler 1	1	0	0	1	1	1
Enabler 2	0	1	0	0	1	0
Enabler 3	1	1	1	1	1	1
Enabler 4	0	0	0	1	1	0
Enabler 5	1	1	1	1	1	0
Enabler 6	0	1	0	0	1	1

The pair-wise relationship is expressed in the form of V, A, X and O, where $V =$ parameter i will lead to j; $A =$ parameter j will lead to I; $X =$ parameter i and j will lead to each other and $O =$ parameter i and j are not related.

The results of the above stated SSIM matrix is converted into binary digits wherein 1 indicates that factor i is dependent on j and 0 indicates that i and j are independent. The obtained matrix is then checked for transitivity and reformed after removing any transitive relations to generate the final reachability matrix as shown in Table 4.

Next, the levels of various enablers in the ISM model will be determined using the results of final reachability matrix. First, the reachability set which indicates the enabler itself and the other enabler it is affecting an antecedent set which marks the enabler itself and the enablers it is getting affected by are derived for each set. Those factors for which the reachability set and antecedent set are intersecting occupy the topmost position in the ISM and are removed for further iterations. Subsequent iterations are conducted until all enablers have been ranked. The iterations have been shown in Tables 5, 6 and 7, respectively.

Table 5 First iteration

Element	Reachability	Antecedent	Intersection	Rank
1	1,4,5,6	1,3,5	1,5	
2	2,5	2,3,5,6	2,5	I
3	1,2,3,4,5,6	3,5	3,5	
4	4,5	1,3,4,5	4,5	II
5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	III
6	2,5,6	1,3,6	6	

Table 6 Second iteration

Element	Reachability	Antecedent	Intersection	Rank
1	1,6	1,3	1	
3	1,3,6	3	3	
6	6	1,3,6	6	IV

Table 7 Third iteration

Element	Reachability	Antecedent	Intersection	Rank
1	1	1,3	1	V
3	1,3	3	3	VI

After the partitioning has been completed, the various elements are arranged in levels with the lowermost level indicating the most important elements. Pursuing these elements would lead to the achievement of subsequent elements automatically. The various levels can be connected by directional arrows indicating relationship amongst the elements which is obtained by eliminating the transitivity, i.e., if element *A* leads to *B* and *B* to *C*, it is assumed that *A* leads to *C*, hence any redundant relationships are hence eliminated to construct a simpler version of the digraph.

2.3 ISM Formulation

The results obtained from iterations depicted in Tables 4, 5 and 6 are used to determine the level partitioning in the final ISM model. The enablers at the bottommost level are root enablers and are most quintessential for implementation of lean management approach in an industry as they would lead to the other enablers. The various relationships existing amongst the factors are determined by reachability matrix wherein 1 indicates that relation exists and 0 indicates no relation. This coupled with the level partitions helps to construct the final ISM model as shown in Fig. 1.

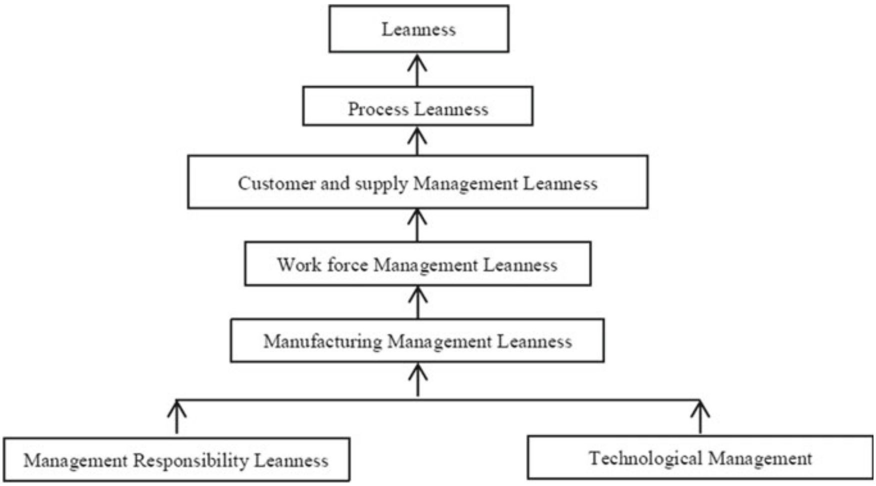


Fig. 1 ISM model

The arrows indicated the relation amongst the enablers and the boxes indicate the enablers themselves.

3 Results and Discussion

The study was conducted with dual ambitions, one being identifying the importance of various lean enablers with respect to each other and the other being depiction of the interrelationship amongst the enabler along with identifying the key enablers. The AHP study indicates that Technological Management is the highest-ranking lean management enabler in MSMEs whereas Customer and Supplier Management is identified as lowest ranking enabler. This pertains to the fact that since the adoption of lean management principles requires reconstruction of the whole supply chain and also vitally relies over smoother flow of information across it, advancement in technology in terms of sophisticated logistics, manufacturing and information systems is paramount for accommodating these changes. Customer and Supplier Management on the other hand are viewed as somewhat of a trivial factor which are more relevant when it comes to increasing stakeholder value and overall company's image rather than effecting adoption of a novel management policy. The ISM indicates that Management Process leanness and Technological Management are the most influential enablers which should be focused more while implementation of lean methodology, because pursuing them more diligently would ensure that other enablers are automatically getting fulfilled. Adoption of a novel management method relies on two factors- first being progressiveness of upper management in accepting the method and educating each player towards its pros and other being the dynamism of supply chain to accommodate these changes. Both these factors are kept in check by enablers Management Responsibility Leanness and Technological Management, respectively. Achieving Technological Management would in turn submit the supply chain players in complying with various socio-economic factors and educating the workforce towards lean management methods which leads to Manufacturing Management Leanness and Work Force Management leanness, respectively. Process Leanness is the weakest enabler due to the fact that once all the enablers are pursued, ideal activities and supply chain waste generation are already curtailed to a large extent.

4 Conclusions

MSMEs play a vital role in contributing to a nation's GDP. The latest trend of a self-reliant India presents golden opportunity for Indian MSME sector to expand their business due to anticipated increase in demand for indigenous products. But the COVID lockdown has impacted the MSME business negatively and hence it becomes imperative for the organizations to adapt a highly productive as well as efficient management methodology which strives towards zero waste generation, hence lean management method is the most sought out method in today's times. But the lack of efficient method to adopt leanness strategies specifically for small to medium industries has left most of the management gurus in a state of jeopardy. By this study, we aim to provide a comprehensive blueprint of various strategies of lean management methods and how to implement them especially in small to medium enterprises. The enabler identification and ranking is aimed at guiding the managers to identify which specific factors to target first and would prove to be the most vital whilst adopting lean strategies by using AHP technique to provide a lucid ranking of various enablers of lean methodology. The study further makes the use of a visual cum analytical tool ISM to provide a clear understanding of the various interrelationships existing amongst the various enablers. This would provide the managers with a blueprint of the most optimum and effective strategy to be followed while using lean management methods in their respective organizations.

References

1. Yadav, V., Khandelwal, G.: Development of leanness index for SMEs (2018)
2. Thomas, T., Saleeshya, P.G., Harikumar, P.: A combined AHP and ISM-based model to assess the leanness of a manufacturing company (2017)
3. Vinodh, S., Chintha, S.K.: Leanness assessment using multi-grade fuzzy approach (2011)
4. Ravikumar, M.M., Marimuthu, K., Parthiban, P.: Evaluating lean implementation performance in Indian MSMEs using ISM and AHP models (2015)
5. Afonso, H., Cabrita, M.R.: Introduction to Multi-Criteria Decision Making and the Evidential Reasoning Approach (2015)
6. Vidhyadhar, R., Sudeep Kumar, R.: Application of interpretative structural modelling integrated multi criteria decision making methods for sustainable supplier selection (2016)
7. Zanjirchi, S.M., Tooranlo, H.S., Nejad, L.Z.: Survey on Multi Criteria Decision Making Methods and Its Applications (2010)
8. Phanden, R.K., Ferreira, J.C.E.: Biogeographical and variable neighborhood search algorithm for optimization of flexible job shop scheduling. In: Advances in Industrial and Production Engineering (pp. 489–503). Springer, Singapore (2019)
9. Bayoua, M.E., de Korvinb, A.: Measuring the leanness of manufacturing systems—A case study of Ford Motor Company and General Motors (1997)

Analysis of Influential Enablers for Sustainable Smart Manufacturing in Indian Manufacturing Industries Using TOPSIS Approach

Sharjil Talib, Abhimanyu Sharma, Sumit Gupta, Gaurav Gaurav, Vimal Pathak, and Rajendra Kumar Shukla

Abstract Sustainable Smart Manufacturing (SSM) has played an important role in current competitive business environment. Manufacturing organizations generate waste and environmental pollution through various manufacturing process. This research presents the development of TOPSIS based model for sustainable smart manufacturing practices in Indian industries. TOPSIS method gives an order of preference based on the separation from ideal solution. This paper provides suggestions and directions for manufacturing industries to implement sustainable smart manufacturing practices towards sustainable competitiveness. This research is very much useful for the industry people for selecting the right enabler to implement SSM in the organization.

Keywords Smart manufacturing · Sustainable manufacturing · TOPSIS

1 Introduction

In the current scenario, Sustainable Smart Manufacturing (SSM) has been nominated as one of the most successful strategy in the industrial revolution. With the development of intelligent system in the manufacturing is a sign of high resource efficiency, adaptability and sustainability [1]. In India, the manufacturing industries are not aware about the adoption of SSM and they are also less aware about the enablers of

S. Talib · A. Sharma · S. Gupta (✉)
Department of Mechanical Engineering, ASET, Amity University, Noida, India
e-mail: sumitgupta2007@gmail.com

G. Gaurav
Department of Mechanical Engineering, Malaviya National Institute of Technology Jaipur, Jaipur, India

V. Pathak
Department of Mechanical Engineering, Manipal University Jaipur, Jaipur, India

R. K. Shukla
Department of Mechanical Engineering, ABES Engineering College, Ghaziabad, Uttar Pradesh 201009, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_55

Table 1 Enablers of sustainable smart manufacturing

Enablers	Name of enabler	Source
E_1	Reduction the use of energy, raw material or any other natural resource	[5, 6]
E_2	Investment in technology and innovation	[7, 8]
E_3	Improve the image of organization to adopt green strategies	[9, 10]
E_4	Long term benefits by adoption of Sustainable smart concepts	[11, 12]
E_5	Use of IoT and big data to improve productivity	[13, 14]
E_6	Corporate social responsibility	[15, 16]
E_7	Workers safety and health issues	[17, 18]
E_8	Organizational laws for environmental sustainability	[19, 20]
E_9	Government policies and regulations	[15, 17, 20]
E_{10}	Disposal of waste	[21, 22]

SSM [2]. The objective of this research is to find out the influential enablers of sustainable smart manufacturing and assess those using TOPSIS in Indian manufacturing industries.

2 Literature Review

Sustainable Smart manufacturing (SM) has evolved beyond the product life cycle. SSM practices initiate the close loop manufacturing system towards the manufacturing excellence [3]. This research focused on the enablers of sustainable smart manufacturing. The enablers deal to the attainment of sustainability in industrial firms [4] within the organization. Based on literature and expert opinion, 10 enablers are identified as given in Table 1.

3 Research Methodology

Research methodology used in this research is cross-sectional in nature. Literature pertaining to sustainable and smart manufacturing is collected through scholarly books, journal articles, conference papers and the Internet.

From the literature, there are various enablers are identified and priorities through the TOPSIS approach. The brainstorming sessions were conducted among the experts in order to finalize the list of enablers. The research methodology is shown in Fig. 1.

TOPSIS Method

TOPSIS is multicriteria decision-making approach to choose alternatives for final outcome [23, 24]. The steps for selecting of best enablers are given below:

Step 1: Identify the Enablers

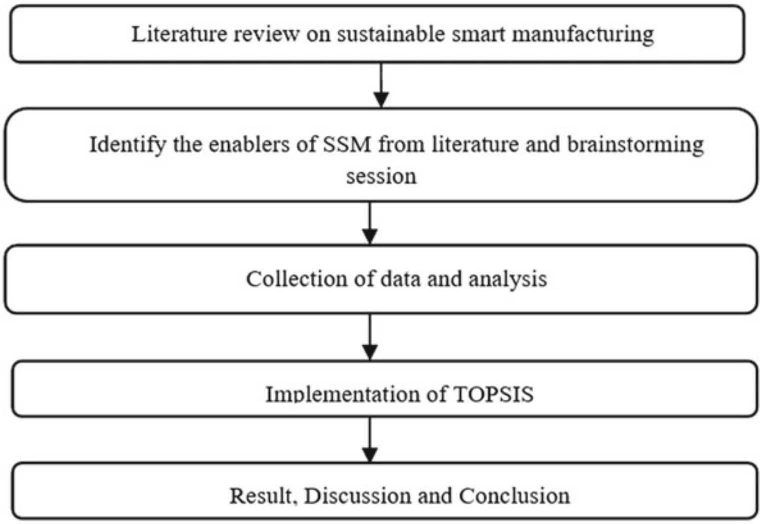


Fig. 1 Flow chart of research methodology

Step 2: This step represents a matrix
Step 3: Obtain the normalized decision matrix

$$r_{ij} = X_{ij} / \sqrt{\sum_{i=1}^{m} X_{ij}^2}$$

Step 4: Calculation of the normalised decision matrix

$$T = (t_i j)_{m \times n} = (\omega_j r_{ij})_{m \times n}, \quad i = 1, 2, \ldots, m$$

where,

$$\omega_j = W_j / \sum_{j=1}^{n} W_j, \quad j = 1, 2, \ldots, n$$

Step 5: Determine A_w and A_b:

$$A\omega = \{\{\max(t_{ij}|i = 1, 2, \ldots, m)|j \in J -\rangle, \langle \min(t_{ij}|i = 1, 2, \ldots, m)|j \in j \; +\rangle\} \equiv \{t_{wj}|j = 1, 2 \ldots, n\};$$

$$Ab = \{\{\min(t_{ij}|i = 1, 2, \ldots, m)|j \in J -\rangle, \langle \max(t_{ij}|i = 1, 2, \ldots, m)|j \in j \; +\rangle\} \equiv \{t_{bj}|j = 1, 2 \ldots, n\},$$

Step 6: Calculation of $d_{iw \text{ and }} d_{ib}$

$$d_{i\omega} = \sqrt{\sum_{j=1}^{n} (t_{ij} - t_{\omega j})^2}, \quad i = 1, 2, \ldots, m$$

$$d_{ib} = \sqrt{\sum_{j=1}^{n} (t_{ij} - t_{bj})^2}, \quad i = 1, 2, \ldots, m$$

Step 7: Calculate the similarity to the worst condition:

$$s_{i\omega} = d_{i\omega}/(d_{i\omega} + d_{ib}), \quad 0 \le siw \le 1, \quad i = 1, 2, \ldots, m$$

Step 8: Rank the alternatives according to s_{iw} ($i = 1, 2\ldots\ m$).

An assumption of TOPSIS is that the criteria are monotonically increasing or decreasing [12].

4 Data Analysis and Discussion

The TOPSIS method is applied for above enablers as discussed in Tables 2, 3, 4 and 5. the assessment of enablers of sustainable smart manufacturing. The objective is to evaluate the alternatives. There are total 10 attributes and 4 alternatives. E_1, $E_{2\ \ldots}E_{10}$ represents attributes and A_1, A_2, A_3 and A_4 represents alternatives. A_1, A_2, A_3 and

Table 2 Formation of decision matrix

Alternative	Attributes									
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}
A_1	4.5	4.2	4.5	4.2	4.2	3.8	4.0	3.8	4.0	4.2
A_2	4.0	4.0	4.0	4.0	4.2	3.6	3.8	3.8	3.8	4.0
A_3	4.4	4.2	4.4	4.0	4.0	4.0	4.0	4.0	4.0	4.0
A_4	3.8	4.2	3.6	3.8	3.4	4.0	3.6	3.8	3.4	3.0
$\sqrt{\sum E^2}$	8.31	8.3	8.23	8.0	7.93	7.7	7.7	7.7	7.61	7.6

Table 3 Normalized decision matrix

Alternative	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}
A_1	0.530	0.506	0.534	0.525	0.529	0.494	0.519	0.494	0.525	0.549
A_2	0.481	0.481	0.486	0.500	0.529	0.467	0.494	0.494	0.499	0.522
A_3	0.530	0.506	0.534	0.500	0.504	0.519	0.519	0.519	0.525	0.522
A_4	0.457	0.506	0.437	0.475	0.428	0.419	0.494	0.494	0.446	0.392
σ	0.0366	0.0125	0.0464	0.0204	0.0478	0.0248	0.0248	0.0125	0.0372	0.0707

Table 4 Weighted normalized matrix

	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}
A_1	0.058	0.019	0.074	0.032	0.076	0.036	0.038	0.018	0.058	0.115
A_2	0.053	0.017	0.067	0.030	0.076	0.035	0.036	0.018	0.055	0.110
A_3	0.058	0.019	0.074	0.030	0.072	0.038	0.038	0.019	0.058	0.110
A_4	0.050	0.019	0.061	0.029	0.061	0.038	0.035	0.018	0.049	0.083

Table 5 Best and Worst solution

Best	Worst
${E_1}^+ = 0.058$	${E_1}^- = 0.050$
${E_2}^+ = 0.019$	${E_2}^- = 0.017$
${E_3}^+ = 0.074$	${E_3}^- = 0.061$
${E_4}^+ = 0.032$	${E_4}^- = 0.029$
${E_5}^+ = 0.076$	${E_5}^- = 0.061$
${E_6}^+ = 0.036$	${E_6}^- = 0.035$
${E_7}^+ = 0.038$	${E_7}^- = 0.035$
${E_8}^+ = 0.019$	${E_8}^- = 0.018$
${E_9}^+ = 0.058$	${E_9}^- = 0.049$
${E_{10}}^+ = 0.115$	${E_{10}}^- = 0.083$

A_4 denote Electrical Industry, Automotive Industry, Machinery Industry and Process Industry, respectively.

Step 1: Formation of decision matrix

Step 2: Normalized decision matrix

Step 3: Weightage of enablers by SD method

$$\sum \sigma = 0.3337$$

$$W_1 = 0.110,\ W_2 = 0.037,\ W_3 = 0.139,\ W_4 = 0.061,\ W_5 = 0.143,$$
$$W_6 = 0.074,\ W_7 = 0.074,\ W_8 = 0.037,\ W_9 = 0.111,\ W_{10} = 0.211$$

Step 4: Weighted normalized matrix

Step 5: The next step is to obtain the ideal (best) and negative ideal (worst) solution.

Step 6: The next step is to obtain the separation measures, and these are calculated as:

$$\begin{aligned} S_1^+ &= 0.0022 & S_1^- &= 0.039 \\ S_2^+ &= 0.0114 & S_2^- &= 0.0322 \\ S_3^+ &= 0.0067 & S_3^- &= 0.0345 \\ S_4^+ &= 0.036 & S_4^- &= 0.0036 \end{aligned}$$

Table 6 Relative closeness of alternatives

	S_i^+	S_i^-	$S_i^+ + S_i^-$	$S_i^-/S_i^+ + S_i^-$	Rank
A_1	0.0022	0.039	0.0412	0.9466	1
A_2	0.0114	0.0322	0.0436	0.7385	3
A_3	0.0067	0.0345	0.0412	0.8373	2
A_4	0.036	0.0036	0.0396	0.0964	4

Step 7: The relative closeness of a particular alternative to the ideal solution

In TOPSIS analysis, data obtained from expert opinion is used to find normalized matrix. From normalized matrix, weightage is found for enablers using standard deviation method. From weighted normalized matrix found out best and worst alternative for each enabler. Further, we found separation from best and worst solution. Found the separation index and according to separation index we ranked alternatives in descending orders. The order of preference comes out A_1–A_3–A_2–A_4 as shown in Table 6.

5 Conclusion

This research has presented a TOPSIS-based model for enablers of sustainable smart manufacturing. TOPSIS method gives order of preference based on the separation from ideal solution. The company's score was calculated against the SSM enablers. Finally, the industry rank was calculated based on their scores. It provides the direction for industries to take appropriate actions for enhancing the sustainable smart manufacturing. This research has some limitation like the different kind of tool and techniques may apply for better assessment of enables of SSM.

6 Implications of the Study

This research is very much useful for Industry professionals and managers. The best enablers of sustainable smart manufacturing are implemented in various organizations. With the help of TOPSIS model, the managers will select the best alternative enabler to implement in the organization.

References

1. Davis, J., Edgar, T., Porter, J., Bernaden, J., Sarli, M.: Smart manufacturing, manufacturing intelligence and demand-dynamic performance. Comput. Chem. Eng. **47**, 145–156 (2012)

2. Bhanot, N., Rao, P.V., Deshmukh, S.G.: Enablers and barriers of sustainable manufacturing: results from a survey of researchers and industry professionals. Procedia CIRP **29**, 562–567 (2015)
3. Garetti, M., Taisch, M.: Sustainable manufacturing: trends and research challenges. Prod. Plann. Control **23**(2–3), 83–104 (2012)
4. Golinska, P., Romano, C.A.: Environmental Issues in Supply Chain Management: New Trends and Applications. Springer Science & Business Media (2012)
5. Borchani, M.F., Hammadi, M., Yahia, N.B., Choley, J.Y.: The usage of a system engineering approach for integrating machining constraints in the upstream design stage. In: 2017 IEEE International Systems Engineering Symposium (ISSE), pp. 1–7. IEEE (2017)
6. Askary, Z., Singh, A., Gupta, S., Shukla, R.K., Jaiswal, P.: Development of AHP framework of sustainable product design and manufacturing of electric vehicle. In: Advances in Engineering Design, pp. 415–422. Springer, Singapore (2019)
7. Koho, M., Torvinen, S., Romiguer, A.T.: Objectives, enablers and challenges of sustainable development and sustainable manufacturing: views and opinions of Spanish companies. In: 2011 IEEE International Symposium Assembly and Manufacturing (ISAM), pp. 1–6. IEEE (2011)
8. Ghazilla, R.A.R., Sakundarini, N., Abdul-Rashid, S.H., Ayub, N.S., Olugu, E.U., Musa, S.N.: Drivers and barriers analysis for green manufacturing practices in Malaysian SMEs: a preliminary findings. Procedia CIRP **26**, 658–663 (2015)
9. Zhang, B., Bi, J., Liu, B.: Drivers and barriers to engage enterprises in environmental management initiatives in Suzhou Industrial Park, China. Front. Environ. Sci. Eng. China **3**(2), 210–220 (2009)
10. Singh, A., Askary, Z., Gupta, S., Sharma, A.K., Shrivastava, P.: AHP based model for evaluation of sustainable manufacturing enablers in Indian manufacturing companies. In: Advances in Industrial and Production Engineering, pp. 397–403. Springer, Singapore (2019)
11. Mittal, V.K., Egede, P., Herrmann, C., Sangwan, K.S.: Comparison of drivers and barriers to green manufacturing: a case of India and Germany. In: Re-Engineering Manufacturing for Sustainability, pp. 723–728. Springer, Singapore (2013)
12. Gupta, S.: Some Issues In Sustainable Manufacturing: A Select Study of Indian Manufacturing Companies. Doctoral dissertation, MNIT Jaipur (2016)
13. Gupta, S., Dangayach, G.S., Singh, A.K., Meena, M.L., Rao, P.N.: Adoption of sustainable supply operation quality practices and their impact on stake-holder's performance and sustainable performance for sustainable competitiveness in Indian manufacturing companies. Int. J. Intell. Enterp. **5**(1–2), 108–124 (2018)
14. Valiaveetil, J.J., Singh, S., Jain, A., Gupta, S.: Design and development of an online process measurement system for zero defect production. In: Advances in Industrial and Production Engineering, pp. 791–800. Springer, Singapore (2019)
15. Gupta, S., Dangayach, G.S., Singh, A.K., Rao, P.N.: Analytic hierarchy process (AHP) model for evaluating sustainable manufacturing practices in Indian electrical panel industries. Procedia-Soc. Behav. Sci. **189**, 208–216 (2015)
16. Mathur, B., Gupta, S., Meena, M.L., Dangayach, G.S.: Impact of supply chain practices on organizational performance with moderating effect of supply chain performance in Indian health care industry. Int. J Sup. Chain. Mgt. **7**(4), 30 (2018)
17. Gupta, S., Dangayach, G.S., Singh, A.K., Meena, M.L. and Rao, P.N.: Implementation of sustainable manufacturing practices in Indian manufacturing companies. Benchmarking Int. J. **25**(7), 2441–2459 (2018b)
18. Jaiswal, P., Kumar, A., Gupta, S.: Prioritization of green manufacturing drivers in Indian SMEs through if-TOPSIS approach. U.P.B. Sci. Bull. Ser. D V **80**(2), 277–292 (2018)
19. Aggarwal, A., Gupta, S., Ojha, M.K.: Evaluation of key challenges to industry 4.0 in Indian Context: a DEMATEL approach. In: Advances in Industrial and Production Engineering, pp. 387–396. Springer, Singapore (2019)
20. Singh, M., Arora, R., Ojha, A., Sharma, D., Gupta, S.: Solid waste management through plasma arc gasification in Delhi: a step towards Swachh Bharat. In: Advances in Industrial and Production Engineering, pp. 431–440. Springer, Singapore (2019)

21. Jamwal, A., Aggarwal, A., Gupta, S., Sharma, P.: A study on the barriers to lean manufacturing implementation for small-scale industries in Himachal region (India). Int. J. Intell. Enterp. **6**(2–4), 393–407 (2019)
22. Vahdani, B., Mousavi, S.M., Tavakkoli-Moghaddam, R.: Group decision making based on novel fuzzy modified TOPSIS method. Appl. Math. Model. **35**(9), 4257–4269 (2011)
23. Rao, R.V.: Decision Making in the Manufacturing Environment: Using Graph Theory and Fuzzy Multiple Attribute Decision Making Methods. Springer Science & Business Media
24. Assari, A., Mahesh, T.M., Assari, E.: Role of public participation in sustainability of historical city: usage of TOPSIS method. Indian J. Sci. Technol. **5**(3), 2289–2294 (2012)

Lean Manufacturing Implementation in Crankshaft Manufacturing Company

Sagar Sapkal and Abhishek Joshi

Abstract Companies that are experiencing vast improvements in production and quality in terms of products are widely using lean manufacturing techniques. Lean manufacturing is a systematic approach with the scope of identifying and eliminating the wastes by continuous improvement. Waste can include any activity, step or process that does not add value to the product. Value stream mapping is a lean tool that helps to identify the current flow of material and information in the process and highlights opportunities for improvement that will significantly impact the overall production. This paper illustrates the application of value stream mapping for implementing lean manufacturing in the crankshaft manufacturing company. The current state map was prepared and improvements in the line are suggested and implemented. After implementing future state map, the results show that on application of lean techniques there is a reduction in lead time, material movement and work in process inventory and that in turn lead to increase in productivity to meet the customer demand.

Keywords Lean manufacturing · Value stream mapping · Productivity improvement

1 Introduction

'Lean' concept originally defined for elimination of waste (Muda). It is an approach that systematically optimizes non-value-added activities in the processing using continuous improvement. Lean production reduces manufacturing system divergence and lead time to the customer [1]. In the lean philosophy 'Value' is defined by end customer that means identifying for what customer is willing to pay for. Hence all the manufacturing processes are to be designed and established as per the customer's point of view. Value Stream Mapping (VSM) is a lean tool, widely used to establish

S. Sapkal (✉)
Walchand College of Engineering, Sangli, Maharashtra, India
e-mail: sagarus1201@gmail.com

A. Joshi
Sinhgad Institute of Technology, Lonavala, Maharashtra, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_56

optimized layout that ultimately reduce or eliminate non-value-added activities from the existing manufacturing process. VSM technique involves flowcharting the steps, activities, material flow, information flow and all other elements that are associated with the process. So VSM can explore value-added and non-value added activities within the process that brings the raw material to the end product [2]. A study is carried out in a leading forging company producing a variety of products like axle beams, crankshaft, steering knuckle, etc. The present work is carried for crankshaft processing line in which heat-treated parts after shot blasting are checked visually and then forwarded to machining department. The old processing line for crankshafts, unable to full fill customer demand because of more cycle time, old technology related to material handling, improper material flow, huge work in process inventory, less automation, etc.

The objectives of this study are to establish lean flow of material to improve productivity to cope up customer demand by reducing non-value-added activities in existing processing line and by identifying bottlenecks in current line using VSM. The creation of future state maps and related action plans help to generate improvements and changes within the company. Gracanina et al. [3] have implemented lean manufacturing using VSM technique in crankshaft manufacturing company and concluded that VSM can be effectively used to eliminate waste and to create flexibility in manufacturing system. Sapkal and Jadhav [4] have implemented Kanban and VSM in residual current circuit breaker manufacturing company and concluded that this approach helps to analyze loopholes in the current system. Also, this approach helps to find the exact location of problems and gives opportunities to improve upon it. By implementation of this approach, they have achieved lead time reduction of 48.9% and about 18% reduction in processing time. Haefner et al. [5] developed method for Quality Value Stream Mapping (QVSM) and proved that it can be effectively used for optimizing manufacturing process from the quality point of view. Ramachandran and Kesavan [6] have studied Cycle time in manufacturing industry for truck body assembly process and concluded that line balancing is one of the method to reduce cycle time to a great extent. Also, lean tools can be used to identify the waste time and eliminate it step by step to reduce cycle time by proper line balancing. They have used software tools, standardized work to validate the results. Oberhausen and Plapper [7] have developed common VSM method accompanied by standardized software and process interface to ensure robust product and information flow within the company and throughout the supply chains. To implement common VSM approach, techniques like flexibility, labelling of elements and use of sequence or connection points in VSM can be used. They have used Barcode-based collection of data for the VSM. Rahani and Ashraf [8] have proved from their study of assembly line that the use of VSM in lean manufacturing can reveal hidden waste that affects productivity. In the study, they observed that significant amount of time is spent on waiting and non-value-added time. Jadhav and Sapkal [9] carried out the study on inventory management in terms of ABC analysis. Inventory reduction is also possible by using lean manufacturing concepts.

2 Value Stream Mapping

The value stream starts at the concept and ends at delivery to the customer. Every stage the product goes through should add value to the product, but often this is not the case. Mapping of the value stream aids the identification of value adding and non-value adding (i.e., waste) activities [10]. The mapping of the current state is done based on the data from the industry and the processing line, the current state map is generated which is shown in Fig. 1.

As per the data from the industry, customer demand is 100,000 pieces/month, daily demand is 4167, daily working hours are 21.5 and TAKT time is 18.6 s. The current state map is drawn by considering 24 days of working in a month. Monthly customer demand data is supplied to the forging and heat treatment department through electronic information channel. Inventory value between the stations and distance moved by component between the stations are mentioned in the same map. It is clear that cycle time for shot blasting, visual inspection and magnetic particle inspection is more and exceeds TAKT time (18.6 s). Hence these are the bottlenecks. Inventory of 15,000 pieces of crankshaft is found before shot blasting station. This inventory is major source of increasing non-value-added time. Total changeover time is about 35 min. There are many useful critical factors to determine the success of implementing the concept of lean manufacturing [11]. Some of them represent possible ways to reduce cycle time for respective processes.

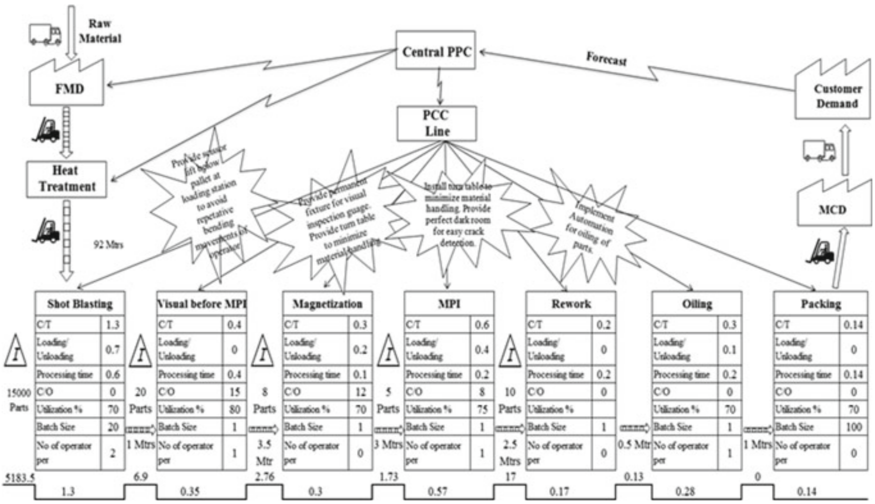


Fig. 1 Current State VSM

3 Development of Future State Map

After analysis of various types of waste in crankshaft processing line, various proposals (Kaizen) have been suggested. Need of 5 s implementation was found for operations of namely visual inspection, shot blasting and packaging.

Introduction of Automation: Robots-based automatic processing line is installed with automated robotic oiling. Laser-based automatic TIR checking system is also installed. For continuous part feeding, turn table are installed at MPI and visual inspection booth. Chain conveyors are installed from visual and MPI booth to the rework and packing station.

Introduction of fixture: Visual inspection gauges are fixed to avoid loss in process time due to frequent movement of gauges. Smooth rotary crankshaft supporting rollers are installed to facilitate visual inspection and MPI.

Reduction in WIP: WIP inventory before shot blasting is reduced by installation of 3 chamber shot blasting machine.

Ergonomic improvement: Epoxy flooring, proper machine layout, instruction charts at the working area helped to improve ergonomic condition as compared to old layout. Separate air-conditioned booths are installed for MPI and visual station to reduce operator fatigue.

After implementing above Kaizens, the distance of the shot blasting process from the previous station is reduced from 92 to 70.5 m and improvement in the process time for shot blasting is mentioned in Table 1.

The improvement in the operation time in case of visual inspection and magnetic particle inspection is summarized in Table 2.

Based on suggested improvements, future state map is drawn as shown in Fig. 2.

Table 1 Before and after status for shot blasting

Operations	Before (s)	After (s)
Pick up job from pallet	11	5
Load the job on hanger	9	4
Actual cycle time	720	240
Unload job from hanger	22	9

Table 2 Before and after status for visual inspection and magnetic particle inspection

Operations	Visual inspection		Magnetic particle inspection	
	Before (s)	After (s)	Before (s)	After (s)
Check all sides of crankshaft by rotating it using lever	11	5	8	4
Remove surface defects using appropriate grinder	8	5	3	–
Mark operator punch	2	2	2	2

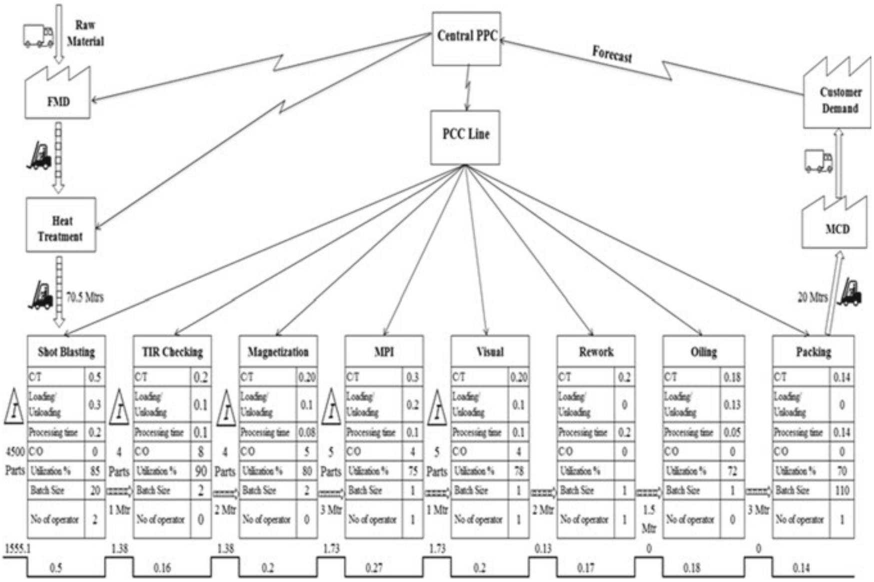


Fig. 2 Future State VSM

4 Results and Discussion

Figure 3 represents the machine balance chart for current state of crankshaft processing line. In current state, cycle time for shot blasting operation exceeds beyond TAKT time because of more processing time (about 12 min), and more loading and unloading time due to operator fatigue. Similarly for visual and MPI process time loss was due to more waiting time for parts, and loading and unloading time.

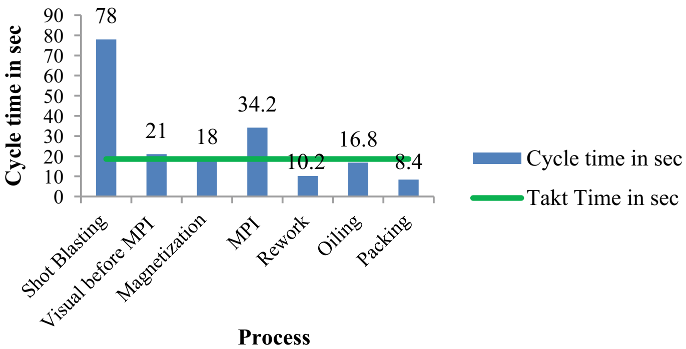


Fig. 3 Machine balance chart for current state

Figure 4 represents the machine balance chart for future state of crankshaft processing line. It can be seen that after implementation of lean technique, cycle time of process is reduced below TAKT time except for shot blasting process. Though cycle time for shot blasting is reduced from 78 to 30 s, there is no significant reduction in loading and unloading time. Hence, processing time for it exceeds TAKT time of the line. The improvement in various performance measures observed after implementation of lean is summarized in Table 3.

Lead time to customer is decreased by 70% as shown in Fig. 5. Reduction is observed due to reduction in processing time, loading–unloading time (robot-based material handling) and significant reduction in WIP inventory. Total inventory level is brought down from 15,043 pieces to 4518 pieces of crankshaft as shown in Fig. 6, which is achieved mainly due to cycle time reduction of shot blasting process. Material transport from the first process to the last process in processing line is reduced by 21.83%. Also, the change over time is reduced from 35 to 21 min due to advanced machines and calibration system.

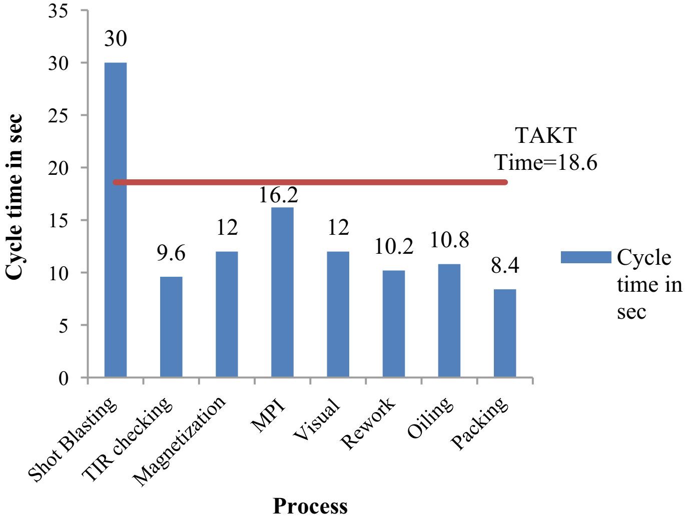


Fig. 4 Machine balance chart for future state

Table 3 Comparison of parameters

Parameter	Before implementation	After implementation
Value-added time (min)	3.11	1.82
Non-value-added time (min)	5212	1561.5
Manpower	39	30

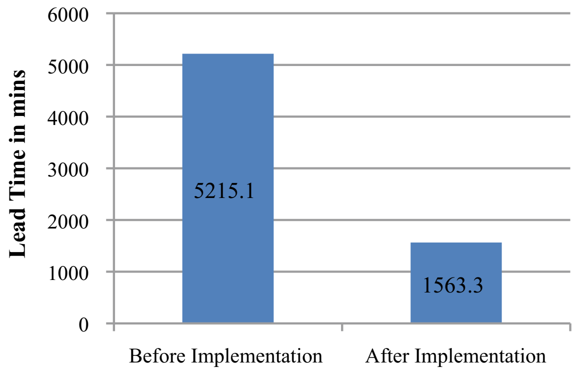


Fig. 5 Improvement in lead time

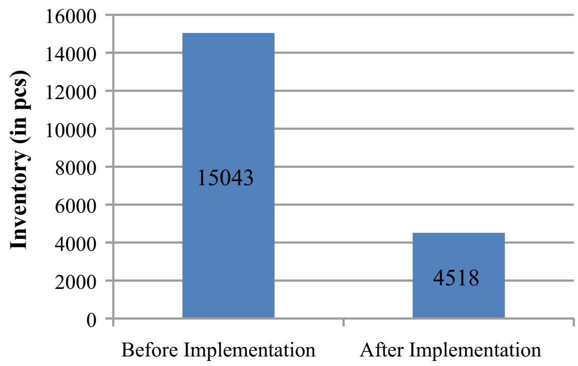


Fig. 6 Reduction in total inventory

5 Conclusion

This study is performed with the objectives of reducing cycle time, removing non-value-added activities from the process and to suggest improvement from lean point of view. Lean manufacturing gives idea that how layout of plant has to be arranged in accordance with value stream activities. It has been found from literature and case study that lean techniques can be used effectively to reduce lead time to customer, WIP inventory and processing time, etc. VSM is an effective lean tool which gives clear picture of multiple process involved in workflow and helps to identify potential problems that may be encountered in the future state. By implementing lean strategy and VSM technique 70% reduction in lead time, 69.9% reduction in inventory and 21.83% reduction in total distance travelled is achieved. That leads to significant improvement in productivity.

Acknowledgements Authors are thankful to the industry Bharat Forge Ltd. for providing the facilities and necessary support for this research work.

References

1. Sundar, R., Balaji, A.N., Satheesh Kumar, R.M.: A review on lean manufacturing implementation techniques. In: 12th Global Conference on Manufacturing and Management, pp. 1875–1888 (2014)
2. Lacerda, A.P., Xambre, A.R., Alvelos, H.M.: Applying value stream mapping to eliminate waste: a case study of an original equipment manufacturer for the automotive industry. Int. J. Prod. Res. **54**(6), 1708–1720 (2016)
3. Gracanina, D., Buchmeisterb, B., Lalica, B.: Using cost-time profile for value stream optimization. Procedia Eng. **69**, 1225–1231 (2014)
4. Sapkal, S.U., Jadhav, R.: Productivity improvement by using value stream mapping in manufacturing company. In: 3rd International Conference on Industrial Engineering, vol. 1, pp. 496–501 (2015)
5. Haefner, B., Kraemer, A., Stauss, T., Lanza, G.: Quality value stream mapping. In: Proceedings of the 47th CIRP conference on manufacturing systems, pp. 254–259 (2014)
6. Ramachandran, A., Kesavan, R.: An application of lean manufacturing principle in automotive industry. IOSR J. Mech. Civil Eng., 25–29 (2014)
7. Oberhausen, C., Plapper, P.: Value stream management in the lean manufacturing laboratory. In: 5th Conference on Learning Factories, pp. 144–149 (2015)
8. Rahani, A.R., Muhammad al- Ashraf.: Production flow analysis through value stream mapping: a manufacturing process case study. In: International Symposium on Robotics and Intelligent Sensor, pp. 1727–1734 (2012)
9. Jadhav, R., Sapkal, S.U.: ABC analysis in manufacturing company. In: 3rd International Conference on Industrial Engineering, vol. 2, pp. 1424–1428 (2015)
10. Modi, D., Thakkar, H., Thinking, L.: Reduction of waste, lead time, cost through lean manufacturing tools and technique Int. J. Emerg. Technol. Adv. Eng. **4**, 339–344 (2014)
11. Achanga, P., Shehab, E., Roy, R., Nelder, G.: Critical success factors for lean implementation within SME's. Int. J. Manuf. Technol. Manage. **17**, 460–471 (2006)

Transient Numerical Simulation of Solidification in Continuous Casting Slab Caster

Vipul Kumar Gupta, Pradeep Kumar Jha, and Pramod Kumar Jain

Abstract A three-dimensional transient coupled model is developed to investigate the flow field, temperature distribution and solidification in slab caster mold. Finite volume code Fluent is used for solving the governing differential equations of continuity, momentum, energy and turbulence. The enthalpy porosity technique is used for solidification. Different parameters, such as solidification thickness, temperature distribution, velocity vectors are investigated. Solidification thickness is computed at different time intervals: 50, 100, 150 s. The results show that solidification in the mold achieves equilibrium after 100 s. Maximum heat removal occurs at the corners of the mold. Two circulation loop forms after jet strike at narrow face and contributes in superheat transfer and inclusion removal. Solid shell thickness first increases from meniscus then decrease at impinge point due to high superheat transfer and then further increase.

Keywords Slab caster · Solidification · CFD · Numerical simulation

Abbreviations

A_{mush}	Mushy zone constant
C_1, C_2, C_μ	Turbulent constants
g	Gravitational acceleration (9.81 m/s^2)
H	Total material enthalpy (J kg^{-1})
h	Sensible enthalpy (J kg^{-1})
G_{k}	Turbulent kinetic energy generation
ΔH	Latent heat content (J kg^{-1})
ΔH_f	Material Latent heat (J kg^{-1})
k	Turbulent kinetic energy (m^2 s^{-2})
K_1	Laminar thermal conductivity (W m^{-2} K^{-1})

V. K. Gupta (✉) · P. K. Jha · P. K. Jain
Department of Mechanical & Industrial Engineering, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand 247667, India
e-mail: vgupta1@me.iitr.ac.in

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_57

K_t	Turbulent thermal conductivity (W m^{-2} K^{-1})
K_{eff}	Effective thermal conductivity (W m^{-2} K^{-1})
i	Pressure (kg m^{-1} s^{-2})
Pr_t	Turbulent Prandtl number
q_m	Mold heat flux (W m^{-2})
q_s	Surface heat flux (W m^{-2})
s	Strain rate (s^{-1})
$T_{solidus}$	Solidus temperature (°K)
$T_{liquidus}$	Liquidus temperature (°K)
u_x, u_y, u_z	Velocity components in x, y, z directions (m s^{-1})
U	Casting speed (m s^{-1})
U_{in}	Liquid inlet velocity (m s^{-1})
β	Volume liquid fraction
ρ	Density (kg m^{-3})
σ	Stefan constant (5.6696×10^{-8} W m^{-2} K^{-4})
σ_k	Turbulent kinetic energy Prandtl number
σ_ε	Turbulent Prandtl number
ε	Energy dissipation rate (m^2 s^{-3})
μ_l, μ_t, μ_e	Laminar, turbulent, effective viscosity (kgm^{-1} s^{-1})
ν	Kinematic viscosity (m s^{-2})
η	Dimensionless mean strain rate

1 Introduction

Continuous casting is a continuous process in which molten metal flows from tundish to the mold through a submerged entry nozzle (SEN). Solidification starts after superheat dissipated and thin skin of solidified metal form. As it goes down further, skin thickness increases. Mold is given reciprocating motion to reduce the risk of breakout. Mold length is optimized to satisfy the criteria of minimum friction between strand and mold inner wall and to maximize the solidification thickness to withstand the molten metal pressure. After entering into the secondary cooling zone, due to water spray cooling, solidification thickness grows very fast. Heat transfer, fluid flow pattern, and solidification plays a key role in the defect-free casting. Many researchers developed coupled numerical models to account for all these phenomena. Different thermal and geometrical parameters like casting speed, slab shape, the behavior of heat resistance due to air gap have been analyzed using mathematical models [1]. Mechanical parameters mold distortion and bulging have been studied[2]. Surface defects such as depression and longitudinal cracks near to meniscus region analyzed. The effect of different casting speeds on these parameters is investigated by many researchers [3–5]. Two dimensional, transient finite-element model numerical study are carried out to study heat transfer near to meniscus [6]. Steady-state heat transfer study of top surface flux at different nozzle shapes is analyzed and a coupled model is developed [7]. Mathematical model of superheat dissipation at the start of casting has been developed to investigate flow field, temperature gradients in molten steel in mold, solute distribution inside the solidification front, and their combined effect on quality of caster in terms of surface defects [8]. A transient mathematical model of billet casting for fluid flow study has been investigated [9]. One dimensional model of heat conduction in the mold is coupled with a two-dimensional model flow to investigate molten steel flow parameters and thermal parameters numerically [10]. A three-dimensional numerical model of heat flux inside the billet mold for continuous casting of low carbon steel is presented [11]. Plant experiments data are compared with large eddy numerical simulation to study the turbulent parameters kinetic energy and energy dissipation rate in the outlet region of SEN for thin steel slabs [12]. The influences of carbon content in steel, casting rate, mold oscillation frequency, scale formation on the surface of the slab after secondary cooling, have been examined [13]. An integrated numerical simulation model of turbulent flow, heat transfer coupled with volume of fluid (VOF) model using enthalpy-porosity scheme is conducted and the flow pattern in both longitudinal and transverse directions analyzed [14]. A three dimensional transient thermoelastic viscoplastic finite element model is studied for the thermomechanical behavior of solid shell during solidification in mold [15]. Effect of water circulation rate in water slots on mold heat transfer examined and verified using temperature values [16]. Multiphase modeling of fluid flow and argon gas is carried out using Eulerian approach [17]. Shell deformation and air gap dynamics study with flux penetration is carried out [18]. Lubrication model is developed to investigate the thermal resistance and interface study is carried out for different casting speeds [19]. The shape of solid/liquid interface, shell thickness, segregation and dendritic growth rate morphology are also studied [20]. Solute distribution characteristics with centreline segregation is examined using coupled multiphase model [21]. Most of these numerical studies are carried out using coupled steady state models and ignore the initial solidification. Hence in the present study, a transient three-dimension coupled numerical model is developed to investigate different flow and thermal parameters.

2 Mathematical Model

2.1 Geometry Details

Schematic diagram of calculation domain is shown in Fig. 1. Only a quarter of the slab is taken for study due to symmetry about *ZX* and *ZY* plane. All the details of the geometry are given in Table 1.

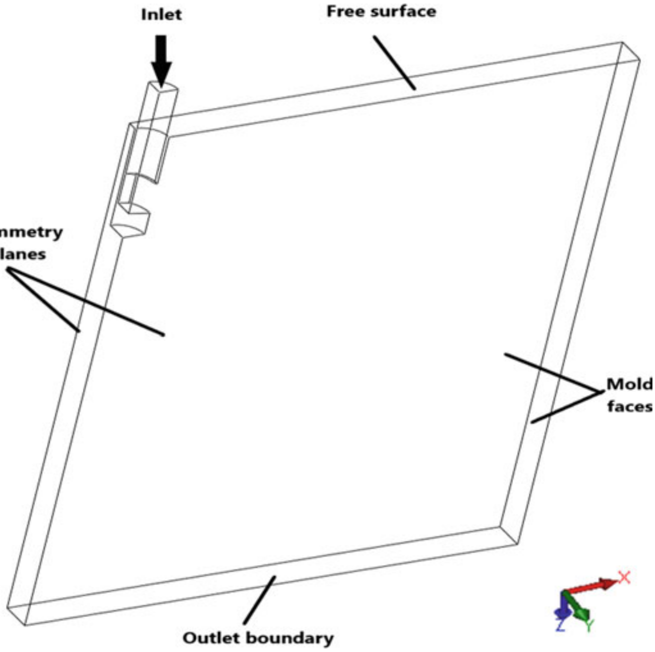


Fig. 1 Schematic model of slab

Table 1 Geometry details of slab

Parameters	Value
Slab size (m × m)	1.58 × 0.1
Mold length (m)	1
SEN inner diameter (m)	0.06
SEN outer diameter (m)	0.08
Depth of submergence of SEN (m)	0.16
SEN port angle (°)	15
SEN type	Double port

2.2 Governing Equations [22–24]

A three-dimensional flow field is calculated by solving Navier–Stokes Eqs. (1–2).

Continuity equation

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u_i)}{\partial x_i} = 0 \tag{1}$$

Momentum equation

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial(\rho u_i u_j)}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\mu_e\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)u\right) - S_{\text{sink}} + \rho\vec{g} \tag{2}$$

$$S_{\text{sink}} = \frac{\partial p}{\partial x_i} - \frac{(1-\beta)^2}{\left(\beta^3 + 0.001\right)} A_{\text{mush}}(u_i - u_s)$$

momentum sink term S_{sink} is introduced due to reduced porosity of cell to account for pressure drop caused by solidification.

A realizable k-ε model is used for turbulence modeling. This model is differed from standard k-ε due to its alternative formulation of turbulent viscosity and modified dissipation rate equation. Turbulent kinetic energy and dissipation rate equations are given by Eqs. (3–4).

$$\frac{\partial \rho k}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho k u_j\right) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k - \rho\varepsilon \tag{3}$$

G_k represents the generation of turbulence kinetic energy due to the mean velocity gradients.

$$\frac{\partial \rho\varepsilon}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho\varepsilon u_j\right) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \rho C_1 S\varepsilon - \rho C_2\frac{\varepsilon^2}{k + \sqrt{\upsilon\varepsilon}} \tag{4}$$

Energy equation

$$\frac{\partial \rho H}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i H) = \frac{\partial}{\partial x_i}\left(\frac{k_{eff}}{c_p}\frac{\partial H}{\partial x_i}\right) - \frac{\partial\left(\rho\beta u_i \Delta H_f\right)}{\partial x_i} - \frac{\partial\left[\rho(1-\beta)\left(u_i - u_j\right)\Delta H_f\right]}{\partial x_i} \tag{5}$$

where

$$\mu_e = \mu + \mu_t, \quad G_k = \mu_t\frac{\partial u_j}{\partial x_i}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right),$$

$$C_1 = \max.\left[0.43, \frac{\eta}{\eta+5}\right], \ \eta = S\frac{k}{\varepsilon},$$

$$\mu_t = \rho C_\mu\frac{k^2}{\varepsilon}, \ C_\mu = \frac{1}{A_O + A_S\frac{kU^*}{\varepsilon}}, \ U^* = \sqrt{S_{ij}S_{ij} + \hat{\Omega}_{ij}\hat{\Omega}_{ij}}$$

$$\hat{\Omega}_{ij} = \Omega_{ij} - 2\varepsilon_{ijk}\omega_k; \ \Omega_{ij} = \overline{\Omega}_{ij} - \varepsilon_{ijk}\omega_k,$$

$$A_O = 4.04, \ A_s = \sqrt{6}\cos\emptyset$$

$$\emptyset = \frac{1}{3}\cos^{-1}\sqrt{6}W,\ W = \frac{S_{ij}S_{jk}S_{ki}}{\hat{S}^3},\ \hat{S} = \sqrt{S_{ij}S_{ij}}\ S_{ij} = \frac{1}{2}\left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j}\right)$$

$$\Delta H = \beta\Delta H_f,\ H = h + \Delta H,\ h = h_{\text{ref}} + \int_{\text{ref}}^{T} C_{\text{p}}\text{d}T,\ k_{\text{eff}} = k_l + \frac{C_{\text{p}}\mu_t}{Pr_t}$$

$$\beta = 0 \quad \text{if } T < T_{\text{Solidus}}$$

$$\beta = l \quad \text{if } T > T_{\text{liquidus}}$$

$$\beta = \frac{T - T_{\text{Solidus}}}{T_{\text{liquidus}} - T_{\text{Solidus}}} \quad \text{if } \ T_{\text{Solidus}} < T < T_{\text{liquidus}}$$

2.3 Assumption and Boundary Conditions

Due to the complexity of numerical modeling following assumption are incorporated

1. Mold oscillation is neglected.
2. Mold powder effect is not considered.
3. Argon flow in mold is ignored.
4. Inclusion transport and entrapment are not considered.
5. Steel surface shape fixed and fluctuation of the top surface is ignored.

Velocity inlet boundary conditions are given to the inlet face. Other inlet variables kinetic energy and energy dissipation are computed using Eq. (6). In addition, pouring temperature 1811 K is given to inlet face. Zero shear stresses are provided to the free surface. Due to symmetry about two planes (*ZX* and *ZY*), only a quarter of slab caster is taken for study. No-slip is provided to walls that are in contact with molds and moving wall boundary condition is provided for wall motion. Casting speed is 1.6 m/min and same is given to outlet. Liquidus and solidus temperature values are 1805 and 1783 K. Temperature-dependent-specific heat and thermal conductivity are taken. Savage and Prichard [25] expression is used as UDF for mold wall heat flux. Other physical parameters and process variables are given in Table 2

Table 2 Physical properties of steel and process variables [21]

Specific heat capacity (J kg^{-1} K^{-1})	319.59 + 0.19 T
Thermal conductivity (W m^{-1} K^{-1})	57.524–0.016 T
Viscosity (Pa s)	0.0067
Solidus temperature (K)	1783
Latent heat of solidification (J/kg)	272,000

$$k_{\text{in}} = 0.01u_{\text{in}}^2, \quad \varepsilon_{\text{in}} = \frac{k_{\text{in}}^{3/2}}{R_{\text{Nozzle}}} \tag{6}$$

2.4 Numerical Solution Procedure

The academic research CFD code FLUENT 19.2 is used for solving the governing equations. Structured Hexagonal mesh is used for meshing. Near wall mesh is fine because of the high thermal gradient and solidification near wall. Both convection and diffusion terms are discretized using second-order upwind scheme. First order upwind scheme is for turbulent terms kinetic and dissipation energy terms. SIMPLE algorithm is used for numerical solution schemes. Realizable k-ε model is used for turbulent modeling. Standard wall function is used for near-wall treatment. Enthalpy-porosity method has been used for the solidification process. In this method, the interface of solid and liquid is not tracked explicitly. Instead, a quantity called the liquid fraction, which gives the fraction of cell volume that is not in solid form, is coupled in all the cells in the domain. The liquid fraction is computed at each iteration, based on an enthalpy balance. Due to solid fraction in the cell, it associated as a sink term in the momentum equation as shown in Eq. (2). Pull velocity is patched after solution initialization. Simulation is carried out on a computer with a 2.20 GHz Intel® Xeon® 5120 CPU, 64 GB RAM. Residual is set at 10^{-4}. Initially, 0.00001-time step size is used. After solution stabilization, it increased to 0.0001.

2.5 Grid Independence Test

A grid independence test is carried out to find the best grid size. Temperature values are computed at equally distributed five points along axial direction on wide face at midplane of narrow face and nozzle center plane. Three different mesh sizes (coarse grid, fine grid, very find grid) are taken and temperature values are computed as shown in Fig. 2. Temperature values are almost same for fine and very fine grid sizes. Therefore, fine grid sizes are taken for this study and corresponding mesh is shown in Fig. 3.

2.6 Validation Study

Due to the non-availability of experimental data, the current numerical method is validated against previously published results [11] of solid shell thickness for mold dimension of 0.162 m × 0.162 m × 0.78 m. They had used quarter of the domain for simulation. Species dependent liquidus and solidus temperature were taken. Surface

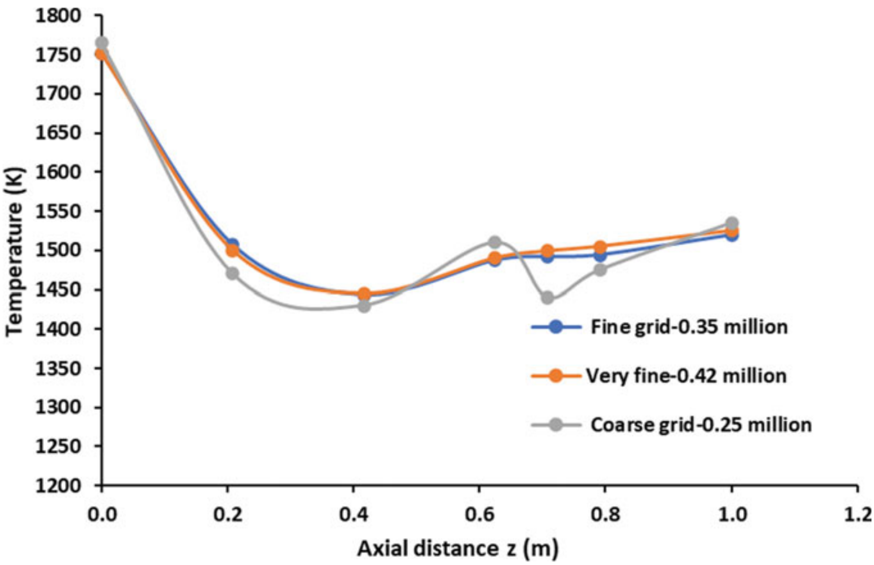


Fig. 2 Temperature values along axis at mid plane of narrow face and nozzle center plane

heat flux was provided as boundary conditions. Result of shell thickness correspond to liquid fraction 0.3 is shown in Fig. 4. It can be seen that the present model result almost matches with the published literature result. Therefore, the current numerical model can be used for further study.

3 Results and Discussion

Figure 5 represents velocity vectors and turbulent kinetic energy contour at symmetry plane *ZX*. A strong jet is formed after molten metal comes out from nozzle port and directed towards the narrow face. Jet velocity decreases significantly before it strikes at an impinge point and forms two circulating zones. Turbulent kinetic energy is very high near to the nozzle port region and contributes to momentum transfer to the nearby fluid. Location of impinge point mainly depends on the nozzle port angle. Circulating zones play an important role in superheat transfer. Upper circulation zone also assists in drifting inclusions to upwards direction and subsequently captured by molten slag.

Figure 6 shows temperature contours along different sections at 100 s. Temperature uniformity is more near to the nozzle region. High heat transfer rate near to wide face and narrow face leads to non-uniform temperature distribution near to wall region. Corners are seen colder compared to other regions due to its fast heat removal. Superheat dissipation rate is more at nearby narrow face section, therefore, solidification starts from corner as shown in Fig. 6a. Solid fraction increases on moving

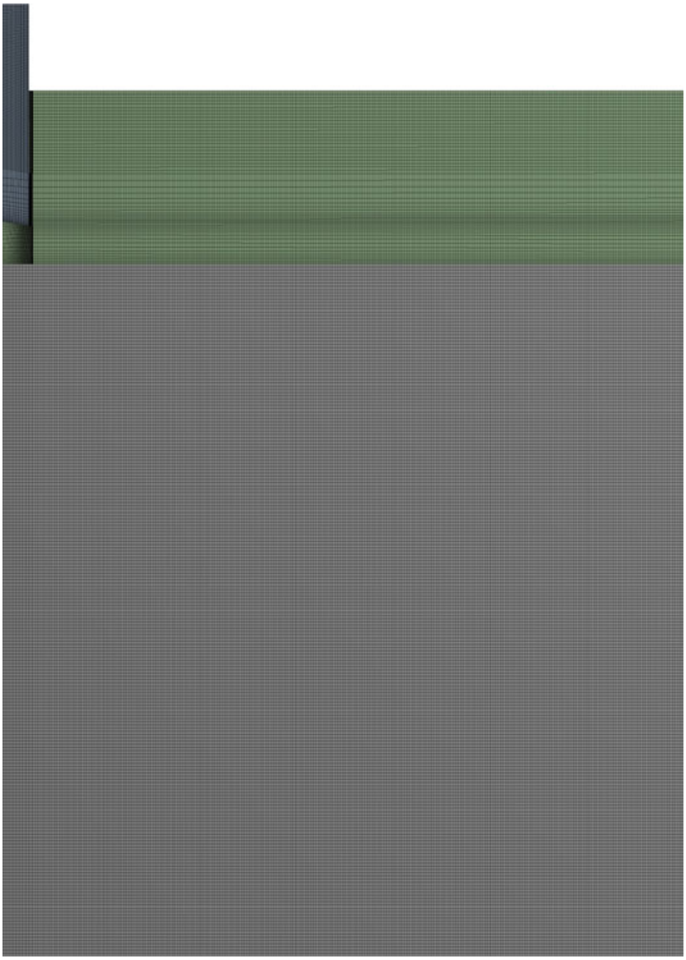


Fig. 3 Mesh adopted for study

from top to bottom section as shown in Fig. 6b. Transfer of superheat decreases as the distance from nozzle increases. Solidification close to the nozzle region vanishes continuously due to continuous supply of superheat by fresh molten metal.

Figure 7 shows shell thickness along axial direction at different time intervals: 50, 100, 150 s. Line shows shell thickness at the center plane at width growing in thickness direction. Thickness increases continuously in axial direction up to 0.65 m than it decreases and beyond 0.8 m, it again increases. This pattern arises because high-speed jet from nozzle strikes at narrow face at imping point and transfer superheat continuously and consequently melt initial solidification. Curves for 100 and 150 s are almost same as an indication of steady-state achieved by the process.

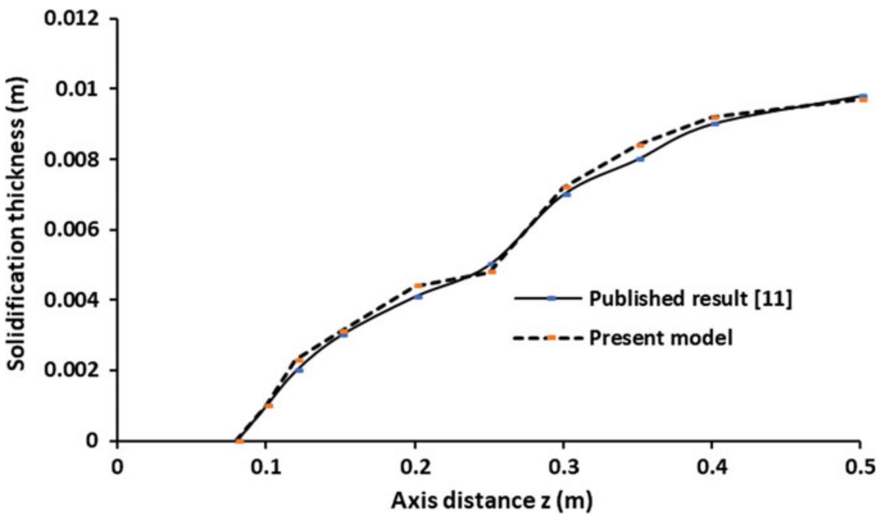


Fig. 4 Validation study

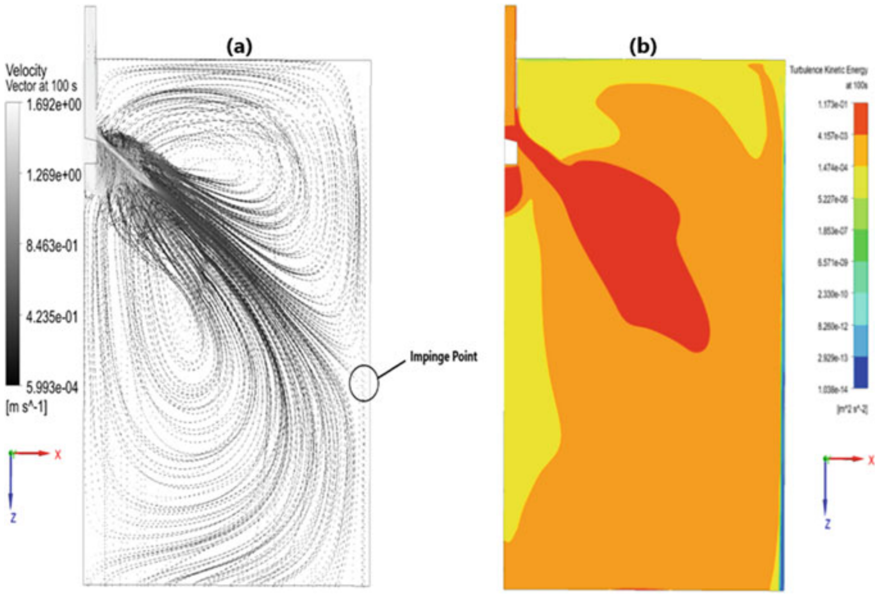


Fig. 5 Symmetry plane ZX **a** velocity vectors, **b** turbulent kinetic energy contour

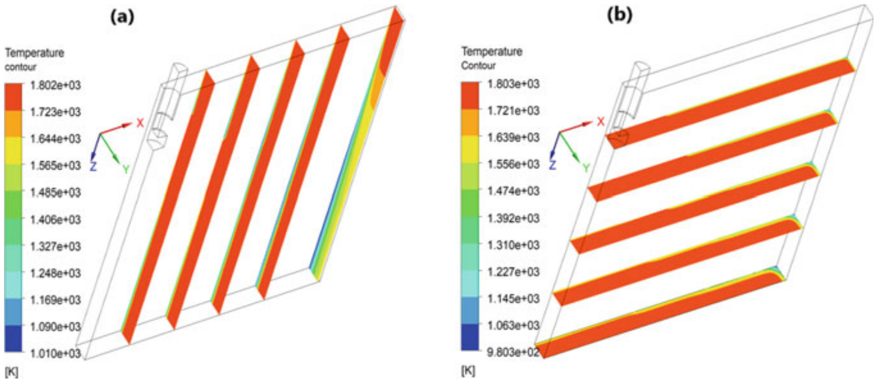


Fig. 6 Temperature contours **a** vertical sections across caster, **b** transverse section down caster

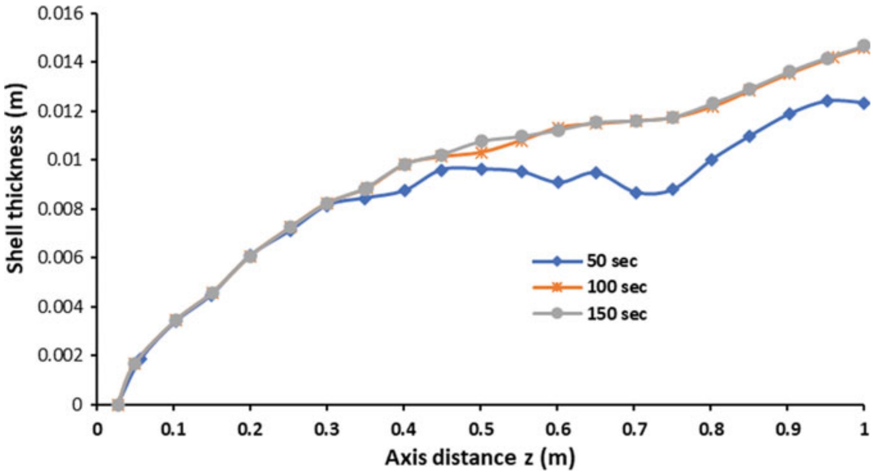


Fig. 7 Shell thickness along axial direction at different time

4 Conclusions

A three-dimensional transient coupled fluid flow, heat transfer and solidification model is developed to investigate different flow and thermal parameters. The findings can be summarized as follows:

1. Two circulating zones are formed after jet strike at nozzle face. Upper zones help in superheat transfer and drift inclusions to slab top surface.
2. Temperature distribution is non-uniform near to narrow face due to high heat removal. Solidification in continuous casting mold achieves equilibrium after 100 s.

3. Shell thickness first increases along axial direction then decreases at impinge point due to high superheat transfer and then further increase. Maximum heat removal observed at corners.

References

1. Grill, A., Brimacombe, J.K.: Heat flow, gap formation and break-outs in the continuous casting of steel slabs. Metall. Trans. B, **7** (1976)
2. Mahapatra, R.V., Brimacombe, J.K., Samarasekera, I.V., Walker, N., Paterson, E.A., Young, J.: Mold behaviour and its influence on quality in the continuous casting of steel slabs: part 1.industrial trials, mold temperature measurements, and mathematical modeling. Metall. Trans. B, **22** (1991)
3. Zhang, L., Shen, H.F., Rong, Y., Huang, T.Y.: Numerical simulation on solidification and thermal stress of continuous casting billet in mold based on meshless methods. Mater. Sci. Eng. A **466**(1–2), 71–78 (2007)
4. Zhang, L., Yang, S., Cai, K., Li, J., Wan, X., Thomas, B.G.: Investigation of fluid flow and steel cleanliness in the continuous casting strand. Metall. Mater. Trans. B Process Metall. Mater. Process. Sci., **38**(1), 63–83 (2007)
5. Wang, X.D., Yao, M., Du, B., Fang, D.C., Zhang, L., Chen, Y.X.: Online measurement and application of mould friction in continuous slab casting. Ironmak. Steelmak. **34**(2), 138–144 (2007)
6. Thomas, B.G., Zhu, H.: Thermal distortion of solidifying shell near meniscus in continuous casting of shell. Solidif. Sci. Process. Conf. Honolulu, p. 12 (1995)
7. McDavid, R.M., Thomas, B.G.: Flow and thermal behavior of the top surface flux/powder layers in continuous casting molds. Metall. Mater. Trans. B Process Metall. Mater. Process. Sci.**27**(4), 672–685 (1996)
8. Huang, X., Thomas, B.G., Najjar, F.M.: Modeling superheat removal during continuous casting of steel slabs. Metall. Trans. B **23**(3), 339–356 (1992)
9. Takatani, K., Tanizawa, Y., Mizukami, H., Nishimura, K.: Mathematical model for transient fluid flow in a continuous casting mold. ISIJ Int. **41**(10), 1252–1261 (2001)
10. Meng, Y., Thomas, B.G.: Heat-transfer and solidification model of continuous slab casting: CON1D. Metall. Mater. Trans. B Process Metall. Mater. Process. Sci.**34**(5), 685–705 (2003)
11. Janik, M., Dyja, H.: Modelling of three-dimensional temperature field inside the mould during continuous casting of steel. J. Mater. Process. Technol., **157**–**158**, no. SPEC. ISS., 177–182 (2004)
12. Zhao, B., Thomas, B.G., Vanka, S.P., O'Malley, R.J.: Transient flow and temperature transport in continuous casting of steel slabs. Metall. Mater. Trans. B **127**(8), 807 (2005)
13. Guo, L., Wang, X., Zhan, H., Yao, M., Fang, D.: Mould heat transfer in the continuous casting of round billet. ISIJ Int. **47**(8), 1108–1116 (2007)
14. Feng Wu, D., Cheng, S.S., Jian Cheng, Z.: Characteristics of shell thickness in a slab continuous casting mold. Int. J. Miner. Metall. Mater., **16**(1), 25–31 (2009)
15. Wang, T.M., et al.: Continuous casting mould for square steel billet optimised by solidification shrinkage simulation. Ironmak. Steelmak. **37**(5), 341–346 (2010)
16. Xie, X., Chen, D., Long, H., Long, M., Lv, K.: Mathematical modeling of heat transfer in mold copper coupled with cooling water during the slab continuous casting process. Metall. Mater. Trans. B Process Metall. Mater. Process. Sci., **45**(6), 2442–2452 (2014)
17. Jonayat, A.S.M., Thomas, B.G.: Transient thermo-fluid model of meniscus behavior and slag consumption in steel continuous casting. Metall. Mater. Trans. B Process Metall. Mater. Process. Sci., **45**(5), 1842–1864 (2014)

18. Xin Song, J., Zhen Cai, Z., Yun Piao, F., Yong Zhu, M.: Heat transfer and deformation behavior of shell solidification in wide and thick slab continuous casting mold. J. Iron Steel Res. Int.**21**, no. SUPPL.1, 1–9 (2014)
19. Odagaki, T., Aramaki, N., Miki, Y.: Estimation of lubrication and heat transfer by measurement of friction force in mold. Tetsu-To-Hagane **102**(10), 560–566 (2016)
20. Zhong, H., Chen, X., Han, Q., Han, K., Zhai, Q.: A thermal simulation method for solidification process of steel slab in continuous casting. Metall. Mater. Trans. B Process Metall. Mater. Process. Sci., **47**(5), 2963–2970 (2016)
21. Chen, H., Long, M., Chen, D., Liu, T., Duan, H.: Numerical study on the characteristics of solute distribution and the formation of centerline segregation in continuous casting (CC) slab. Int. J. Heat Mass Transf. **126**, 843–853 (2018)
22. Dušek, J., Chrust, M., Bouchet, G.: Transitional dynamics of freely falling discs. Notes Numer. Fluid Mech. Multidiscip. Des. **133**(3), 105–116 (2016)
23. Kader, B.A.: Temperature and concentration profiles in fully turbulent boundary layers. Int. J. Heat Mass Transf. **24**(9), 1541–1544 (1981)
24. Bird, R.B., Stewart, W.E., Lightfoot, E.W.: Transport Phenomena. Wiley International Edition, New York (1960)
25. Savage, J., Prichard, W.H.: Savage. In: Prichard, J. W. H.," Jr. iron steel, p. 269 (1954)

Filler Composition Effect on the Mechanical Behavior of the Dissimilar Welds Joint

Sanjeev Kumar, Chandan Pandey, and Amit Goyal

Abstract The dissimilar welding of nuclear grade P91 and P92 steel was carried out using the shielded metal arc welding (SMAW) process. The dissimilar welded joint (DWJ) was subjected to mechanical and metallographic testing for as welded and post-weld heat treatment (PWHT) conditions. The SMAW joint was produced using the different filler composition (P91 filler and P92 filler). For the mechanical behavior of the DWJ, room temperature tensile tests, and Charpy toughness test was conducted for as welded and PWHT state. PWHT of the DWJ contributed a good amount of the ductility of the welded joint. The W and Mo-enriched P92 filler showed a higher tendency to unwanted δ ferrite phase formation as compared to the P91 filler.

Keywords Nuclear grade steel · SMAW · Charpy toughness · PWHT

1 Introduction

In the present day, the main aim of the new generation power plant is to operate at high efficiency with low emission of pollutants. The efficiency and emission of the pollution contents are mainly controlled by the working temperature and pressure of the stream. The operating temperature cannot be increased beyond a limit due to the instability of the microstructure and reduction in mechanical properties at high temperatures [1–3]. To meet the higher demand for efficiency, austenitic steels are replaced with martensitic grade Cr–Mo steel. P91, P92, P911, 10% Cr are the commonly used martensitic steels of the Cr–Mo family [4, 5]. As compared to austenitic steels, Cr and Mo-enriched martensitic steel offer a good combination of the strength and ductility as well as superior thermos-physical and mechanical properties at elevated temperature condition.

S. Kumar · A. Goyal
Mechanical Engineering Department, SRM IST Modinagar, Modinagar, Uttar Pradesh 201204, India

C. Pandey (✉)
Mechanical Engineering Department, IIT Jodhpur, NH 65 Nagaur Road, Karwar, Jodhpur 342037, India
e-mail: chandanpy.1989@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_58

The joint of martensitic steels is possible by many of the arc welding processes, but still, there is a number of weldability issues. Untempered martensitic crack susceptible microstructure in weld fusion zone, residual stresses, diffusible hydrogen, δ ferrite and variation in microstructure across the welded joint are the major issues that arise during the welding of such steels [6–9]. The δ ferrite formation in the welded joint is controlled by the rate of the heat input and ferrite stabilizer content in base metal and filler metal. The δ ferrite formation in the welded joint also leads the variation in mechanical properties, and Pandey et al. [10] also reported the hardness of the δ ferrite about 190–240 HV, which is approximately half of the hardens of the main matrix (untempered martensite). The heterogeneity introduced in microstructure as a result of the formation of the δ ferrite also governs the variation in mechanical properties, and it reduces the Charpy toughness and high-temperature mechanical performance of the welded joint [11, 12].

In present work, joining of the dissimilar P91 and P92 steel plates were performed for different filler composition. The effect of the filler composition on the tensile behavior and Charpy toughness (CT) of DWJ were studied. PWHT of the welds joint was also performed and mechanical properties of the welds joint in PWHT state compared with the as-welded joint.

2 Experimental Procedure

For the dissimilar joining normalized and tempered P91 and P92 steel plates of the dimension of 200 mm × 60 mm × 12 mm were utilized, and the chemical compositions of steel plates are depicted in Table 1. The welds joint were prepared using the shielded metal arc welding process (SMAW). A conventional V-groove design with groove angle 37.5, root height 1.5, root opening 1.5 and groove opening of 14.58 mm was prepared. For the groove filling purpose, flux coated P91 (9Cr–Mo–V–N) and P92 electrode (9Cr–Mo–1.8 W–V–N) of 4 mm diameter were utilized and the composition of the filler metals are depicted in Table 1. After the joining, PWHT at 750 °C/1 h has been conducted to impart the ductility to the DWJ and various conditions are depicted in Table 2. Table 3 shows the welding parameters used for making the DWJ.

For mechanical characterization, tensile and CT tests were conducted at room temperature. For tensile testing, standard specimen were prepared as per ASTM

Table 1 P91 and P92 steel and filler composition (wt.%)

Elements	C	Mn	Cr	Mo	W	V	Nb	Si	Rest
P91 base	0.10	0.52	9.30	1.05	-	0.20	0.05	0.50	Fe
P92 base	0.09	0.55	9.15	0.50	1.82	0.22	0.06	0.48	Fe
P91 filler rod	0.10	0.65	9.46	0.95	1.05	0.21	0.08	0.28	Fe
P92 filler rod	0.11	0.60	8.50	1.10	1.82	0.24	0.07	0.25	Fe

Table 2 Various welding and heat treatment conditions

Passes	Base plate	Filler metal
AW-P91	P91 and P92	P91 filler
AW-P92	P91 and P92	P92 filler
PWHT-P91	P91 and P92	P91 filler
PWHT-P92	P91 and P92	P92 filler

Table 3 Process parameters of the welding

Passes	Process	Welding current (I) amps	Arc voltage (V) volts	Welding travel speed (T) (mm/min)
Root pass	GTAW	115–120	14–15	110
Filler pass 1–8	SMAW	135	20–22	120–140

E8-04 standards, and tests were performed at a crosshead speed of 1 mm/min. The sub-size (55 mm × 10 mm × 7.5 mm) CT specimen was prepared for the DWJ as per ASTM A370. The micro-hardness of DWJ was performed on Vickers Hardness Tester for a load of 500 g.

3 Results and Discussion

3.1 As-Received Microstructure of P91 and P92 Steel

The micrograph of P91 and P92 steel consist of tempered martensite with prior austenite grain boundaries (PAGBs), distinct lath blocks, and lath packets with coarse Cr, W and Mo-enriched $M_{23}C_6$ precipitates of size 200 nm and fine Nb and V-rich

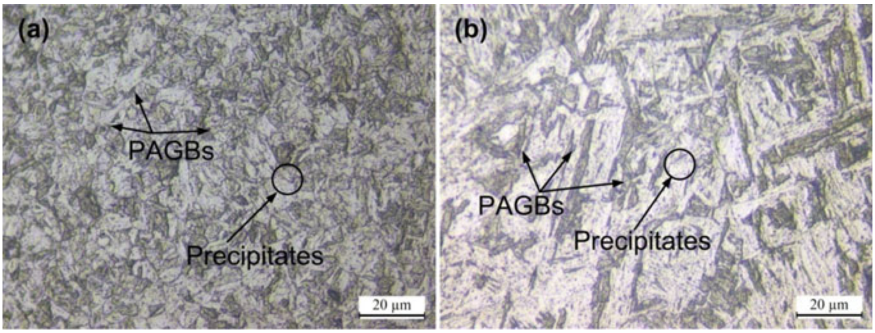


Fig. 1 **a** Optical micrograph of as-received P91 steel, **b** as-received P92 steel

MX precipitates of size less than 40 nm. Figure 1 shows (a) Optical micrograph of as-received P91 steel, (b) as-received P92 steel.

3.2 Micrograph of Weld Fusion Zone

Figure 2 shows the typical SEM image of the weld fusion zone (WFZ) for DWJ in the different heat treatment conditions. The welding heat results in an increase in solid solution hardening and formation of brittle untempered martensite with a high carbon weight percentage. The heat input during the welding results in higher carbon and nitrogen in solid solution of the weld fusion zone due to precipitates consumption. Figure 2a shows the typical martensitic lath blocks in WFZ for AW–P91 condition. Microstructure looks similar for AW–P92 condition except the presence of ferrite patches that make the microstructure heterogeneous for P92 filler (Fig. 2b). The effect of PWHT is shown in Fig. 2c, d. The PWHT imparts the ductility to the welded joint and removes the quench stresses due to precipitation hardening. The micrograph after PWHT revealed the presence of the tempered martensite with precipitates along with lath blocks and PAGBs for both the filler condition; however, ferrite patched remains unaffected, as shown in Fig. 2d. In PWHT–P92 condition, δ ferrite formation is

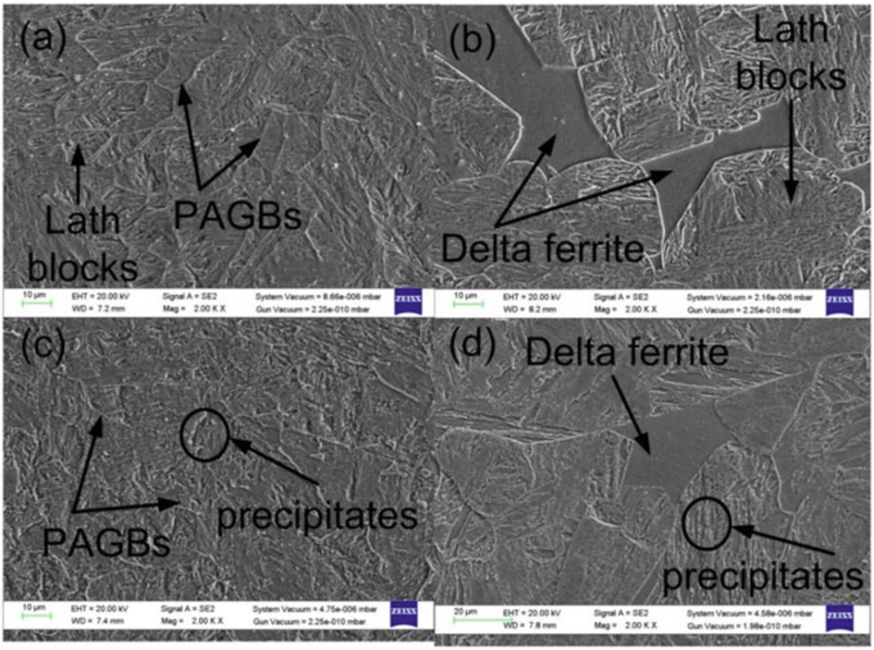


Fig. 2 SEM image of weld fusion zone for DWJ showing lath blocks, PAGBs, precipitates and delta ferrite for different condition: **a** AW–P91, **b** AW–P92, **c** PWHT–P91 and **d** PWHT–P92

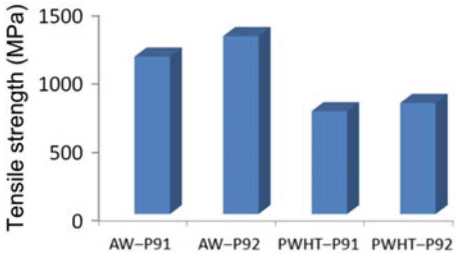


Fig. 3 Tensile strength of DWJ for different conditions

attributed to the presence of the higher amount of ferrite stabilizer (W, and Mo) in P92 filler.

3.3 *Mechanical Testing*

In the as-welded (AW) condition, tensile strength was measured 1150 ± 15 and 1300 ± 15 MPa for P91 and P92 filler (Fig. 3). The higher strength of DWJ in AW condition is attributed to solid solution hardening. For the as-received plate, the UTS were 714 and 650 MPa, respectively. In P92 filler, higher weight percentage of W might be the possible cause of higher tensile strength in AW–P92. After PWHT, considerable lowering in the tensile strength is attributed to the evolution of precipitates in the form of carbide and nitrides. Tensile strength was measured 750 ± 25and 810 ± 20 MPa for PWHT–P91 and PWHT–P92 condition, respectively.

The average hardness was measured 510 ± 15 and 490 ± 22 HV for P91 and P92 filler, respectively. However, tensile strength was measured maximum for P92 filler, but the average hardness of WFZ was measured less than that of P91 filler and lowering in hardness value might be the cause of δ ferrite patches. The hardness was also measured along the DWJ and it shows a significant variation. The heterogeneity in the hardness of WFZ for P92 filler might be due to the formation of δ ferrite patches. The heating of the filling passes by subsequent filling passes also causes the variation in hardness in WFZ due to the tempering reaction. The change in hardness along the DWJ also confirms the heterogeneous microstructure formation along the DWJ. The average hardness of WFZ was reduced after PWHT, and it was measured 300 ± 10 and 345 ± 14 HV for P91 and P92 fillers, respectively. The lowering in hardness value of DWJ after PWHT is attributed to the reduction in solid solution hardening as a result of tempering reaction. The hardness variation along the welded joint for different filler and PWHT condition are given in Fig. 4. The δ ferrite hardness measured in the range of 300–235 HV that also might be the possible cause of the failure of the welded joint.

The CT test results for the WFZ are depicted in Table 4. The CT of the WFZ (as-welded) was measured less than the minimum required value of 47 J and poor CT of WFZ is attributed to the presence of brittle martensite with higher weight percentage of C and N. The PWHT of DWJ results in drastic increase in the CT. It occurs due to

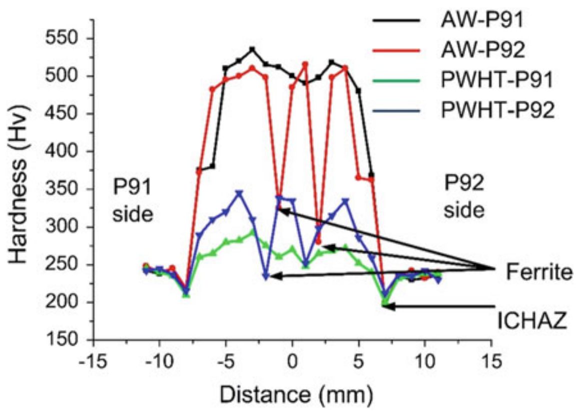


Fig. 4 Hardness variation across the P91 and P92 welded joint for different and filler PWHT condition

Table 4 Charpy toughness of WFZ for different welds condition

Weld condition	Charpy toughness (J)
AW–P91	10 ± 2
AW–P92	8 ± 4
PWHT–P91	70 ± 5
PWHT–P92	35 ± 2

the tempering of the martensite and carbide and nitride precipitates formation. After PWHT, CT was measured 70 ± 5 and 35 ± 2 for P91 and P92 filler, respectively. The CT for P92 filler is still measured lower than the minimum recommended value, and it requires the PWHT for more than 1 h.

4 Conclusions

1. The inferior mechanical properties were measured for the P92 filler metal than that of P91 filler, and it occurred due to the formation of δ ferrite patches for P92 filler.
2. For as-welded joint, strength and hardness were measured much higher than that of PWHT joint due to untempered martensite. The poor CT of WFZ for both the filler conditions is also due to untempered martensitic microstructure.
3. PWHT resulted in the reduction in tensile strength as a result of tempering reaction for different filler condition. The decrease in microhardness and tensile strength might be due to the tempering of the martensite. The improved Charpy toughness was observed after the PWHT.

References

1. Li, L., Silwal, B., Deceuster, A.: Creep rates of heat-affected zone of grade 91 pipe welds as determined by stress-relaxation test. Int. J. Press. Vessel. Pip. **146**, 95–103 (2016)
2. Silwal, B., Li, L., Deceuster, A., Griffiths, B.: Effect of postweld heat treatment on the toughness of heat-affected zone for Grade 91 steel. Weld. J. **92**, 80s–87s (2013)
3. Pandey, C., Mahapatra, M.M., Kumar, P., Saini, N.: Some studies on P91 steel and their weldments. J. Alloys Compd. **743**, 332–364 (2018)
4. Greenfield, P., Marriott, J., Pithan, K.: A Review of the Properties of 9–12% Chromium Steels for Use as HP/IP Rotors in Advanced Steam Turbines (1989)
5. Abson, D.J., Rothwell, J.S.: Review of type IV cracking of weldments in 9–12 % Cr creep strength enhanced ferritic steels. Int. Mater. Rev. **58**, 437–473 (2013)
6. Schafer, L.: Influence of delta ferrite and dendritic carbides on the impact and tensile properties of a martensitic chromium steel. J. Nucl. Mater. **258–263**, 1336–1339 (1998)
7. Sam, S., Das, C.R., Ramasubbu, V., Albert, S.K., Bhaduri, A.K., Jayakumar, T., Rajendra Kumar, E.: Delta ferrite in the weld metal of reduced activation ferritic martensitic steel. J. Nucl. Mater. **455**, 343–348 (2014)
8. Mayr, P., Mitsche, S., Cerjak, H., Allen, S.M.: The impact of weld metal creep strength on the overall creep strength of 9% Cr steel weldments. J. Eng. Mater. Technol. **133** (2011)
9. Pandey, C., Mahapatra, M.M., Kumar, P., Saini, N., Srivastava, A.: Microstructure and mechanical property relationship for different heat treatment and hydrogen level in multi-pass welded P91 steel joint. J. Manuf. Process. **28**, 220–234 (2017)
10. Pandey, C., Mahapatra, M.M., Kumar, P., Saini, N., Thakre, J.G., Vidyarthy, R.S., Narang, H.K.: A brief study on d-ferrite evolution in dissimilar P91 and P92 steel joint and their effect on mechanical properties. Arch. Civ. Mech. Eng. **18**, 713–722 (2018)
11. Pandey, C., Giri, A., Mahapatra, M.M.: Effect of normalizing temperature on microstructural stability and mechanical properties of creep strength enhanced ferritic P91 steel. Mater. Sci. Eng. A. **657**, 173–184 (2016)
12. Saini, N., Pandey, C., Mahapatra, M.M.: Characterization and evaluation of mechanical properties of CSEF P92 steel for varying normalizing temperature. Mater. Sci. Eng. A. **688**, 250–261 (2017)

Trochoidal Tool Path Planning Method for Slot Milling with Constant Cutter Engagement

A. Jacso, Gy. Matyasi, and T. Szalay

Abstract For high-speed machining, special tool paths are required wherewith the tool load is well-controlled, and the path is sufficiently smooth. One of the most effective solutions for controlling the tool load is to keep the cutter engagement constant. For this purpose, advanced tool path generating cycles are available in CAM systems. In case of slot machining, these cycles result in a trochoidal tool path. Since the CAM systems generate these tool paths regardless of the special geometric boundary conditions, each trochoidal period must be calculated separately. However, in our previous researches, it has been observed that the loops of the trochoidal tool path which provide a constant cutter engagement become uniform after a few periods. In this paper, a new method is presented, which can be used for generating this uniform trochoidal tool path shape. The developed method was compared to conventional trochoidal strategies, that were using circular or cycloid curves, and it proved to be significantly better than the traditional solutions. Considering its improved machining efficiency, simplifying the calculation process of this modern strategy can facilitate a wider use. In addition, the formal description of the path generation method provides further opportunities for optimisation.

Keywords Slot milling · Trochoidal tool path · Cutter engagement · Tool path generation · HSM machining

1 Introduction

Cutting technology still plays a leading role in manufacturing. The advancement of high-speed machining (HSM) was a major step forward in terms of both machining quality and efficiency. However, this technology not only imposes new requirements on the machine tool but also needs a different approach in tool path planning. Conventional tool path strategies where the path curvature is not continuous and the tool load fluctuates strongly cannot be used for HSM [1]. To ensure uniform tool load and to

A. Jacso (✉) · Gy. Matyasi · T. Szalay
Department of Manufacturing Sciences and Engineering, Faculty of Mechanical Engineering, Budapest University of Technology and Economics, Budapest, Hungary
e-mail: jacso@manuf.bme.hu

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_59

avoid sharp corners in the tool path, spiral and trochoidal tool paths are best suited [2]. With these strategies, it is possible to control the cutter engagement, which means that sudden increases in cutting force can be avoided even without using adaptive feed rate [3]. This paper deals with machining of straight slots, where trochoidal tool paths are especially preferable.

The trochoidal strategy has some specific application area [4], but it is particularly useful for difficult-to-cut materials for which full tool immersion is not allowed. In conventional trochoidal tool paths, the loops consist of circular or cycloid-shaped arcs. Formulas have been deduced for these tool paths to calculate chip thickness [5] and cutter engagement [6]. However, these values are constantly changing along the path; therefore, the tool can work in optimal conditions only temporarily. In this regard, modifying the shape of trochoidal loops to overcome this problem is still an important research area [7].

This paper is based on our previous work wherein it was examined how to keep the cutter engagement at a constant value in contour milling. For this purpose, we have developed a new tool path generation algorithm [8]. The method has been tested on different sample geometries, one of which was a straight slot. Due to geometric constraints, this was only possible with a trochoidal tool path. By analysing the trochoidal loops, it was observed that after a few periods the same shape was repeated. In other words, the generated loops converged to a uniform shape. Tests run with different input parameters resulted in the same conclusion. This recognition significantly simplifies the application since, for a long slot, it is not necessary to perform the calculations for the entire tool path, but it is sufficient to determine only one loop. In this paper, the method of calculating this single loop is described in detail.

2 The Advanced Tool Path Generation Method for Slot Milling

The path generation process can be divided into consecutive stages. Firstly, the input data have to be provided. After that, a trochoidal loop has to be generated for an initial contour. This step consists of three tasks: (1) determining the starting point for tool entering, (2) calculating the internal path segment by controlling the engagement, (3) determining the path for tool exiting. Once this is done, the machined contour has to be calculated, which can be used to generate the next trochoidal loop by the previous procedure. This process must be repeated until the iteration reaches a path shape that no longer changes. After that, the final task is to link the loops. In the following sections, these steps will be detailed in greater depth.

2.1 Input Data

During the development of the algorithm, we tried to minimise the number of input data. Accordingly, the calculations have been developed for a normalised geometry. However, this does not impose any restrictions on the application since the path shape can be applied under any circumstances by using geometric transformations such as scaling, rotating and translating. The geometric normalisation can be formulated as follows: (1) the tool radius is a unit length ($r = 1$), (2) the slot's longitudinal axis is parallel to the Y-axis, and (3) the slot's starting point is (0,0). As a result, the tool path can be defined by three parameters: (1) the ratio of the tool radius and the slot width ($b = sw/r$), (2) the desired value of cutter engagement (θ), and (3) the radius of path curvature for tool entering and exiting (ρ). The correct choice of ρ depends on the machine tool's acceleration capability (a) and the feed rate to be used (v_f). Namely, the nominal feed rate can be maintained along the arcs only if the following condition is met: $\rho \geq v_\mathrm{f}^2/a$. It would be possible to specify separate values for rolling in and out, however, it is not addressed in this paper, because the main focus is on the cutting part of the tool path.

The shape of the initial contour should also be discussed. During the development, it has been observed that the initial contour does not influence the resulting path shape. For this reason, it is possible to start from a curved contour, which facilitates the implementation of the method. Based on this, a semicircular arc was chosen. In order to provide consistency with the subsequent steps, the starting contour should be defined as a parametric equation on the interval [0, 1]:

$$\vec{c}(t) = \left(b/2 - bt, \sqrt{(b/2)^2 - (b/2 - bt)^2}\right) \tag{1}$$

where $t \in [0, 1]$ is the parameter, and b is the ratio of tool radius and slot width.

2.2 Tool Entering

At the beginning of each loop, the tool rolls into the material along a circular arc. However, at this stage of path planning, it is not possible to determine the starting point of this arc, because the position of the previous loop is not yet known. Therefore, only the endpoint of tool entering is to be calculated. This is shown in Fig. 1.

The following notation shall be introduced: P_0 is the tool centre point, C_0 is the entry point of tool edge, Q_0 is the exit point of tool edge, $\vec{v}_0$ is the tool path's tangential unit vector corresponding to point P_0. When the tool touches the slot's sidewall, the tool path tangent must be parallel to it: $\vec{v}_0 = (0, 1)$. According to Fig. 1, the X coordinate of point C_0 can be calculated: $C_{0(x)} = b/2 - r(1 - \cos\theta)$. Since the point C_0 lies on the contour curve $\vec{c}(t)$, where only one point is associated with each X coordinate, the parameter t_0 for point C_0 can be determined by solving the

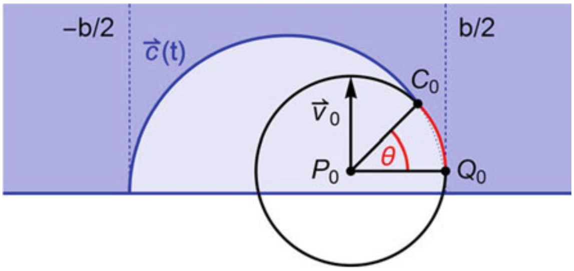


Fig. 1 Determining the endpoint of tool entering

following equation for the first coordinate: $\vec{c}(t_0) = \left(C_{0(x)}, C_{0(y)}\right)$. It can be deduced that the current tool position can be determined if the entry point of the tool edge (C_0), the desired cutter engagement (θ), and the feed direction's unit vector ($\vec{v}_0 = (0, 1)$) are known:

$$P_0 = C_0 + \begin{bmatrix} \cos(\pi/2 + \theta) & \sin(\pi/2 + \theta) \\ -\sin(\pi/2 + \theta) & \cos(\pi/2 + \theta) \end{bmatrix} \vec{v}_0 \quad (2)$$

After the endpoint of tool entering has been calculated, it will be possible to determine the internal path segment.

2.3 Internal Path Segment

As mentioned in the introduction, we have developed a new algorithm to generate contour milling tool paths to provide a constant cutter engagement. This algorithm is called FACEOM (Fast Constant Engagement Offsetting Method). In this paper, only a schematic description of the method is provided, the details can be found in Ref. [8].

Figure 2 shows the procedure for calculating the internal points of the path. Assume that two points are known at the parameter t_i: the tool centre point P_i, and the entry point of tool edge $C_i = \vec{c}(t_i)$. The feed direction's unit vector corresponding to point P_i which provides the desired cutter engagement θ can be calculated by the

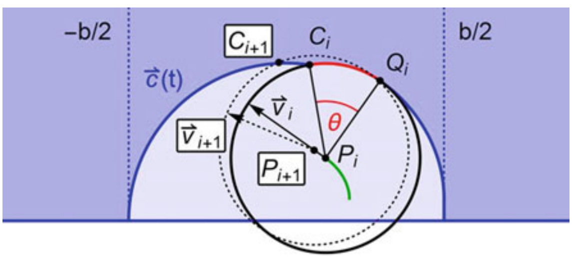


Fig. 2 Determining the internal points of tool path (illustration with a large step size)

following formula:

$$\vec{v}_i = \begin{bmatrix} \cos(\pi/2 - \theta) & -\sin(\pi/2 - \theta) \\ \sin(\pi/2 - \theta) & \cos(\pi/2 - \theta) \end{bmatrix} (C_i - P_i) \tag{3}$$

For determining the subsequent tool position, a new point along the contour has to be calculated: $C_{i+1} = \vec{c}(t_i + \Delta t)$. From point P_i, the tool moves in the direction of the unit vector $\vec{v}_i$. At the subsequent point marked with P_{i+1}, the tool's boundary reaches the point C_{i+1}. Thus, the point P_{i+1} can be determined by solving a parametric equation. After that, the appropriate feed direction corresponding to P_{i+1} can be recalculated based on Eq. (3). By changing the step size Δt, the accuracy of cutter engagement control can be adjusted. This procedure can be repeated, generating the tool path in short segments. However, if this calculation method were repeated to the end of the contour, it would form an overcut on the slot's sidewall. Thus, tool exiting must be treated differently.

2.4 Tool Exiting

The tool leaves the material along a circular arc, and when the tool reaches the slot's sidewall, the tangent vector of the tool path must be parallel to it. However, determining the angular position at which the roll-out begins requires some calculations. This transitional situation is shown in Fig. 3.

The following markings should be introduced: P_i is the last calculated tool path point, $\vec{v}_i$ is the unit vector of the corresponding feed direction. If the tool is far enough away from the slot's sidewall, the tool path will continue at point P_{i+1} as calculated in the previous section. If it is not far enough, the tool moves along the unit vector $\vec{v}_i$ only to P_n, and rolls out to P_{m} along a circular arc with centre point P_{ro} and radius $\rho = \left|\overline{P_{\mathrm{m}} P_{\mathrm{ro}}}\right|$. Tool exiting begins when the following condition is met:

$$P_{i+1(x)} < -b/2 + r + \rho(1 - \cos\alpha) \tag{4}$$

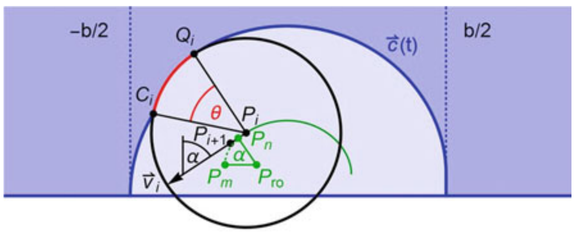


Fig. 3 Determining the start point of tool exiting

where $P_{i+1(x)}$ is the first coordinate of point P_{i+1}, α is the angle between the vectors $(0, -1)$ and $\vec{v}_i$, which is equal to the central angle of the circular arc with radius ρ.

2.5 Iteration for Determining the Uniform Path Shape

After accomplishing the previous steps, the first loop is completed. For repeating this procedure, the actual workpiece boundaries must be recalculated after each loop. This is possible by determining the offset curve of the tool path. This can be expressed with the parametric equation of the calculated tool path and the path tangent. Unfortunately, in this phase, the tool path's parametric equation is not available. This deficiency can be overcome by fitting a spline to the calculated points P_i. However, it is better to determine the exit points of tool edge for each calculated tool position, and directly fit a spline to these points, getting the new contour curve. From the known data, these points can be calculated using the following equation:

$$Q_i = P_i + \begin{bmatrix} 0 & \mathrm{r} \\ -r & 0 \end{bmatrix} \vec{v}_i \tag{5}$$

For spline fitting, cubic B-Spline was used with chord length parameterisation and non-uniform knot vector. The reason for using a so-called average knot vector is to avoid oscillation in the spline curve.

The method can be used to generate loops one after the other by considering the last computed spline function as the parametric equation describing the actual contour. However, it has to be discussed how many iteration steps must be executed to get the uniform path shape. For this, the deviation between the consecutive loops has to be quantified. The simplest way to perform this is to align the forwardmost point of each loop to the same Y coordinate, and then the distance between the adjacent curves along the Y-axis can be calculated. The iteration must be performed until this deviation is greater than a predefined accuracy limit. Figure 4 shows the evolution of the mean and maximum deviations according to the iteration steps for the following normalised input data: $\theta = 45°$, $r = 1$, $b = 10/3$, $\rho = 1/3$.

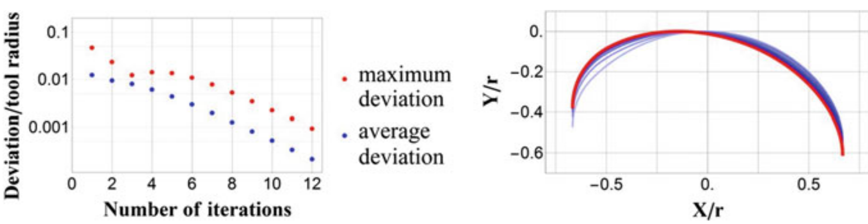


Fig. 4 Evolution of the tool path's shape during the iteration

Figure 4 shows the evolution of the trochoidal loops, where the accuracy limit was applied to the maximum deviation: $\varepsilon_{\max} \leq 0.001$. The convergence is fast and, in the vast majority of cases, monotonous. If the final path shape has been established, a spline can be fitted to the points of the last loop as a parametric equation of the path ($\vec{p}(t)$). In addition, the distance from the previous loop along the Y-axis determines the value of the trochoidal step (w).

2.6 Linking the Trochoidal Loops

The last step of tool path planning is to calculate the linking segments between the trochoidal loops. At this point, both the cutting section of the tool path ($\vec{p}(t)$) and the trochoidal step (w) are known. Similar to tool exiting, circular roll-in and roll-out segments have been used for transitions. During the experiments, the same radius (ρ) was used in both cases; however, the radius for linking can be increased if required. Since the tool path's tangents are parallel to the slot's sidewalls at the start and endpoint of the curve $\vec{p}(t)$, the centre points of the circular rolling arcs can be specified by offsetting these points along the X-axis by a distance ρ. After that, the linking section can be defined by a straight segment that touches both circular arcs. Since there is no cutting along the linking path segment, an increased feed rate can be applied beyond the safety distance from the slot's sidewall. Finally, the loops need to be repeated one after the another at a distance w.

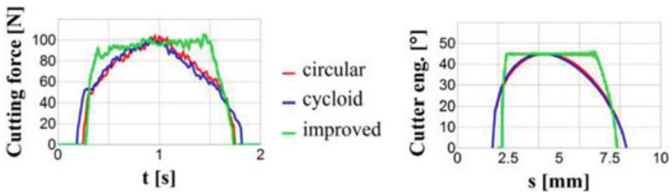
2.7 Experimental Validation

In order to prove the machining efficiency of the created tool path, a practical example is presented. During the experiment, tool paths were generated for the same sample geometry. Three different methods were investigated: the circular, the cycloid-shaped, and the improved trochoidal strategy. The following geometric data were used: tool diameter 6 mm slot width 10 mm, cutter engagement 45°, and tool path radius for tool entering and exiting 1 mm. In conventional strategies, the contact angle is not an input parameter, but a proper choice of trochoidal step ensured that their maximum values were also 45°. The experimental comparison is shown in Table 1.

The cutting experiments were performed on a KONDIA 640B 3-axis milling centre. The workpiece material was Al6061 aluminium alloy, and the tool was an uncoated solid carbide flat-end mill with one tooth (Garant, No. 2010406, $d = 6$ mm) and 26° helix. During cutting flood coolant and the following technological parameters have been used: cutting speed $v_c = 120\,\text{m/min}$, feed rate $v_f = 255\,\text{mm/min}$, axial depth of cut $a_p = 6\,\text{mm}$. During the experiments cutting force was measured with a Kistler 9257B type piezoelectric dynamometer. For data acquisition, the

Table 1 Experimental comparison of trochoidal slot milling strategies

Strategy	Circular	Cycloid	Improved
Shape			
Trochoidal step (mm)	0.365	0.369	0.444
Path length (cutting)	6.283 mm/loop	6.285 mm/loop	5.470 mm/loop
Path length (linking)	6.648 mm/loop	6.285 mm/loop	5.204 mm/loop



Labview was used. The sampling frequency was 12, 800 Hz (~120 measured points per tool revolution). In the evaluation, the maximum force per each tool revolution was calculated in the machining plane, and a Gaussian filter was used to reduce the noise.

Table 1 shows that by using the new path shape, there was a significant improvement in terms of both trochoidal step and path length without increasing the maximum cutting force. As it can be seen in the graph of cutter engagement, the tool worked longer at the permitted load, therefore in the cutting segment the average material removal rate has increased by nearly 40% (889mm^3/min, 898 mm^3/min vs. 1242 mm^3/min). Thus, comparing to the conventional, repetitively applicable path shapes, the new strategy can significantly increase the machining efficiency.

2.8 Further Developments Opportunities

Since the method has been developed for a normalised geometry, it is possible to generate tool path patterns in advance. If a sufficient number of patterns were collected in a database, the uniform tool path could be specified for any input parameter as a linear combination of path shapes that have similar parameters. By generalizing this solution, it would also be possible to define a formula that directly determines the tool path as a function of input data. Furthermore, for tool entering and exiting simple circular arcs were used, although an optimised path could also be applied for these segments. Optimising the linking sections has not been the subject of this study but the path tracking time could be further reduced by considering the machine tool's speed and acceleration capabilities. Furthermore, the application of the algorithm could also be widened by extending the method to curved and variable-width slots.

3 Summary

This paper presents a newly developed method to generate trochoidal tool paths for slot milling with constant cutter engagement. The algorithm's input data are normalised geometric dimensions. In this way, tool path patterns can be created which can be applied in general cases by using geometric transformations such as scaling, rotating and translating. To investigate the new method's machining efficiency, a practical example was presented. The results proved that controlling the cutter engagement can reduce the tool path length and consequently, the machining time. In addition to the promising results, further suggestions for improvement were presented, too.

Acknowledgements The research reported in this paper has been supported by the National Research, Development and Innovation Fund (TUDFO/51757/2019-ITM, Thematic Excellence

Program), and the 2017-1.3.1-VKE-2017-00029 grant of the Hungarian National Research, Development and Innovation Office (NKFIH).

References

1. Held, M., Spielberger, C.: Improved spiral high-speed machining of multiply-connected pockets. Comput.-Aided Des. Appl. **11**(3), 346–357 (2014). https://doi.org/10.1080/16864360.2014.863508
2. Zhuang, C., Xiong, Z., Ding, H.: High speed machining tool path generation for pockets using level sets. Int. J. Prod. Res. **48**(19), 5749–5766 (2010). https://doi.org/10.1080/00207540903232771
3. Dumitrache, A., Borangiu, T.: IMS10-image-based milling toolpaths with tool engagement control for complex geometry. Eng. Appl. Artif. Intell. **25**(6), 1161–1172 (2012). https://doi.org/10.1016/j.engappai.2011.09.026
4. Geier, N., Szalay, T., Biró, I.: Trochoid milling of carbon fibre-reinforced plastics (CFRP). Procedia CIRP 77:375–378. https://doi.org/10.1016/j.procir.2018.09.039
5. Pleta, A., Niaki, F.A., Mears, L.: Investigation of chip thickness and force modelling of trochoidal milling. Procedia Manuf. **10**, 612–621 (2017). https://doi.org/10.1016/j.promfg.2017.07.063
6. Wu, S., Ma, W., Bai, H., Wang, C., Song, Y.: Engagement angle modeling for multiple-circle continuous machining and its application in the pocket machining. Chin. J. Mech. Eng. **30**(2), 256–271 (2017). https://doi.org/10.1007/s10033-017-0092-6
7. Li, Z., Xu, K., Tang, K.: A new trochoidal pattern for slotting operation. Int. J. Adv. Manuf. Techn. **102**(5), 1153–1163 (2019). https://doi.org/10.1007/s00170-018-2947-0
8. Jacso, A., Matyasi, G., Szalay, T.: The fast constant engagement offsetting method for generating milling tool paths. Int. J. Adv. Manuf. Techn. (2019). https://doi.org/10.1007/s00170-019-03834-8

Modeling and Optimization of Turning Process Using White Coconut Oil as Metalworking Fluid Through Desirability Function

Anish Kumar, Jatinder Chhabra, Rakesh Kumar Phanden, and Arun Kumar Gupta

Abstract Rapid demand of advanced materials for high-performance applications an immense pact of industrial issue; they also have considerable confront in machining due to poor machinability characteristics. On the other hand, environmental friendly machining techniques have been given major fame and use of coconut oil as metalworking fluid was one of them. For long haul natural contamination and risk to worker's well-being, the utilization of mineral and synthetic oils based as metalworking liquids has incredible imminent. Machining characteristic under different parametric conditions such as Spindle speed (S_s), Feed rate (F_r), Depth of cut (t), and work material (D) was investigated through response surface methodology using coconut oil as metalworking fluid. Box–Behnken design approach was employed to perform the experimental runs and further they have been optimized through desirability approach. The analysis of variance was applied to identify the significance of created model. The test outcomes approve and sufficiency of the created model. The test results support and adequacy of the made model. The results evidently indicated the favorable aspects of coconut oil.

Keywords Box–Behnken design · Analysis of variance · Coconut oil · Surface roughness · Material removal rate · Response surface methodology · Desirability

1 Introduction

Since the beginning of industrial revolution, when metal first began to cut machines, cutting fluids have been an important aspect of machining operations. Earlier, the animal fats were normally considered for lubrication and cooling purposes between the two mating surfaces. However, these lubricants tended to become rancid and

A. Kumar (✉) · J. Chhabra · A. K. Gupta
Mechanical Engineering Department, M.M. Deemed To Be University Mullana, Ambala, Haryana 133207, India
e-mail: anish_kaushik@rediffmail.com

R. K. Phanden
Department of Mechanical Engineering, Amity University Uttar Pradesh, Sector 125, Noida, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_60

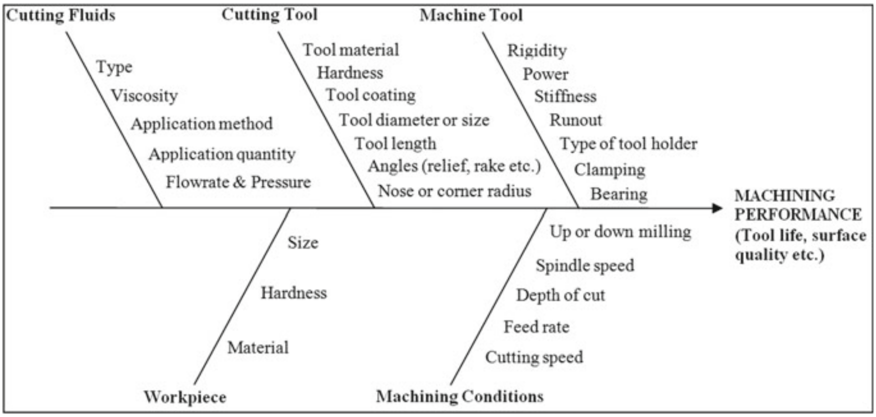


Fig. 1 Cause and effect diagram for performance measures

produce distasteful odor, and sometimes became the cause of rashes on the skin of operators. The lard oil could not be applicable independently, and it can be considered as an additive in cutting oil. Similarly, water without any integrant also could not be applied due to its corrosive nature with machine parts and workpiece. Therefore, the water is mixed with oil and that emulation is applied for heat dissipation without any oxidation with the metal. Nowadays many petroleum-based products are being used as cutting fluids for high rate of production. Mineral oil-based metalworking fluid is higher sought after as these items are estimated sensibly and have great specialized properties [1]. Biodegradability of these oils leads to long-standing pollution and hazard to the health of workers. Therefore, the researchers have showed their interest in the development environment-friendly metalworking fluid in the recent past. The parameters normally influencing the cutting-performance are as shown in Fig. 1. However, the mineral oil's availability depends upon the political will and wish. Therefore, the accessibility of mineral oil is not certain in future [2]. Present days, the interest of ecological well-disposed cutting fluids are high popular. For this reason, biodegradable fluid such as vegetable oil are considered as substitution of mineral based cutting fluids. The vegetable based metalworking fluid is progressively reasonable, because of the reducing accessibility of mineral oil-based metalworking fluid. The cutting fluids may be ordered into four classifications: cutting oils, soluble oils, synthetic fluids, semi-synthetic fluids.

2 Literature Review

High surface finishes with high material removal rate are the essential features required by most of the automobile and aerospace component manufacturers in the present cut through competition. It has been absorbed by most of the researchers that with the passage of time the fatigue of machine parts increases, and this leads to increase in surface roughness of the machining components [3]. Therefore, to maintain the quality of production, these parameters should be under controlled limits [4]. The surface roughness is mostly influenced by the cutting tool geometry, cutting fluid properties, and certain machining parameters. Therefore, the selection of proper combination of these parameters decreases the surface roughness and aging effect on the components. Most of the researchers have taken the minimization of surface roughness as the prime objective and studied verity of cutting fluids. Avila and Abrao [5] have also investigated the effect of 3 different types of MWFs such as mixed alumina inserts ($Al_2O_3 + TiC$) during dry cutting on hardened AISI 4340 steel (49HRC). The tool life, surface roughness, tool wear, and chip shape are the prime investigation parameters during roughing and finish machining.Few researchers have investigated the problems faced by the industry in emulsions such as bacteria growth and fungi. This raises the health-related problems for the operators and also affects the MWFs life cycle. The shown result describes that coolant lubricity capability degrades by the bacteria [6, 7]. In machining with low Spindle speed, cutting fluids with high lubricant are for the most commonly utilized, for example, gear cutting, screw cutting and furthermore on hard to cut materials, then again cutting fluids with high cooling ability are as often as possibly utilized in rapid machining [8, 9]. The effects of vegetable-based oils have been investigated on AISI 316L austenitic stainless steel drilling with the help of conventional Spindle speed High Spindle speed Steel 'cobalt (HSS-Co) tools [10]. Six cutting oils were selected, and their efficacy is investigated by measuring cutting force, tool life, and chip formation. Through cylindrical turning of three materials (copper, mild steel), the outcome of some direct organic oils on the cutting force is evaluated [11]. The impact of cutting fluid on surface roughness and tool wear during turning of AISI 304 austenitic tempered steel with carbide tool utilized three unique sorts of cutting oils [12]. Through the processing of AISI 304, austenitic hardened steel with carbide tool power and tool wear observed on two diverse vegetable oil-based cutting oils were produced from mixture of sunflower oil and refined canola [13]. To study the surface roughness using the Taguchi method was initiated. They resolved that the cut act depth plays a very important role in producing the roughness of the lower surface, followed by the less important role of FR and cutting Spindle speed on the surface roughness [14]. The cutting parameters (S_S, T, and F_R) on EN 9 mild steel examined by [15] at the time of turning operation and as a result the combination of the optimal levels were observed in order to get the lowest surface roughness. Bhowmik et al. [16] investigated on Aluminum is changing to the role of green machining on the AA1050 to measure surface roughness. Comparisons between VBCF and MBCF under different cutting conditions, using either Neat or direct sunflower oil and coconut oil, were conducted using the same machining parameter setup. From the background overview, it was seen that research into the use of vegetable oil-based metalworking fluids in machining forms has seen an extraordinary potential lately. Critically, much of the work on literature has been done on steels with the function of vegetable oil-based metalworking fluid. However, as far as a comparative investigation of steels using coconut oil was concerned, less work has been reported with

HSS tool. Now, the novelty of this research work was an empirical model for SS and MS using coconut oil with effect of prominent input parameters were investigated. And also Complex stochastic process mechanisms that require the use of empirical or experimental studies aim to derive mathematical models to enhance process performance.

3 Material and Methods

In this research work, experiments were performed on heavy duty lathe machine (Make: Welpro industries Ltd., Ludhiana, India) as shown in Fig. 2a. Round bars (Ø25.4 mm) of SS (AISI 316) and MS used for experimentation and machined samples were observed in Fig. 2b. The chemical composition of SS $C = 0.08$, Mn = 2.0, Si = 0.75, P = 0.045, S = 0.03, Cr = 18.0, Mo = 3.0, Ni = 14.0, N = 0.10 and for MS: C = 0.2, Mn = 0.9, Si = 0.4, P = 0.04, S = 0.05. High-speed Steel (Make: Miranda S-400, 5/8" × 6") tool was used to perform experiments. Coconut oil (extracted from 5 to 6 months old coconuts) was selected so that comparative study was done. And base oil with coconut oil was prepared by mixing 100 ml coconut oil, 25 g acacia powder, and 50 ml mineral water. This mixture was used for machining by mixing thoroughly it with water in ratio 1:5. Acacia powder acts as emulsifier agent without which it would not be possible to mix coconut oil with water. The surface morphology of machined samples was analyzed using scanning electron microscope (Model: JEOL JSM-6510LV). With the support of literature, survey and pilot experimentation analyzes levels of process parameters have been acquired in Table 1. The procedure manuals and machine limits have additionally been considered for the equivalent.

Fig. 2 **a** Experimental setup for carrying out turning operation, **b** machined samples

Table 1 Input machining parameters and their levels

S. No.	Machining parameters	Units	Levels		
			1	2	3
A	Spindle speed (S_s)	r.p.m	70	165	260
B	Feed rate (F_r)	mm/rev	0.05	0.13	0.21
C	Depth of cut (t)	mm	0.5	1.0	1.5
D	Work material	–	SS—stainless steel	–	MS—Mild steel

3.1 Measurement of Response Measures

The experimental responses were estimated as far as material removal rate and surface quality. Material removal rate was calculated from the difference of weight of material beforehand and afterward experiment.

$$\text{Material removal rate } = \frac{W_i - W_f}{t - \rho}\ \text{mm}^3/\text{s} \tag{1}$$

where W_i = Primary weight before machining
W_f = Ultimate weight before machining
t = Machining time, ρ = Density of material being machined (For SS, ρ = 7.88 g/cm^3 and For MS, ρ = 7.80 g/cm^3).

Digital balance meters have been used to measure the weight of a workpiece in high accuracy (make: citizen), with the ability to measure up to 10^{-3} g of accuracy. The contact type stylus-based surface roughness tester was used to measure surface roughness (Make: Mitutoyo Surftest, Model: SJ-301) with a least count of 0.001 μm. The cut-off length has been set to 0.8 mm.

3.2 Experimental Design

Response surface methodology-based Box–Behnken Design (BBD) was used to develop the empirical relationship between process parameters and performance measures (surface roughness and material removal rate). Box–Behnken design is to explore mathematical and experimental evaluation of the interaction and main effects of parameters [17]. In RSM, a following mathematical model was developed between the independent input parameters and the desired responses represented by the equation:

$$Y = \varnothing\,(S_s,\ F_r,\ t \text{ and } D) \pm \varepsilon \tag{2}$$

$\varnothing$: Function of independent

where Y: Response

ε: residual errors.

Using design expert 7.0 a statistical tool, the design matrix with their outputs is shown in Table 2. The estimation of response function had been developed by using second-order polynomial regression equation, also known as quadratic model. The quadratic model for the parameters of the k input parameters is described by the following equation:

$$Y_i = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i<j} \beta_{ij} x_i x_j + \varepsilon \tag{3}$$

4 Results and Discussion

4.1 Empirical Modeling for Surface Roughness

Table 3 depicted the analysis of variance after backward elimination for surface roughness at 95% confidence level. The normal probability plots as shown in Fig. 3 depicts that all the residuals points were falling within three sigma limits and clustered to straight line. The model's F-value is 56.11, and p-value is less than 0.001. It infers that there was only a 0.01% chance that such large F-value of model can take place due to noise. The model F-value was calculated as a 'model' mean square divided by the 'residual' mean square. Moreover, in the present case, there was a lack of fit of 0.3126 implied that it was not significant relative to pure error. Henceforth, the developed model could be accepted. To check further whether the fitted model truly depicted the experimental data, determination coefficient (R^2) was computed. Determination coefficients showed the ratio of explained variation to the total variation. A ratio greater than 4 was desired. The coefficient of variation (CV) of the model is the ratio of the standard deviation to the mean. The inferior value (15.01%) specifies better exactness and accuracy. In real factors, the concluding practical relationship between surface roughness and the measured process variables is obtained as follows::

$$\text{Surface Roughness SS}_{(\text{COCONUT OIL})} = 0.18698 + 4.76316E - 003 \times S_\text{s} - 14.71115 \times F_\text{r} + 1.20605 \times t - 4.65789E - 003 \times \text{Ss} \times t + 67.45877 \times F_\text{r}^2 \tag{4}$$

$$\text{Surface Roughness MS}_{(\text{COCONUT OIL})} = 0.47672 + 9.51316E - 003 \times S_\text{s} - 7.85178 \times F_\text{r} + 1.20605 \times t - 4.65789E - 003 \times S_\text{s} \times t + 67.45877 \times F_\text{r}^2 \tag{5}$$

Table 2 Experimental design with output responses

Run	S_s	F_r	t	D	Surface roughness Ra (μm)	Material removal Rate (mm^3/s)
1	165	0.13	1.00	SS	0.88	21.94
2	165	0.13	1.00	MS	1.55	22.13
3	165	0.13	1.00	MS	1.47	21.63
4	165	0.21	0.50	MS	2.94	23.06
5	70	0.21	1.00	SS	1.24	19.18
6	70	0.13	0.50	MS	0.69	4.98
7	165	0.05	0.50	SS	0.41	5.67
8	165	0.21	0.50	SS	1.01	23.16
9	70	0.21	1.00	MS	2.62	18.72
10	165	0.13	1.00	MS	1.69	22.11
11	260	0.21	1.00	SS	1.25	61.37
12	260	0.13	0.50	SS	0.61	17.56
13	260	0.05	1.00	MS	2.05	15.67
14	165	0.13	1.00	MS	1.78	22.42
15	165	0.05	0.50	MS	0.85	5.66
16	70	0.05	1.00	MS	0.98	4.85
17	260	0.13	1.50	MS	2.14	54.21
18	70	0.13	1.50	SS	0.95	14.19
19	165	0.05	1.50	MS	1.54	16.08
20	165	0.13	1.00	SS	0.48	21.98
21	260	0.13	0.50	MS	2.32	18.19
22	260	0.13	1.50	SS	0.55	52.83
23	165	0.05	1.50	SS	1.27	16.98
24	260	0.21	1.00	MS	2.94	60.65
25	165	0.21	1.50	SS	1.49	56.62
26	260	0.05	1.00	SS	0.78	16.96
27	165	0.13	1.00	SS	0.71	21.38
28	165	0.13	1.00	MS	1.35	22.03
29	70	0.13	0.50	SS	0.20	5.22
30	70	0.13	1.50	MS	1.47	13.28
31	70	0.05	1.00	SS	0.72	4.98
32	165	0.21	1.50	MS	3.12	56.42
33	165	0.13	1.00	SS	0.96	21.88
34	165	0.13	1.00	SS	0.79	22.34

Table 3 Analysis of variance (After backward elimination) for surface roughness

Source	SS	DF	MS	F-value	Prob > F (p-value)	Remarks	% contribution
Model	18.35	8	2.29	56.11	<0.0001	Significant	
A	0.89	1	0.89	21.72	<0.0001	Significant	4.59
B	4.01	1	4.01	98.07	<0.0001	Significant	20.69
C	0.77	1	0.77	18.72	0.0002	Significant	3.97
D	8.70	1	8.70	212.79	<0.0001	Significant	44.89
AB	0.39	1	0.39	9.58	0.0048	Significant	2.01
AC	0.81	1	0.81	19.92	0.0001	Significant	4.18
BC	1.20	1	1.20	29.46	<0.0001	Significant	6.19
B^2	1.58	1	1.58	38.61	<0.0001	Significant	8.15
Lack of fit	0.77	17	0.045	1.43	0.3126	Not significant	

Standard deviation 0.20
Mean 1.35
Coefficient of variation 15.01
PRESS 1.90
R^2 0.9472
Adj. R^2 0.9304
Pred. R^2 0.9019
Adequate precision 30.082
SS Sum of square, *MS* Mean square, *DF* Degree of freedom

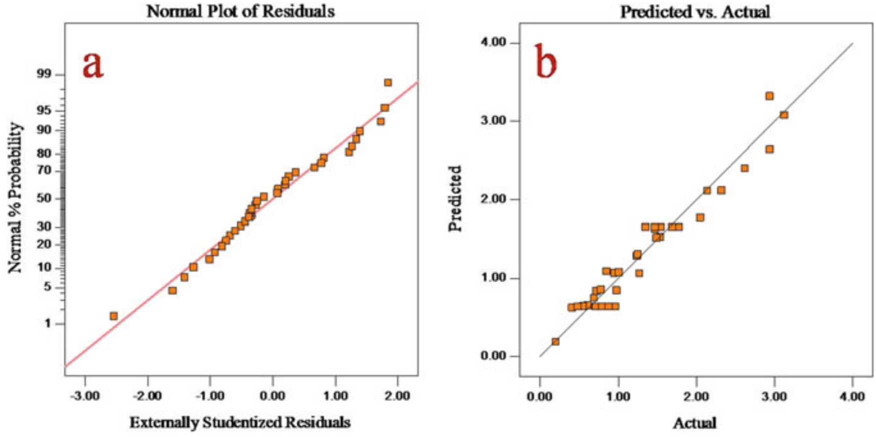


Fig. 3 **a** Residuals for normal probability, **b** plot for actual versus predicted of surface roughness

Table 4 ANOVA results for material removal rate

Source	SS	DF	MS	F-value	Prob > F (p-value)	Remarks	% contribution
Model	9317.67	8	1164.71	5740.88	<0.0001	Significant	
A	2810.06	1	2810.06	13,850.86	<0.0001	Significant	30.14
B	3373.58	1	3373.58	16,628.45	<0.0001	Significant	36.19
C	1960.50	1	1960.50	9663.34	<0.0001	Significant	21.03
AB	470.02	1	470.02	2316.73	<0.0001	Significant	5.04
AC	364.77	1	364.77	1797.96	<0.0001	Significant	3.91
BC	254.14	1	254.14	1252.66	<0.0001	Significant	2.73
B^2	82.05	1	82.05	404.41	<0.0001	Significant	0.88
C^2	1.20	1	1.20	5.92	0.0225	Significant	0.013
Lack of fit	4.28	17	0.25	2.53	0.0918	Not significant	

Standard deviation 0.45
Mean 23.72
Coefficient of Variation 1.90
PRESS 10.66
R^2 0.9995
Adj. R^2 0.9993
Pred. R^2 0.9989
Adequate precision 40.56
SS Sum of square, *MS* Mean square, *DF* Degree of freedom.

It was observed from Table 4 that A, B, C, D, AB, AC, and BC are the significant model terms. The surface roughness was mainly affected by the S_s, F_r, and t and work material. Variation of individual process parameters and interaction plots was observed in Figs. 4 and 5. It has been perceived that as the S_S increases the surface roughness increased with value of 1.19 to 2.11 µm for mild steel (MS). Another surface roughness was increased less suggestively with value of 0.63–0.65 µm while turning of stainless steel (SS). It means coconut oil gives better surface roughness with decrease in S_s whether the material SS or MS. This is on the grounds that coconut oil has less time to infiltrate the chip tool interface at higher S_s because of higher viscosity of coconut oil. It is also observed that surface roughness is improved for both SS and MS with decrease of F_r. Similarly, surface roughness decreases with increase in t. When F_r was increased from 0.046 to 0.23 mm/rev, keeping S_s constant at 259 RPM, the surface roughness of S_s decreased until a minimum value was reached beyond which it increased from 0.787 to 1.249 µm and for MS the roughness was increased from 2.05 to 2.94 µm. When F_r was varied from 0.05 to 0.22 mm/rev at constant S_s of 69 rpm, the surface roughness of S_s increased from 0.719 µm to 1.223 µm and surface roughness value for MS increased from 0.98 to 2.62 µm. Surface qualities for both of materials are increasing with increase in F_r but their magnitude is different. Also, effect of F_r and type of material on surface roughness is greater than other parameters, i.e., Ss and t. In order to obtain better surface roughness of SS during turning with coconut oil as MWF, the optimum parameter combination obtained is

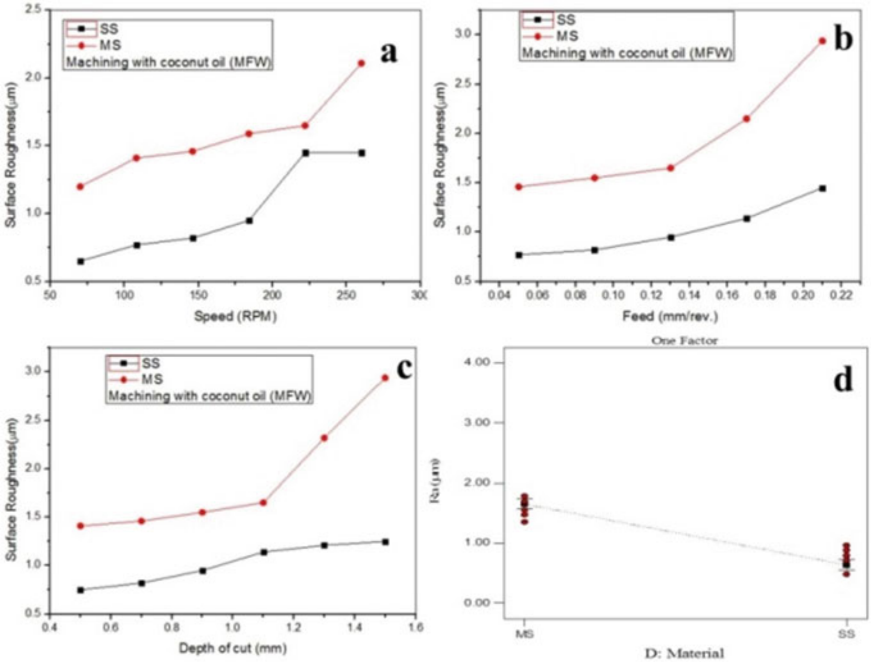


Fig. 4 Variation of parameters on surface roughness

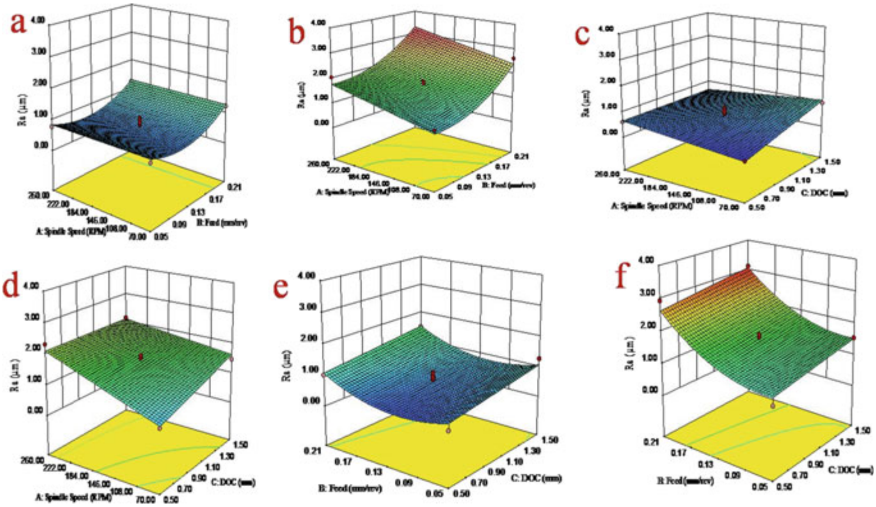


Fig. 5 3-D interaction plots for surface roughness

$S_s = 71$ rpm, $F_r = 0.145$ mm/rev, $t = 0.49$ mm and for MS is $S_s = 70$ rpm, $F_r = 0.05$ mm/rev, $t = 0.45$ mm.

4.2 Empirical Modeling for Material Removal Rate

Quadratic model for material removal rate was recommended after backward elimination method and fit summary is given in Table 5. It indicates that *F*-value of the model is 5741 and corresponding *p*-value is less than 0.0001. The *p*-value of lack of fit is greater than 0.049. Thus, lack of fit is insignificant. Further, lack of fit value of 0.0918 implies that it is not significant relative to pure error. Moreover, R^2 value of 0.9995 shows that 99.95% of the variation of material removal rate is attributed to control factors. This confirms that accuracy and general ability of polynomial model is good. The normal probability plot of residuals appeared clustered, whereas the errors are normally scattered around the straight line is shown in Fig. 6a, b. Similar trend is observed in the plot of actual versus predicted values. This also shows that prediction model is very close to the actual output.

By applying the multiple regression analysis on experimental data, the following regression equation was obtained for material removal rate:

$$\begin{aligned}\text{Material removal rate SS}_{(\text{COCONUT OIL})} &= 26.465459498355 - 0.13376973684211 \\ \times S_s - 252.43935032895 \times F_r - 22.651430921053 \times t + 1.0085526315789 \\ \times S_s \times F_R + 0.14215789473684 \times S_s \times t + 140.90625 \times F_r \times t \\ + 487.03741776316 \times F_r^2 + 1.5081578947368 \times t^2 \quad (8)\end{aligned}$$

Material removal rate $\text{MS}_{(\text{COCONUT OIL})}$

Table 5 Optimal solutions for surface roughness and material removal rate

Exp. No	Ss	Fr	t	D	Surface roughness	Material removal rate	Desirability
1	260.000	0.152	1.500	SS	0.740	61.370	0.926
2	259.999	0.152	1.495	SS	0.743	61.370	0.926
3	260.000	0.153	1.500	SS	0.745	61.683	0.925
4	258.882	0.153	1.500	SS	0.746	61.371	0.925
5	260.000	0.153	1.489	SS	0.747	61.419	0.925
6	259.999	0.154	1.500	SS	0.750	62.031	0.925
7	260.000	0.154	1.484	SS	0.750	61.370	0.925
8	259.284	0.154	1.500	SS	0.751	61.813	0.925
9	257.741	0.153	1.500	SS	0.753	61.370	0.924
10	260.000	0.155	1.500	SS	0.757	62.435	0.924

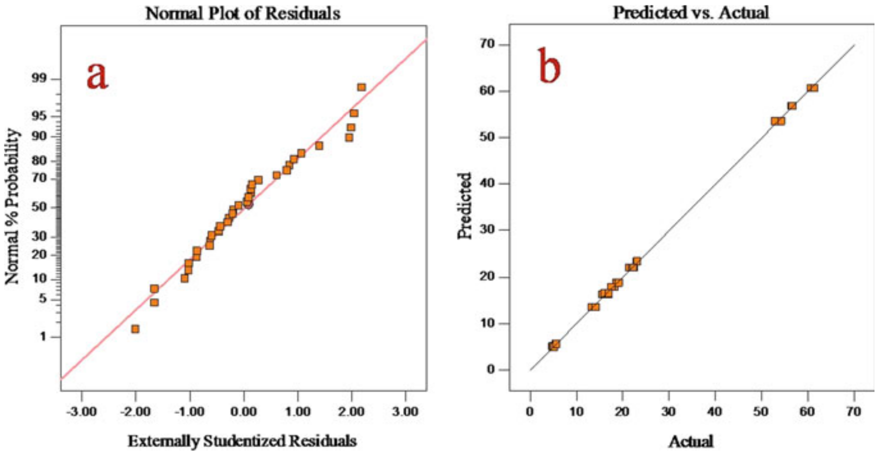


Fig. 6 **a** Residuals for normal probability, **b** plot for actual versus predicted

$$= 29.069109443531 - 0.14448848684211 \times S_s - 311.6262563962 \times F_r - 21.468601973684 \times t + 1.1212171052632 \times S_s \times F_r + 0.14236842105263\, S_s \times t + 161.53125 \times F_r \times t + 589.60503472222 \times F_r^2 \quad (9)$$

From Table 4, S_s and F_r are the most significant parameters for material removal rate as appeared in the F and P-values. It is also observed that A, B, C, AB, AC, and BC were the significant model terms, respectively. It has been seen that MRR increments with the rise in the S_s, F_r, and t. However, the material removal rate (61.37 mm^3/s) of SS and MS is more affected with the F_r than the S_s and t. The main effect and interaction plots are observed in Figs. 7 and 8. The maximum MRR of has been obtained during machining of stainless steel with the coconut oil, whereas the $S_s = 260$ rpm, $F_r = 0.21$ mm/rev, $t = 1.00$ mm.

4.3 Multi-objective Optimization Using Desirability Function

In the ongoing past, the desirability approach was applied to change over the single-objective problem into multi-objective problems by methods of mathematical transformations. In this approach, each response value $\hat{y}$ is transformed to the desirability dz, where $0 \le dz \le 1$. The dz value increases as the index of the response increases. The Composite desirability (CD) the geometric mean of these desirability functions can be defined as [18, 19].

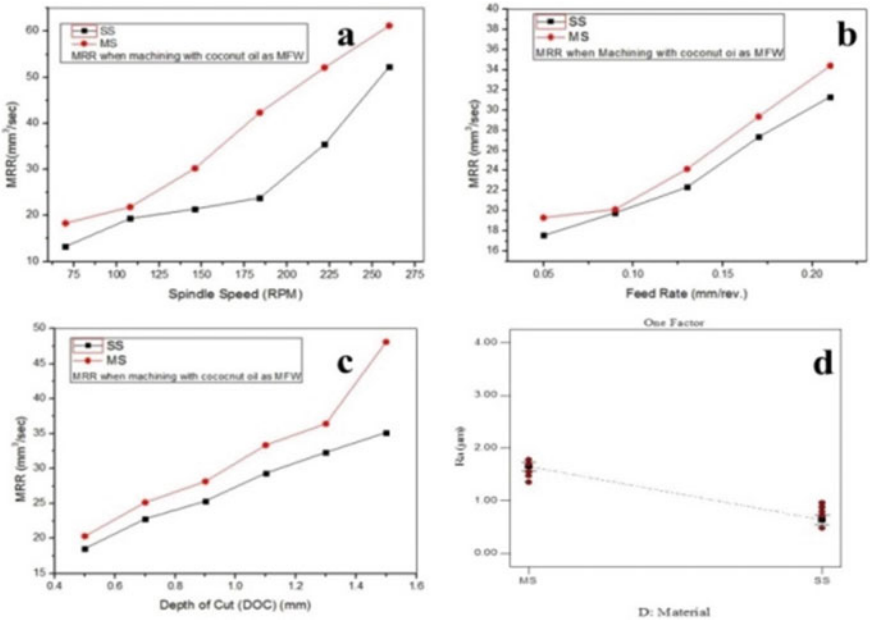


Fig. 7 Variation of parameters on material removal rate

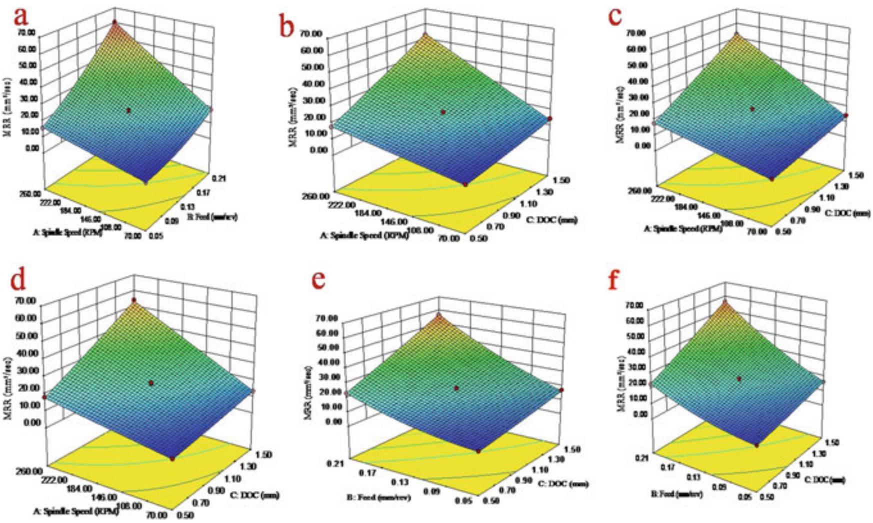


Fig. 8 3-D interaction plots for material removal rate

$$D_G = (d_1 \times d_2 \times d_3 \times \cdots \times d_n)^{1/n} = \left(\prod_{i=1}^{n} \mathrm{d}i\right)^{1/n} \tag{10}$$

where n = no. of responses = 2.

The parameter combinations obtained from the maximum total desirability approach are considered as optimum parameter combination for surface roughness and material removal rate. Table 5 shows the optimal combination of process parameters setting that gives the high value of desirability. For multi-performance characteristics and the overall desirability, bar histogram and ramp graph have been shown in Figs. 9 and 10.

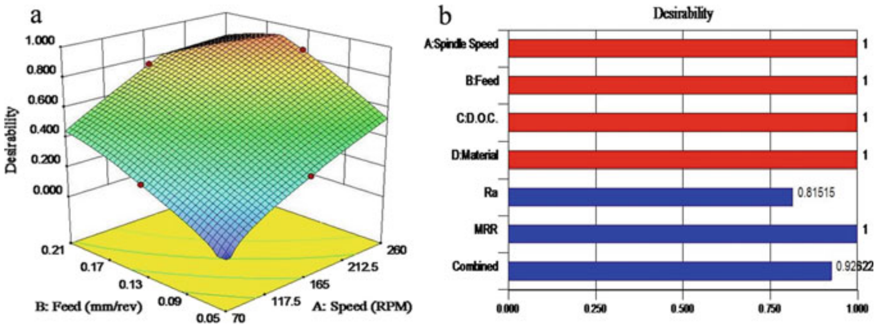


Fig. 9 Composite desirability for all responses

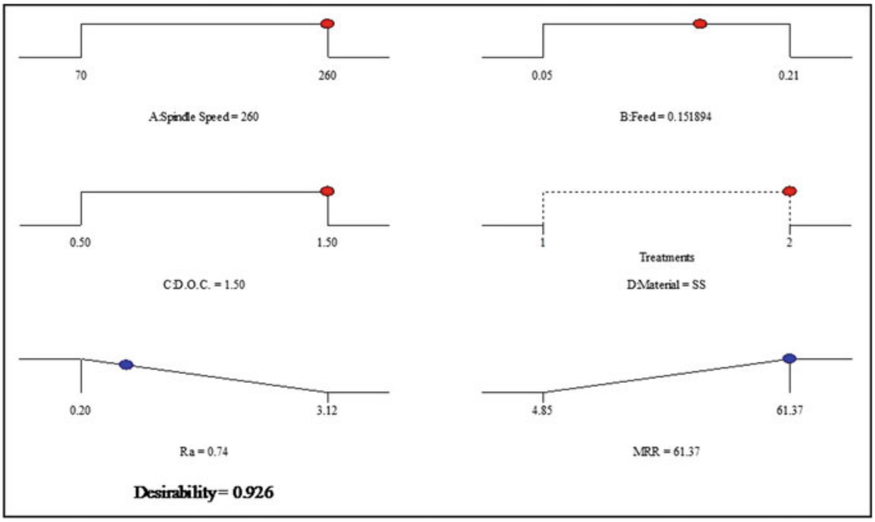


Fig. 10 Ramp graph of optimal setting for all responses

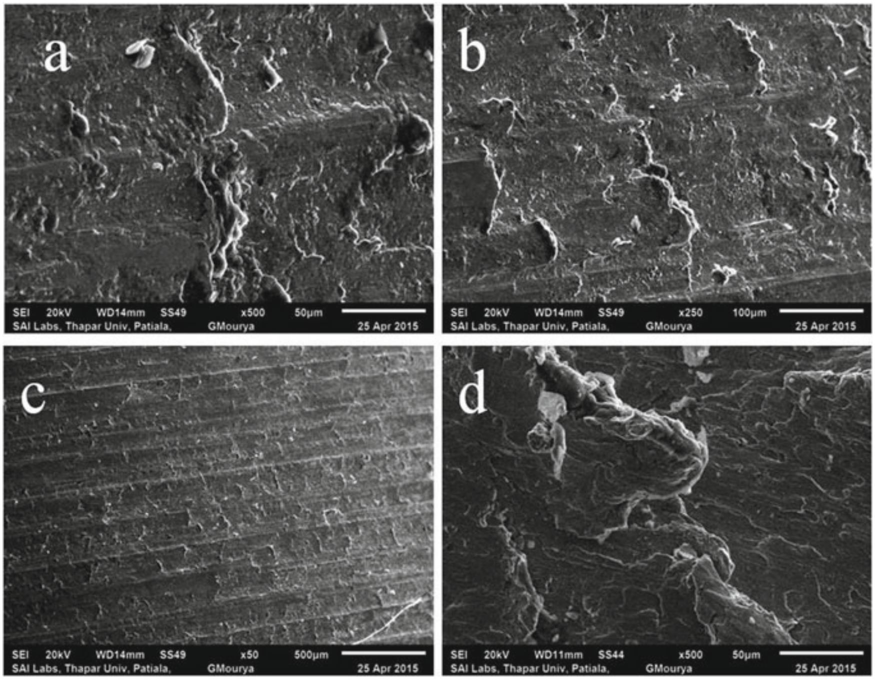


Fig. 11 Micrographs when machining was performed with coconut oil as metalworking fluid, at $S_s = 165$ rpm, $F_r = 0.21$ mm/rev, $t = 1.5$ mm, material = MS, Surface roughness = 3.12 μm, respectively

4.4 Analysis of Machined Surface Topography

Experimental results showed that all parameters significantly affected on the surface morphology with the formation of surface defects. Due to rapid local heating and quenching, an overlapped surface was created on the MS as shown in Fig. 11. Tool marks were also observed in Fig. 12. The formation of these layers depends on the process conditions, and different thermal conductivities of metals cause the coconut oil to act differently while machining two metal types. Fine surface finish was observed with no micro-cracks and tool marks on SS as shown in Fig. 12.

5 Conclusions

1. Within the experimental range, coconut oil gives minimum surface roughness values for stainless steel when used at lower S_s. At lower S_s and F_r rate, coconut oil gives maximum surface roughness for mild steel.

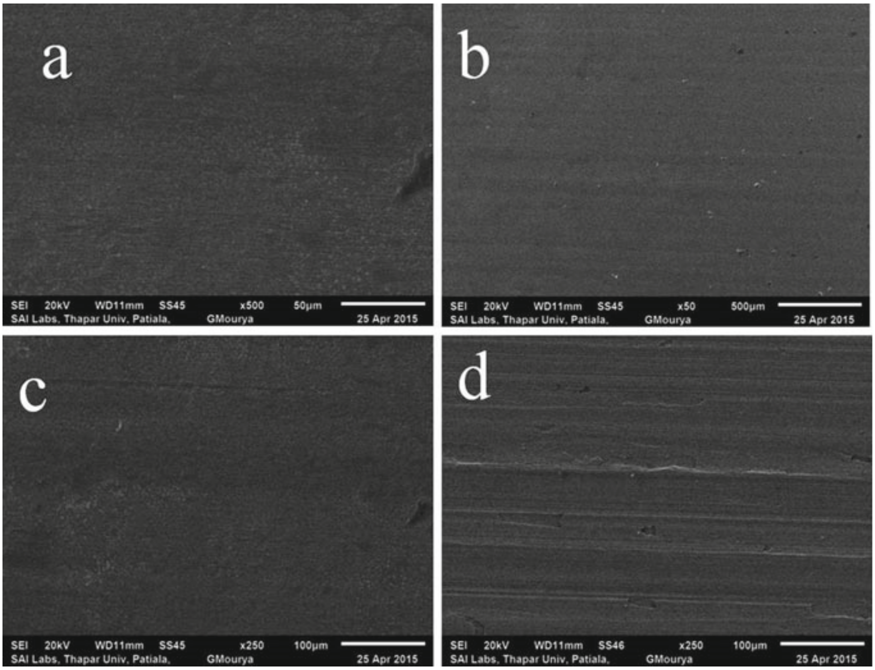


Fig. 12 Shows micrographs when machining was performed with coconut oil as metalworking fluid, at $S_s = 70$ rpm, $F_r = 0.13$ mm/rev, $t = 0.5$ mm, material = SS, Surface roughness = 0.65 μm, respectively

2. Minimum surface roughness of 0.61 μm was obtained when machining SS with coconut oil-based metalworking fluid at S_s of 70 rpm, F_r of 0.13 mm/rev, and t of 0.50 mm. MS gives surface roughness value of 3.14 μm with same conditions.
3. Coconut oil-based metalworking fluid gives 65.3% better surface roughness in S_s contrast to MS on average surface roughness.
4. Utilizing analysis of variance, it has been observed that the t has the most prominent impact on surface roughness for stainless steel and mild steel. Besides, it has been discovered that metalworking fluid has extensive impact on surface roughness for the two sorts of steel. Experimental results clearly show that coconut oil-based metalworking fluid performs better results in case of SS.
5. In order to obtain better surface roughness of SS during turning with coconut oil as metalworking fluid, the optimum parameter combination obtained is S_s = 70 rpm, F_r = 0.13 mm/rev, t = 0.5 mm and that of MS is S_s = 70 rpm, F_r = 0.05 mm/rev, t = 0.5 mm. The percentage contributions of significant parameters are S_s = 4.6%, F_r = 20.7%, t = 4%, Material = 44.9%.
6. Metal removal rate of stainless steel and also that of mild steel increases with increase in all parameters values within range but effect of variation in F_r is more as compared to i_s and t.

7. Maximum material removal rate (61.37 mm^3/s) with coconut oil as metal-working fluid was obtained when the parameters were set at $S_s = 260$ rpm, $F_r = 0.21$ mm/rev, $t = 1.00$ mm, and material = stainless steel.

References

1. Willing, A.: Lubricants based on renewable resources-an environmentally compatible alternative to mineral oil products. Chemos. **43**, 89–98 (2001)
2. Srikant, R.R., Rao, D.N., Rao, P.N.: Experimental investigations on the influence of emulsifier content in cutting fluids on machined surface. Proc. Inst. Mech. Eng. Part. J: Eng. Tribol. **223**, 195–201 (2009)
3. Sharma, V.S, Dhiman, S, Sehgal, R, Sharma. S.K.: Estimation of cutting forces and surface roughness for hard turning using neural networks. J. Intell. Manuf. **19**, 473–483 (2008)
4. Chen, J.C, Lou, M.S.: In process surface roughness recognition system in end milling operations. Int. J. Adv. Manuf. Technol. **15** (1999)
5. Avila, R.F., Abrao, A.M.: The effect of cutting fluids on the machining of hardened AISI4340 steel. J. Mater. Process. Technol. **119**, 21–26 (2001)
6. Srikant,R.R,Rao,D.N,Rao,P.N.:Influenceofemulsifiercontentincuttingfluidsoncuttingforces,cuttingtemperatures,toolwear,andsurfaceroughness. Proc.Inst.Mech.Eng.Part. J:Eng.Tribol., **223**, 203–209 (2009)
7. Hong, S.Y., Broomer, M.: Economical and ecological cryogenic machining of AISI 304 austenitic stainless steel Clean. Prod. Proc. **2**, 157–166 (2009)
8. Fox, N.J, Stachowiak,G.W.:Vegetableoil-basedlubricants-areview of oxidation. Tribol. Int. **40**, 1035–1046 (2007)
9. Abou-El-Hossein,K.A.:CuttingfluidefficiencyinendmillingofAISI304stainless steel. Ind. Lubr.Tribol. **60**(3), 115–120 (2008)
10. Belluco, W., De Chiffre, L.: Performance evaluation of vegetable-based oils in drilling austenitic stainless steel.J. Mater. Process. Technol.**148**, 171–176 (2004)
11. Ojolo, S.J., Amuda, M.O.H., Ogunmola, O.Y., Ononiwu, C.U.: Experimental determination of the effect of some straight biological oils on cutting force during cylindrical turning. Rev. Mater. **13**(4), 650–663 (2008)
12. Xavior, M. Anthony, Adithan, M. Determining the influence of cutting fluids on tool wear and surface roughness during turning of AISI 304 austentic stainless steel. J. Mater. Process. Technol. **209**, 900–909 (2009)
13. Kuram, E., Ozcelik, B., Demirbas, E., Sik, E.: Effects of the cutting fluid types and cutting parameters on surface roughness and thrust force. In: Proceedings of the WCE 2010, London, UK, vol. II, June 30–July (2010)
14. Thamizhmanii, S. Saparudin, S. Hasan, S. Analyses of surface roughness by turning process using Taguchi method. J. Achiev. Mater. Manufac. Engi. **20**(1–2), 503–506 (2007)
15. Saraswat, N., Yadav, A., Kumar, A., Srivastava, P., Bhanu.: Optimization of cutting parameters in turning operation of mild steel. Int. Rev. Appl. Eng. Res. **4**(3), 251–256 (2014)
16. Bhowmik, P., Kumar, U., Arora, G.: Vegetable oil based cutting fluids-green and sustainable machining-I J. Mater. Sci. Mech. Eng. **2**(9), 1–5 (2015)
17. Box, G.E.P., Hunter, W.G., Hunter, J.S.: Statistics for Experimenters. Wiley, New York (1978)
18. Kumar, A., Kumar, V., Kumar, J.: Investigation of micro-cracks susceptibility on machined pure titanium surface in WEDM process. J. Manuf. Sci. Prod. **16**(2), 123–139
19. Kumar, A., Kumar, V., Kumar, S.: Gaurav experimental investigation of multiple quality characteristics of laser beam machined surface using integrated Taguchi and Fuzzy Logic method. J. Manuf. Sci. Prod. (2016).https://doi.org/10.1515/jmsp-2016-0015

Surface Veracity Investigation for the $Wire_{EDM}$ of $Al/ZrO_{2(P)}$-MMC

Sanjeev Kumar Garg, Alakesh Manna, and Ajai Jain

Abstract This paper presents investigation of surface veracity of $Wire_{EDM}$ surface of $Al/ZrO_{2(P)}$-MMC. The optimal set of process parameters for $Wire_{EDM}$ of considered MMC are obtained using response surface methodology (RSM) for maximum MRR and minimum SR (Ra). In the present paper, surface veracity aspects that include composition, surface defects, and thickness of recast layer are investigated for the machined surfaces which are obtained from the set of optimal process parameters. From the investigation, it can safely be concluded that for the $Wire_{EDM}$ of of $Al/ZrO_{2(P)}$-MMCs, lower parameter setting values of PW and SPT along with higher parameter setting value of TBP are desirable from the viewpoint of good surface finish and surface topography of the machined surfaces, however, higher parameter setting values of PW and SPT along with lower parameter setting value of TBP are desirable from the viewpoint of good material removal rate but surface topography of the machined surfaces contains more micro-cracks, porosity, and deep craters. Further, there is transfer of Cu and Zn ions from diffused wire electrode to the obtained surface.

Keywords $Wire_{EDM}$ · MRR · Spark gap · Metal matrix composite · Surface veracity · Recast layer

Abbreviations

Symbol	**Abbreviation**
EDX	Energy dispersive X-ray

S. K. Garg (✉)
Seth Jai Parkash Mukand Lal Institute of Engineering and Technology, Radaur, Haryana, India
e-mail: sgarg.jmit@gmail.com

A. Manna
PEC University of Technology, Chandigarh, India

A. Jain
National Institute of Technology, Kurukshetra, Haryana, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_61

MMC	Metal matrix composite
MRR	Material removal rate
$RL_{t\,avg}$	Average thickness of recast layer
SR	Surface-roughness
$Wire_{EDM}$	Wire-$_{EDM}$
$x_{1,}$ PW	Pulse width
x_3, SCMRV	Servo control mean reference voltage
$x_{5,}$ WFR	Wire feed rate
x_2, TBP	Time beet$_n$ pulses
$x_{4,}$ SPT	Short pulse time
$x_{6,}$ WMT	Wire tension (Mechanical)

1 Introduction

Powder reinforced MMC are tailor-made materials whose properties can be customized to meet the design needs by varying the reinforcements, matrices, and microstructure. It is composed of a metallic matrix such as Aluminum, Copper, Magnesium, and reinforced with ceramics (oxide, carbides). Powder reinforced MMC are used for space shuttles, commercial airliners, electronic substrates, bicycles, automobiles, golf clubs, and a variety of other applications. As per literature available, $Wire_{EDM}$ emerged as an effective machining method to machine the Powder reinforced MMC [1–5].

In the present work, $Wire_{EDM}$ is used to machine the $Al/ZrO_{2(P)}$ MMC. Different optimization methods such as Taguchi [6–14], Grey Relational and Statistical Analysis [7, 15–17], Response Surface Methodology (RSM) [18–25], Neural Network [26], Fuzzy Logic [27], JAYA Algorithm [27], Gaussian Process Regression [28], and Genetic-Algorithm (GA) [29] were used by the researchers to optimize the process parameters of $Wire_{EDM}$.

Bhattacharyya et al. [30] studied the surface veracity in terms of average white layer thickness and surface crack density of M2 die steel machined through $_{EDM}$. Response surface methodology was used by the authors to develop the numerical expressions for correlating the process parameters with performance characteristics. Authors analyzed the effect of parameters on white layer thickness and surface crack density. Han et al. [31] investigated differences in surface morphology and mechanisms of metal removal due to variation in pulse duration were investigated using thermo-analysis by finite element method in the finish cut of $Wire_{EDM}$. Authors found that surfaces machined by discharge current with a short and long duration pulses had similar roughness values when the pulse energy was constant and high enough; however, the surface morphologies obtained were totally different. Rao and Venkaiah [24] investigated the surface veracity issues of Inconel-690 during $Wire_{EDM}$ process. Experiment plan was designed using RSM. The authors investigated the parameters effect on average surface roughness, micro-hardness, and average recast layer thickness. Paramanik et al. [14] investigated the $Wire_{EDM}$ process related to the machining of MMC and the effect of reinforced particulates on the machining performance. They found that the availability of reinforcement protects the matrix material getting melted and vaporized hence reduces the MRR. Sharma et al. [23] optimized the $Wire_{EDM}$ performance characteristics of Inconel-706 and analyzed the WED-machined surface. The authors found that average recast layer thickness is directly proportional to the discharge energy produce in the machining zone. Vijayabhaskar and Rajmohan [21] optimized the $Wire_{EDM}$ process parameters for the machining of Nanosize SiC particulates reinforced in Mg matrix composites using RSM. The authors investigated the effect of nano-particulates reinforcement and morphology of the machined surface. Dey and Pandey [16] investigated the $Wire_{EDM}$ characteristics of AA 6061/cenosphere as cast Aluminum matrix composites and found that the presence of insulating particles in the composite caused the difference in the machining process than that of the monolithic alloy. Bisaria and Shandilya [32] investigated the $Wire_{EDM}$ characteristics of Nimonic C-263 superalloy. They found the presence of craters, micro-voids, and globules of debris in the machined surface.

Literature survey reveals that there is very less work reported on the investigation of WED-machined surfaces of MMC. In the present work, the optimal set of process parameters for $Wire_{EDM}$ of $Al/ZrO_{2(P)}$-MMC are obtained using RSM for maximum MRR and minimum SR (Ra). The surface veracity aspects that include composition, surface defects, and thickness of recast layer are investigated for the machined surfaces which are obtained from the set of optimal process parameters.

2 Material and Methods

The commercially available AA2024/Al alloy and Zirconium di-oxide reinforced particulates (ZrO_2) are used for casting of $Al/ZrO_{2(P)}$-MMC. Central design of the RSM and full factorial approach (Chua et al. [33], Gaitonde et al. 34]) are used to design the experiment with the help of Design-Expert® (8.0 version) software. This design is insensitive to missing data and has more runs initially than the other designs such as Box–Behnken which makes it more robust to the experimental problems (Design-Expert® Help Manual [35]). Table 1 shows the process parameters along with their details used for the experimental runs which are performed as per the experiment design [36] in order to obtain the set of optimal process parameters for maximum MRR and Minimum SR (Ra). The micro-structural analysis of the machined surfaces is carried out through SEM and EDX (JEOL, Tokyo, Japan, Model JSM-6610LV). The machined samples are etched with Keller's etchant to expose the machined surface properly before taking SEM image. The samples are also washed with acetone $(CH_3)2CO$ before taking such images. The machining of material by W_{EDM} produces recast layer which is undesirable as chances of fatigue failure increases [36–39].

Thickness of recast layer deposited on the work surface during W_{EDM} is highly variable in nature. Measuring the thickness at large number of points on the recast

Table 1 Process parameters and their coded and real values for the experiment

S. No.	Process parameters	Units	Levels of the process parameters				
			−1.57	−1	0	+1	+1.57
1	PW (x_1)	μs	0.36	0.5	0.75	1	1.14
2	TBP (x_2)	μs	4.61	8.0	14	20	23.39
3	SCMRV (x_3)	volts	11.52	20	35	50	58.48
4	SPT (x_4)	μs	0.12	0.2	0.35	0.5	0.6
5	WFR (x_5)	m/min	4.87	6	8	10	11.13
6	WMT (x_6)	daN	0.43	0.6	0.9	1.2	1.37
Constant parameters							
7	WorkPiece height	10.1 mm					
8	Machining voltage	80 V					
9	Ignition pulse current	8 units (1/2 A)					
10	Maximum feed rate	10 units (73.2 μm/min)					

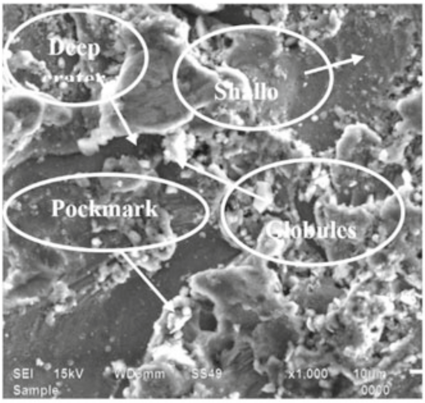
layer and then taking the average does not provide a reasonable basis for estimation of this. So, average thickness of recast layer is calculated in the following manner:

1. SEM image is imported in the Axio Vision (Release 4.8.2 SP2)® software.
2. Scaling option is used to define the scale in μm with the help of the scale provided on the SEM image.
3. Splines are used concurrently to closely mark the area occupied by the recast layer.
4. Recast layer is shown as a closed entity, and texture command is used to identify the recast layer.
5. Area and length of recast layer are automatically generated by the software.
6. Average recast layer thickness = (Area of recast layer)/(length of recast layer).

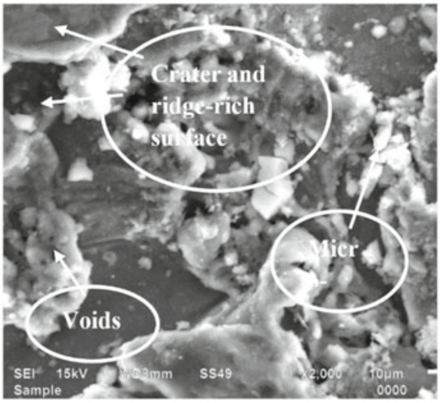
The EDX analysis is used to find the presence of different elements (composition) on the surface of specimens. The EDX spectrum shows peak in correspondence to the energy level at which maximum of the X-rays have been received. Every peak in the spectrum is unique, and higher peak shows the presence of more concentration of the element in the specimen.

3 Results and Discussions

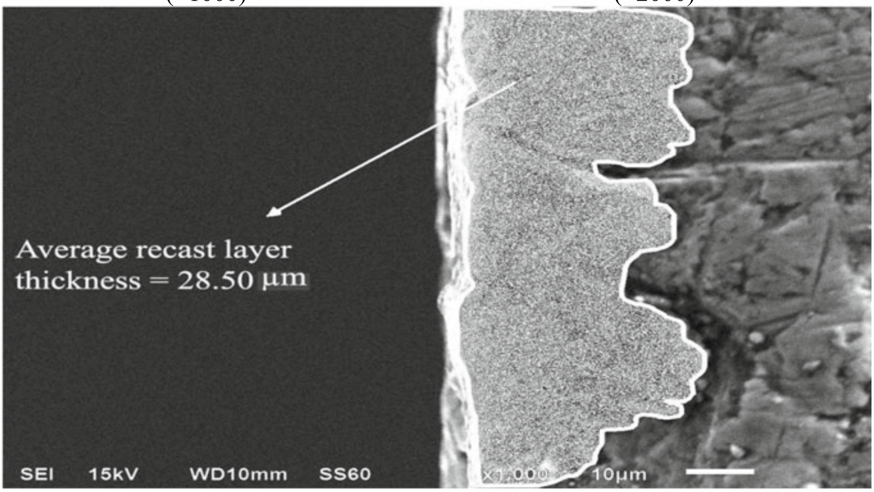
Figure 1a, b shows SEM images of machined surfaces, and Fig. 1c shows recast layer deposited on the machined surface of Al/$ZrO_{2(P)}$-MMC obtained by W_{EDM} corresponding to optimal parameter setting for maximum MRR objective identified using RSM. The optimal parameters values are 1.00 μs for Pulse Width (PW), 11.66 μs for Time Between Pulses (TBP), 0.60 μs for Short Pulse Time (SPT), 28.80 V for Servo Control Mean Reference Voltage (SCMRV), 10.00 m/s for Wire Feed Rate (WFR),



(a) SEM Image of Machined Surface (×1000)



(b) SEM Image of Machined Surface (×2000)



(c) SEM Image of Machined Surface Shows Average Recast Layer Thickness (×1000)

Fig. 1 **a**–**c** SEM images of machined surface obtained by W_{EDM} of Al/5% wt. $ZrO_{2(P)}$-MMC corresponding to maximum MRR objective (PW = 1.00 μs, TBP = 11.66 μs, SPT = 0.60 μs, SCMRV = 28.80 V, WFR = 10.00 m/s, WMT = 0.86 daN, diffused wire electrode) and 0.86 daN for Wire Mechanical Tension (WMT). Figure 1a, b clearly reveals that machined surface produced during W_{EDM} operation is an uneven fusing structure and show the presence of shallow and deep craters, pockmarks, micro-cracks, drops of debris, and micro-voids. These are because of fast heating and cooling of work surface during machining operation. The presence of drops of debris indicates that these are not flushed away by the dielectric medium. The average recast layer thickness obtained from Fig. 1c is 28.50 μm. Figure 2 shows the EDX analysis of machined surface of Al/$ZrO_{2(P)}$-MMC corresponding to optimal parameter setting as specified above.

It reveals that residuals of copper (Cu) and zinc (Zn) are present on the machined surface of Al/5% wt. $ZrO_{2(P)}$-MMC. This implies that during W_{EDM}, material is transferred from diffused wire electrode to the workpiece surface and gets deposited on the obtained surface. The presence of oxygen element on the obtained surface is due to formation of oxides as well as break-up of dielectric fluid (de-ionized water).

Figure 3a, b shows SEM images of machined surfaces, and Fig. 3c shows recast layer deposited on the machined surface of Al/$ZrO_{2(P)}$-MMC obtained by W_{EDM} corresponding to optimal parameter setting for minimum SR (Ra) objective that is identified using RSM. The optimal parameters values are 0.50 μs for Pulse Width (PW), 8.00 μs for Time Between Pulses (TBP), 0.20 μs for Short Pulse Time (SPT), 20.00 V for servo control mean reference voltage (SCMRV), 9.50 m/s for Wire Feed Rate (WFR), and 1.20 daN for Wire Mechanical Tension (WMT)

From surface topography Fig. 3a, b, it is clear that machined surface produced during W_{EDM} operation is an uneven fusing structure and shows the presence of craters, pockmarks, globules of debris, micro-cracks, and voids. The average recast layer obtained from Fig. 3c is 17.54 μm. Figure 3a, b shows shallow craters with larger diameters which imparts better workpiece surface roughness as compared

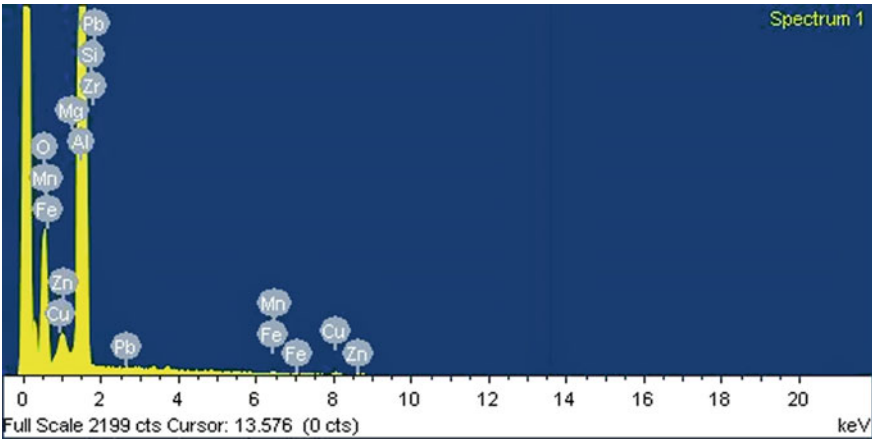
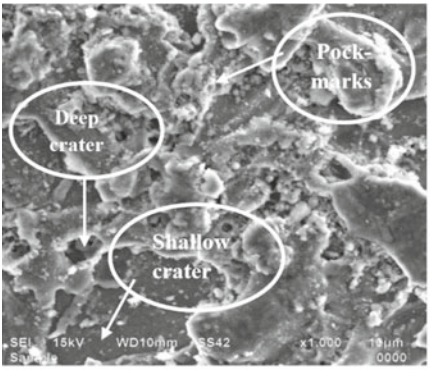
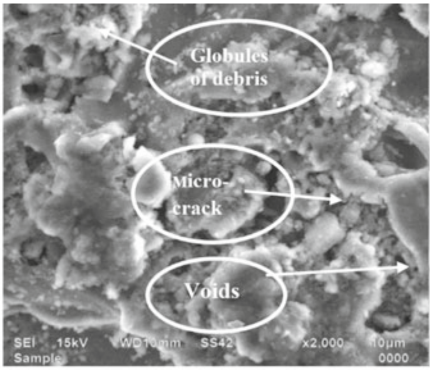


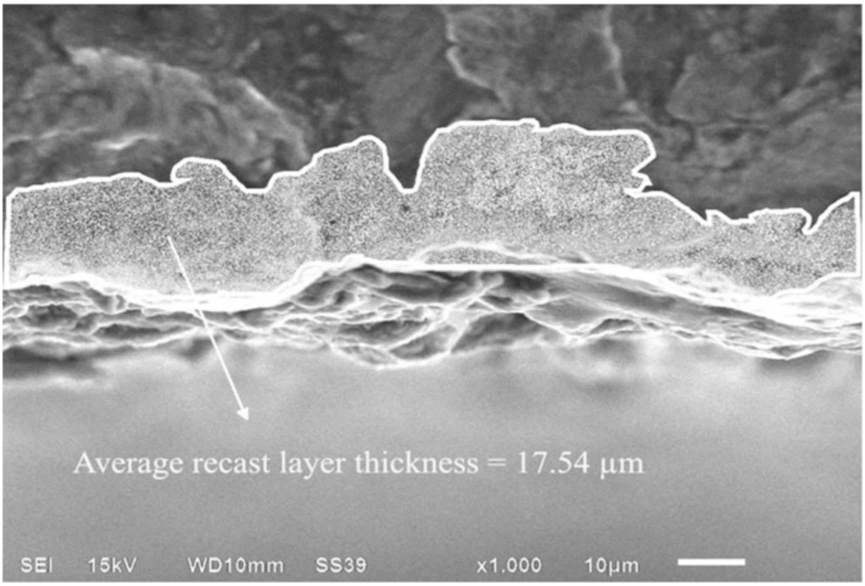
Fig. 2 EDX analysis results for machined surface of Al/5% wt. $ZrO_{2(P)}$-MMC obtained by W_{EDM} corresponding to maximum MRR objective (PW = 1.00 μs, TBP = 11.66 μs, SPT = 0.60 μs, SCMRV = 28.80 V, WFR = 10.00 m/s, WMT = 0.86 daN, diffused wire electrode)



(a) SEM Image of Machined Surface (×1000)



(b) SEM Image of Machined Surface (×2000)



(c) SEM Image of Machined Surface Shows Average Recast Layer Thickness (×1000)

Fig. 3 **a–c** SEM Images of Machined Surface Obtained by W_{EDM} of Al/5% wt. $ZrO_{2(P)}$-MMC Corresponding to Minimum SR (Ra) Objective (PW = 0.50 µs, TBP = 8.00 µs, SPT = 0.20 µs, SCMRV = 20.00 V, WFR = 9.50 m/s, WMT = 1.20 daN, diffused wire electrode)

to Fig. 1a, b corresponding to maximum MRR optimal parametric setting. Average recast layer thickness (17.54 µm) obtained for minimum SR (Ra) optimal parametric combination is less as compared to the average recast layer thickness (28.50 µm) obtained while utilizing optimal parametric combination for maximum MRR (1c). This is due to the fact that lower setting values of parameters pulse width PW (0.50 µs as compared to 1.00 μs) and short pulse time (0.20 μs as compared to 0.60 μs) produce low discharge energy per spark impinged on the workpiece surface and it causes less melting of material.

In order to obtain surface having lesser roughness and good surface integrity, it is important to produce electrical discharge energy at a lower level by setting PW and SPT on a lower side. More deep craters, voids, and cracks are observed in Fig. 1a, b as compared to Fig. 3a, b, respectively. This is due to the fact that higher parameter setting value of PW (1.0 μs as compared 0.5 μs), SPT (0.5 μs as compared to 0.2 μs), and lower parameter setting value of TBP (11.66 μs as compared to 16.97 μs) produces higher discharge energy causing more melting of material. Rapid heating and cooling because of high discharge energy induce high levels of thermal stresses exceeding the ultimate strength of the material on the work surface, thus causes the formation of deeper and wider cracks. Higher discharge energy also produces abrupt sparks causing more pockmarks on the machined surface as observed in Fig. 1a, b compared to Fig. 3a, b, respectively. Lower discharge energy produced during spark due to lower setting values of parameters PW, SPT along with higher setting value of parameter TBP causes formation of shallow craters with larger diameters as observed in Fig. 3a, b, respectively.

Average recast layer thickness is maximum (28.50 μm) for the W_{EDM} of Al/5% wt. $ZrO_{2(P)}$-MMC corresponding to optimal parametric combination for MRR. This is due to the fact that machining operation is carried out utilizing parameters setting values of PW, TBP, SPT, SCMRV, WFR, and WMT as 1.0, 11.66, 0.6 μs, 28.80 V, 10.0 m/s, and 0.86 daN, respectively, which produce higher discharge energy. This further causes more melting of material. The molten metal which is not swept away from the machining zone with the flow of dielectric medium solidifies within a very small time and forms the recast layer. Thus, larger melting of material indicates larger average recast layer thickness.

From the above discussion, it can safely be concluded that for W_{EDM} of Al/5% wt. $ZrO_{2(P)}$-MMC lower setting values of parameters PW and SPT along with higher setting value of parameter TBP is desirable for good surface finish, lesser recast layer thickness, and good surface topography, whereas higher setting values of parameters PW and SPT along with lower setting value of parameter TBP are desirable for higher material removal rates.

4 Conclusions

Based on the Investigation of Surface Veracity of WireEDM Machined Surfaces of Al/ZrO_2(p)-MMC), the Following Points Are Concluded

i. $Wire_{EDM}$ surface shows the availability of shallow and deep craters, micro-voids, pockmarks and globules of debris.
ii. Wire shifting is observed during $Wire_{EDM}$ of Al/$ZrO_{2(P)}$-MMCs which leaves a bending mark on the obtained surface.

iii. There is a transfer of Cu and Zn ions from diffused wire electrode to the obtained surface during the $Wire_{EDM}$ of $Al/ZrO_{2(P)}$-MMC.
iv. The presence of oxygen on the obtained surface is due to oxide formation and break-up of dielectric fluid (de-ionized water).
v. Lower setting values of parameters PW and SPT along with higher setting value of parameter TBP is desirable for good surface finish, lesser recast layer thickness, and good surface topography, whereas higher setting values of parameters PW and SPT along with lower setting value of parameter TBP is desirable for higher material removal rates for $Wire_{EDM}$ of $Al/ZrO_{2(P)}$-MMCs.

The investigation of surface veracity of the $Wire_{EDM}$ machined surfaces of $Al/ZrO_{2(P)}$-MMCs will provide the valuable knowledge to the researchers and the manufacturing engineers to plan the need of subsequent operations to improve the surface veracity and further the life of the products fabricated using these MMCs.

References

1. Vijayabhaskar, S., Rajmohan, T.: Experimental Investigation and Optimization of Machining Parameters in WEDM of Nano-SiC Particles Reinforced Magnesium Matrix Composite, Silicon, 2018, pp. 1–16. https://doi.org/10.1007/s12633-017-9676-0
2. Dey, A., Pandey, K.M.: Wire Electrical Discharge Machining Characteristics of AA6061/Cenosphere as Cast Aluminum Matrix Composites, Material Manufacture Processes, pp. 1346–1353. https://doi.org/10.1080/10426914.2017.1388517
3. Pramanik, A., Littlefair, G.: Wire EDM Mechanism of MMCs with the Variation of Reinforced Particle Size, Material Manufacture Processes, pp. 1700–1708. https://doi.org/10.1080/10426914.2015.1117621
4. Jun, M., Wuyi, M., Jinguang, D., Hao, H., Wenbin, H., Yang, C., Xiaoke, L.: Integrated optimization model in wire electric discharge machining using gaussian process regression and wolf pack algorithm approach while machining SiCp/Al composite. Adv. Mech. Eng., 1–17. https://doi.org/10.1177/1687814018787407
5. Pramanik, A., Islam M.N., Boswell B., Basak, A.K., Dong, Y., Littlefair, G.: Accuracy and finish during wire electric discharge machining of metal matrix composites for different reinforcement size and machining conditions. J. Eng. Manuf., 1068–1078 (2016). https://doi.org/10.1177/0954405416662079
6. Selvakumar, G., Thiruppathi Kuttalingam, K.G., Ram Prakash, S.: Investigation on machining and surface characteristics of AA5083 for cryogenic applications by adopting trim cut in WEDM. J. Braz. Soc. Mech. Sci. Eng., 1678–5878 (2018). https://doi.org/10.1007/s40430-018-1192-7
7. Sharma, P., Chakradhar, D., Narendranath, S., Analysis and Optimization of WEDM Performance Characteristics of Inconel 706 for Aerospace Application, : 921–930. Springer (2017). https://doi.org/10.1007/s12633-017-9549-6
8. Ramamurthy, A., Sivaramakrishnan, R., Muthuramalingam, T., Venugopal, S.: Performance analysis of wire electrodes on machining Ti-6AI-4V alloy using electrical discharge machining process. I.J. Mach. Sci. Technol., 557–592 (2015). https://doi.org/10.1080/10910344.2015.1085314
9. Raj, S.O.N., Prabhu, S.: Modeling and analysis of titanium alloy in wire cut EDM using grey relation coupled with principle component analysis. Aust. J. Mech. Eng., 198–209 (2016). https://doi.org/10.1080/14484846.2016.1251077

10. Kumar, M., Singh, H.: Multi response optimization in wire electrical discharge machining of Iconel X-750 using Taguchi's technique and grey relational analysis. Cogent Eng., 1–14 (2016). https://doi.org/10.1080/23311916.2016.1266123
11. Kandpal, B.C., Kumar, J., Singh, H.: Optimization and characterization of EDM of AA6061/10%Al_2O_3 AMMC using Taguchi's approach and utility concept. Prod. Manuf. Res. 351–370. https://doi.org/10.1080/21693277.2017.1389315
12. Maher, I., Sarhan, A.A.D., Marashi, H., Barzani, M.M., Hamdi, M.: White layer thickness prediction in wire EDM using CuZn coated wire electrode-ANFIS modeling. I.J. Surf., 204–210. https://doi.org/10.1080/00202967.2016.1180847
13. Ma, J, Ming, W., Du, J., Huang, H., He, W., Cao, Y., Li, X.: Integrated optimization model in wire electrical discharge machining using gaussian process regression and wolf pack algorithm approach while machining SiCp/Al composite. Adv. Mech. Eng., 1–17. https://doi.org/10.1177/1687814018787407
14. Pramanik, A., Islam, M.N., Boswell, B., Basak, A.K., Dong, Y., Littlefair, G.: Accuracy and finish during wire electrical discharge machining of metal matrix composites for different reinforcement size and machining conditions. Proc. Inst. Mech. Eng. B J Eng. Manuf., 1–11. https://doi.org/10.1177/0954405416662079
15. Chalisgaonkar, R.; Kumar, J., Parametric Optimization and Modeling of Rough Cut WEDM Operation of Pure Titanium Using Grey Fuzzy Logic and Dimensional Analysis, Cogent Eng., 2014, 1–28, DOI: https://doi.org/10.1080/23311916.2014.979973
16. Dey, A., Pandey, K.M.: Selection of optimal processing condition during WEDM of compocasted AA6061/cenosphere AMCs based on grey based hybrid approach. Mater. Manuf. Processes, 1549–1558 (2018). https://doi.org/10.1080/10426914.2018.1453154
17. Khanna, R., Singh, H.: Comparison of optimized settings for cryogenic treated and normal D-3 steel on WEDM using grey relational theory. Proc I Mech E part l J Mater. Des. App. 1–14 (2014). https://doi.org/10.1177/1464420714565432
18. Garg, S.K., Manna, A., Jain, A.: Experimental investigation of spark gap and material removal rate of Al/ZrO2(P) –MMC machined with wire EDM. J. Braz. Soc. Mech. Sci. & Eng. 481–491 (2016). 10.1007%2Fs40430–015–0394–5
19. Shihab, S.K.: Optimization of WEDM process parameters for machining of friction- stir-welded 5754 aluminum alloy using box- Behnken design of RSM. Arab. J. Sci. Eng. 5017–5027 (2018). https://doi.org/10.1007/s13369-018-3238-7
20. Wang, J., Wang, T., Wu, H.: Experimental study on high speed WEDM finishing in steam waster mist. Int. J. Adv. Manuf. Technol. 3285–3297 (2017). https://doi.org/10.1007/s00170-017-0005-y
21. Vijayabhaskar, S., Rajmohan, T.: Experimental investigation and optimization of machining parameters in WEDM of nano-SiC particles reinforced magnesium matrix composites, silicon, 1–16 (2017). https://doi.org/10.1007/s12633-017-9676-0
22. Senkathir, S.; Aravind, R.; Manoj, S.R.; Arun Raj A.C., Optimization of Machining Parameters of Inconel 718 by WEDM using Response Surface Technology, Advances in Manufacturing Processes, 2018, 383–392, DOI: https://doi.org/10.1007/978-981-13-1724-8_37
23. Sharma, N., Raj, T., Jangra, K.K.: Parameter optimization and experimental study on wire electrical discharge machining of porous Ni40Ti60 alloy. Proc. Inst. Mech. Eng. B J. Eng. Manuf. 1–15, (2015). https://doi.org/10.1177/0954405415577710
24. Rao, M.S., Venkaiah, N.: Experimental investigation on surface integrity issues of inconel-690 during wire-cut electrical discharge machining process. In: Proceedings Institution Mechanical Engineering B Journal Engineering Manufacturing, 1–11 (2016). https://doi.org/10.1177/0954405416654092
25. Garg, S.K., Manna, A., Jain, A.: An investigation on machinability of Al/10% ZrO_2(p)- metal matrix composite by WEDM and parametric optimization using desirability function approach. Arab J. Sci. Eng. 3251–3270 (2014). https://doi.org/10.1007/s13369-013-0941-2
26. Saha, P., Singha, A., Pal, S.K., Saha, P.: Soft computing model based prediction of cutting speed and surface roughness in wire electro-discharge machining of tungsten carbide cobalt composite. Int. J. Adv. Manuf. Technol. 74–84 (2008). https://doi.org/10.1007/s00170-007-1200-z

27. Kumar, A., Abhishek, K., Vivekananda, K., Upadhyay, C.: Experimental Study and Optimization of Process Parameters During WEDM Taper Cutting, Soft Computing for Problem Solving, 721–736 (2018). https://doi.org/10.1007/978-981-13-1595-4_57
28. Zhang, J.H., Lee, T.C., Wu, C.L., Tang, C.Y.: Surface integrity and modification of electro-discharge machined alumina based ceramic composite. J. Mater. Process. Tech., 75–79 (2002). https://doi.org/10.1016/S0924-0136(02)00065–1
29. Kuriakose, S., Shunmugam, M.S.: Multi-objective optimization of wire-electro-discharge machining process by non-dominated sorting genetic Algorithm. J. Mater. Process. Tech. **170**, 133–141 (2005). https://doi.org/10.1016%2Fj.jmatprotec.2005.04.105
30. Bhattacharyya, B., Gangopadhyay, S., Sarkar, B.R.: Modelling and analysis of EDM job surface integrity. J. Mater. Process. Tech., 169–177 (2007). 10.1016%2Fj.jmatprotec.2007.01.018
31. Han, F., Jiang, J., Yu, D.: Influence of discharge current on machined surfaces by thermo-analysis in finish cut of WEDM. Int. J. Mach. Tool Manufact., 1187–1196 (2007). https://doi.org/10.1016/j.ijmachtools.2006.08.024
32. Bisaria, H., Shandilya, P.: Experimental investigation on wire electric discharge machining (WEDM) of Nimonic C-263 superalloy. Mater. Manuf. Process, 1–10 (2018). https://doi.org/10.1080/10426914.2018.1532589
33. Chua, M.S., Rahman, M., Wong, Y.S., Loh, H.T.: Determination of optimal cutting conditions using design of experiments and optimization techniques. Int. J. Mach. Tool Manufact., 297–305 (1993). https://doi.org/10.1016/0890-6955(93)90081-5
34. Gaitonde, V.N., Karnik, S.R., Davim, J.P.: Some studies in metal matrix composites machining using response surface methodology. J. Reinf. Plast. Compos. 2445–2457 (2009). 10.1177%2F0731684408092375
35. Design - Expert ® help manual, https://www.statease.com/dx8_man.html. Accessed 20 Mar. 2015
36. Garg, S.K., Manna, A., Jain, A.: An experimental investigation for optimization of WEDM parameters during machining of fabricated $Al/ZrO_{2(p)}$ MMC. Arab. J. Sci. Eng. **38**(12), 3471–3483 (2013). https://doi.org/10.1007/s13369-013-0657-3
37. Garg, S.K.: Optimization of Wire Electric Discharge Machining Parameters of $Al/ZrO_{2(P)}$ Metal Matrix Composite. Ph.D. thesis, NIT, Kurukshetra, India (2015)
38. Garg, S.K., Manna, A., Jain, A.: An experimental investigation and parametric optimization for wire EDM of Al-5% ZrO_2 particulate reinforced metal matrix composite. Int. J. Mater. Mach., 136–145 (2012). https://doi.org/10.4018/ijmmme.2012100103
39. Kumar, D., Phanden, R.K., Thakur, L.: A review on environment friendly and lightweight magnesium-based metal matrix composites and alloys. Mater. Today Proc. (2020). https://doi.org/10.1016/j.matpr.2020.07.424

Processing and Characterization of Plasma Sprayed LD Slag Coatings on Mild Steel Substrate

Pravat Ranjan Pati

Abstract Indeed in spite of the fact that kind of metal and ceramic powders are recycled as coating fabric, the usage of fabricating squanders for this reason has not been enough found. Hence, the current study reports on the advancement and execution of plasma sprayed coatings using Linz-Donawitz (LD) slag as the leading material. LD slag coatings are kept on mild steel substrates in several weight proportions at input control levels of the plasma torch. The various mechanical properties such as thickness, hardness, strength, and porosity are discussed in this analysis. This type of coating is measured by computing deposition efficiency. The adhesion strength, efficiency, and coating thickness are affected by the control level of the plasma torch. This effort also exposes that LD slag is especially coated on mild steel substrate.

Keywords Plasma spraying · LD slag · Coating · Characterization

1 Introduction

A coating may be a layer, i.e., applied to the external surface of an object, usually assigned to as the substrate. The reason for applying coating may be decorative, functional, or both. There are different types of coating techniques and thermal spraying is one of them. Plasma spraying is one of the methods which are broadly used in several applications [1, 2]. In the present time, plasma spray plays a crucial role in many areas such as steel industry, aircraft industry, automotive industry, medical industry, gas turbine industry, electrochemical industry, hydraulic industry, rolling and foundry mills, textile industry, paper and printing industry, and glass industry. A variety of conventional coating materials, e.g., carbides, oxides, metallic, diamond, etc., are available commercially and have high cost effective. Therefore, an industrial waste, which having less cost compared to other coating material, is used as far as economical analysis is concerned. Sahu et al. [3] studied the preparing and characterization of plasma spray coatings placed on metal substrates. Krishna

P. R. Pati (✉)
Faculty of Science and Technology, ICFAI Foundation for Higher Education, Hyderabad, India
e-mail: pravatpati99@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_62

et al. [4] have investigated the fly-ash coatings on steel substrates. Mishra et al. [5] also attempted the fly-ash coatings by plasma spraying route. Mantry et al. [6] testified the copper slag coatings on steel substrates. Satapathy [7] stated the progress of coating of red mud on many substrates. The enhancements of coatings utilizing fly-ash pre-mixed with metal powder are done by Satapathy et al. [8]. Niebuhr and Scholl [9] examined the execution of plasma sprayed polymer or steel coatings. Cadenas et al. [10] also studied the plasma sprayed tungsten carbide coatings. Dai et al. [11] observed plasma sprayed titania coating against stainless steel. Plasma sprayed coatings of red mud on aluminum and copper substrates have also been reported by Satapathy et al. [12]. The surface coatings of copper slag and aluminum powder have been investigated by Mantry et al. [13]. Gupta and Satapathy [14, 15] studied the coatings of glass microspheres on metal substrates. Recently, Patel et al. [16] discussed various thermal spray techniques. Nayak et al. [17] reported the plasma sprayed YSZ and Al_2O_3 coating on aluminum substrate. Xu and Jean [18] also elucidated the zirconia ceramic coatings using plasma spray technique. So, the current effort finds the improvement of plasma sprayed coatings of LD slag on mild steel substrates.

2 Experimental details

2.1 Coating Material

LD slag is an industrial waste, which emerges from pig iron purifying process through LD converters, being utilized in this work. This type of material is (collected from RSP, Odisha) filtered to get a molecule size within the range of 90–100 μm prior to coating. The major compositions of LD slag are CaO (47.88%), Fe_2O_3 (26.3%), and SiO_2 (12.16%).

2.2 Coating Deposition

Plasma spray deposition is a thermal spray coating technology that the heat ionizes the gas and the gas itself becomes the heat source of the process. The process includes infusion of the material to be kept into a plasma jet emanating from a plasma torch, where they are liquefied at temperature around 10,000 K and the molten particles strike the substrate surface shaping disciple coating. The material can be fed in the form of powder (powder spraying) or wire (wire spraying). This setup comprises a plasma jet generator (spray gun), DC power supplies, cooling water system, gas train, powder feeder, and control console. The preparation of coating is carried out at IMMT, Odisha and the arrangement of plasma spray system is shown in Fig. 1. Sand-blasted mild steel substrates are fitted on the substrate holder and coating is

Fig. 1 Pictorial view of plasma spray setup

done at a continuous powder feed rate of 20 g/min at six dissimilar input control levels.

2.3 Coating Characterization

Coating thickness is measured by an Elcometer 456 thickness gauge. The experimental adhesion strength is performed by the drag out manner ensuing the ASTM C-633. Micro-hardness measurement is done employing a Leitz micro-hardness analyzer. Estimation of porosity is achieved by means of image analysis method.

3 Results and discussion

3.1 Coating Thickness

The deviation of thickness of coating with control input to the torch is shown in Fig. 2. It is obvious that with rises in input control the thickness of the coating increases regardless of the coating fabric. During 13–20 kW power, the coating thickness is found to be substantial and is compared with other results [7] which show significant improvement.

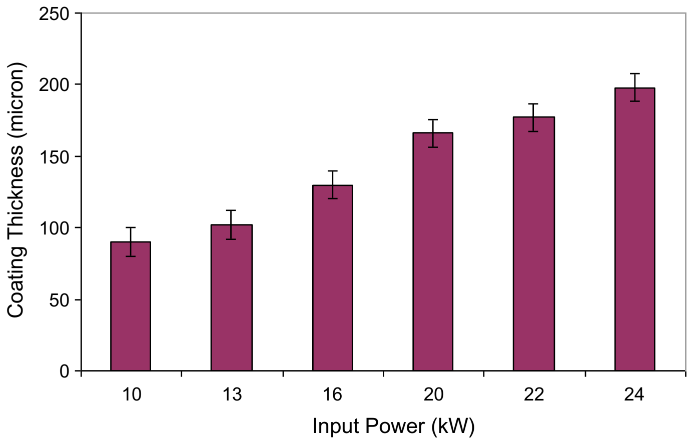


Fig. 2 Deviation of coating thickness with input control

3.2 Coating Deposition Efficiency

Coating efficiency is measured by computing the fraction between the amount of coating kept and the amount of powder fed for a specified time. In this analysis, the coating efficiency rises with rise in input control, as shown in Fig. 3. The deposition efficiency of LD slag coating progresses from 10.4% to 28% as the input control is raised from 10–24 kW.

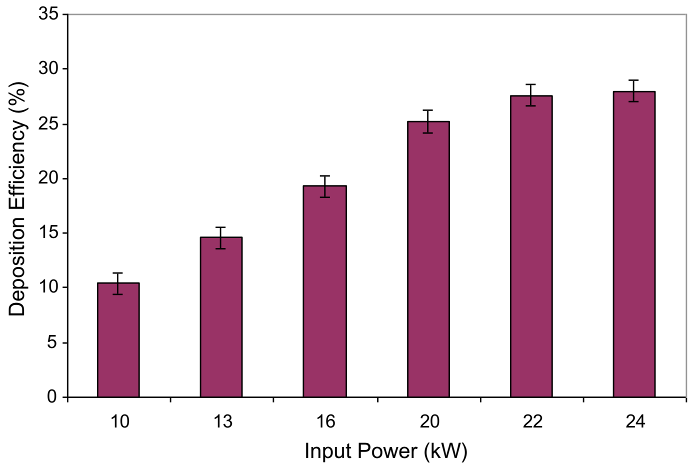


Fig. 3 Deviation of deposition efficiency with input control

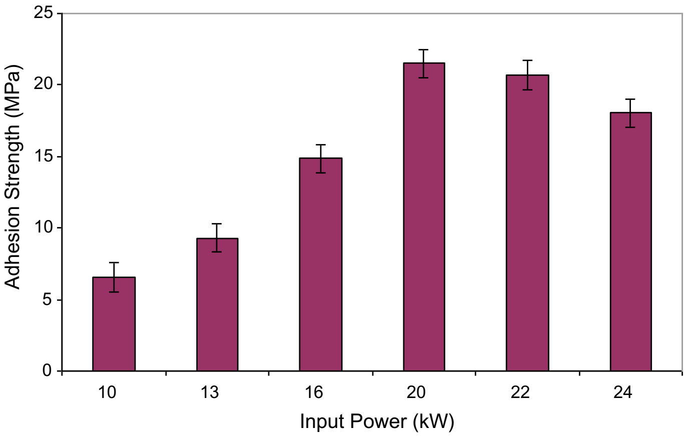


Fig. 4 Deviation of adhesion strength with input control

3.3 Coating Adhesion Strength

The deviation of adhesion strength of LD slag coatings with power input is shown in Fig. 4. It is obvious that the strength fluctuates considerably with input control of the plasma torch and the peak strength is obtained at 20 kW of around 21.5 MPa. The adhesion strength is identified as declining sequence at a power below 20 kW. This outcome is very effective than the other results [7].

3.4 Coating Micro-hardness

The micro-hardness values for coating material at dissimilar input control are given in Table 1. It is found to be 3.52–5.82 GPa as the control input raised from 10 to 24 kW for LD slag-based coatings. The result found in this experimental analysis is more efficient than the result found by other researchers [7].

Table 1 Coating micro-hardness at varying operating input power (kW)

Material	Micro-hardness (GPa)					
LD slag	10	13	16	20	22	24
	3.52	4.54	4.73	4.97	5.46	5.82

3.5 Coating Porosity

The pores present in the LD slag coatings are found to be 4–10%. The least pore is confirmed at 24 kW power. It is also observed that with adding conventional coating material like alumina and titania to raw LD slag, the percentage of pores can be reduced.

4 Conclusions

This experimental research leads to conclude that LD slag is exceptionally coatable. The adhesion strength is prominently influenced by the plasma input control. The other critical coating characteristics like deposition efficiency, thickness, porosity, and hardness are essentially influenced by the torch input control and also show more efficient than other experimental analysis. Thus, LD slag can be utilized as commercial coating material.

5 Future Scope

Some recommendations for future research include the following:

1. Possible use of ceramic/metallic powders as additive in the development of LD slag-based composite coatings.
2. Study on the response of this coating to wear modes such as sliding, abrasion, and slurry erosion.
3. Cost analysis of this coating to assess their economic viability in industrial applications.

References

1. Guessasma, S., Bounazef, M., Nardin, P., Sahraoui, T.: Wear behavior of alumina Titania coatings: analysis of process and parameters. Ceram. Int. **32**, 13–19 (2006)
2. Ouyang, J.H., Sasaki, S.: Tribological characteristics of low pressure plasma-sprayed Al_2O_3 coating from room temperature to 800 °C. Tribol. Int. **38**, 49–57 (2005)
3. Sahu, S.P., Satapathy, A., Patnaik, A., Sreekumar, K.P., Ananthapadmanabhan, P.V.: Development, characterization and erosion wear response of plasma sprayed fly ash-aluminum coatings. Mater. Des. **31**, 1165–1173 (2010)
4. Krishna, L.R., Sen, D., Rao, D.S., Sundararajan, G.: Cotability and characterization of fly ash deposited on mild steel by detonation spraying. J. Ther. Sp. Tech. **12**(1), 77–79 (2003)
5. Mishra, S.C., Rout, K.C., Ananthapadmanabhan, P.V., Mills, B.: Plasma spray coating of fly ash pre-mixed with aluminium powder deposited on metal substrates. J. Mat. Proc. Tech. **102**, 9–13 (2000)

6. Mantry, S., Behera, D., Mishra, S.K., Debasish, D., Jha, B.B., Mishra, B.K.: Erosive wear analysis of plasma-sprayed Cu slag-Al composite coatings. Tribol. Trans. **56**, 196–202 (2013)
7. Satapathy, A.: Thermal Spray Coating of Red Mud on Metals. Ph.D. Thesis, NIT, Rourkela, India (2005)
8. Satapathy, A., Sahu, S.P., Mishra, D.: Development of protective coatings using fly ash premixed with metal powder on aluminium substrates. Waste Manage. Res. **28**, 660–666 (2010)
9. Niebuhr, D., Scholl, M.: Synthesis and performance of plasma-sprayed polymer/steel coating system. J. Therm. Spray Tech. **14**, 487–494 (2005)
10. Cadenas, M., Vijande, R., Montes, H.J., Sierra, J.M.: Wear behaviour of laser cladded and plasma sprayed WC-Co coatings. Wear **212**, 244–253 (1997)
11. Dai, W.W., Ding, C.X., Li, J.F., Zhang, Y.F., Zhang, P.Y.: Wear mechanism of plasma-sprayed TiO_2 coating against stainless steel. Wear **196**, 238–242 (1996)
12. Satapathy, A., Mishra, S.C., Ananthapadmanabhan, P.V., SreeKumar, K.P.: Development of ceramic coatings using red mud-a solid waste of alumina plants. J. Solid Waste Technol. Manag. **33**, 108–113 (2007)
13. Mantry, S., Jha, B.B., Satapathy, A.: Evaluation and characterization of plasma sprayed Cu slag-Al composite coatings on metal substrates. J. Coat. 842865 (2013)
14. Gupta, G., Satapathy, A.: Plasma sprayed coatings of glass microspheres premixed with Al_2O_3 particles. Surf. Eng. **29**, 755–760 (2013)
15. Gupta, G., Satapathy, A.: Processing and characterization of plasma spray coatings of glass microspheres premixed with Al_2O_3 particles. Part. Sci. Technol. **33**, 145–149 (2015)
16. Patel, D., Bhatt, P., Bateriwala, R.: Thermal spray techniques for developing a carbide coating. Int. J. Innov. Technol. Explor. Eng. **8**, 692–700 (2019)
17. Nayak, H., Krishnamurthy, N., Shailesh, R.A.: Studies on plasma sprayed thermal barrier coating with increase in coating thickness. Tribol. Indus. **40**, 420–432 (2018)
18. Xu, M.S., Jean, M.D.: Study of protective coatings and their optimization using a plasma spray technique. Emerging Materials Research **7**, 73–81 (2018)

Role of Bio-cutting Fluids Under Minimum Quantity Lubrication: An Experimental Investigation of a Sustainable Machining Technique

Shrikant U. Gunjal, Sudarshan B. Sanap, Laxman Jadhav, and Nilesh G. Patil

Abstract Cutting fluids with their important characteristics like cooling, lubrication and chip removal functions are always admired highly in the machining industries. Earlier studies show the improvements in overall machining performance with respect to tool life, surface quality, process efficiency and reduced cutting forces. However, environmental and health problems are noted with the use of traditional cutting fluids. Therefore, time demands for alternative to synthetic oil, so bio-cutting fluids are the best possible solution for the same. This study emphasizes on investigations of surface roughness and chip thickness with bio-cutting fluids under the application of minimum quantity lubrication (MQL) condition using Taguchi method. Taguchi orthogonal array has been used for finding best vegetable cutting fluid from three cutting fluids, namely cotton seed, canola and palm oil. Surface finish and chip thickness during turning of AISI 316 is measured. Spindle speed, feed rate and depth of cut are considered as machining parameters. Investigations indicate that the least surface roughness is the outcome of lower feed rate, whereas cutting speed and depth of cut have least impact on surface finish. Shear angle is calculated to find the lowest specific energy required for machining using canola and palm oil.

Keywords Chip thickness · Environment and health · MQL · Shear angle · Surface roughness · Taguchi method · Vegetable oil

1 Introduction

Out of many prospective fluids, the cutting fluid helps in reducing the cutting zone temperature, which in turn leads to longer tool life. However, the mentioned advantage is challenged by negative impact of traditional cutting fluids on environment,

S. U. Gunjal (✉) · S. B. Sanap
MIT ADT University, Loni Kalbhor, Pune 412201, India
e-mail: shrishrikantgunjal@gmail.com

L. Jadhav · N. G. Patil
MIT Engineering College, Beed Bypass, Aurangabad 431009, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_63

product cost and human health [1]. In recent times, there is a demand for comfortable and healthy working environment that would encourage industries to implement bio-lubricants in machining industries as a primary stage [2]. Researchers found that vegetable-based cutting fluids have equal potential of performance which shows better alternative for petroleum-based metal working fluids. These are plant-based products, which possess some superior features, such as higher viscosity and minimized bio-contamination which is the vital motivation to researchers for studying possibilities of vegetable-based cutting fluids in machining industries in various aspects [3]. Good surface finish assures quality, reduces assembly time, and thereby achieves overall cost reduction. Minimum quantity lubrication using vegetable oil is the best way of machining as thermal shocks are reduced, which in turn achieves the better workpiece surface integrity [4]. It is well known that optimized and carefully selected cutting parameters, such as feed rate, cutting speed and depth of cut, lead to improved economics of machining operations. In most of the cases, the cutting parameters are selected using data given in the handbook. In this investigation we have optimized the cutting parameters to reduce surface roughness without affecting the quality of machining for material AISI 316 under MQL condition using three lubricating oils which are eco-friendly by Taguchi method. Further, the paper is emphasized upon study of chip thickness to investigate specific energy requirement during machining by means of shear angle.

2 Review of Relevant Work

MQL, which is also known as "Microlubrication" and "Near-Dry Machining", is an innovative technique which ensures minimum delivery of cutting fluid on an average range of 50–150 ml/h. In MQL technique, one or more nozzles are used to direct atomized flow toward cutting zone [5]. In MQL, the lubricant helps to achieve effective lubrication and pressurized air helps in achieving cooling action. MQL also helps to increase the workpiece surface integrity by reducing the induced thermal shock [4]. Cutting fluids are always found superior as it helps in flushing out chips along with lubrication and cooling of the area under machining, which in turn enhances the surface finish and at the same time it reduces the tool wear [6]. In addition, it fetches issues of environment and health [7]. MQL with bio-cutting fluids has potentially answered the concerns of conventional cutting fluids without affecting machining performance. Agrawal et al. [8] prepared the new green fluid by the mixture of aloe vera gel and cotton seed oil. The performance of green fluid was superior to that of conventional oil as surface roughness was lowered by 6.7% and tool wear by 0.14%.

Wang et al. [9] carried out experimental investigation to compare vegetable-oriented cutting fluids under the application of MQL with flood lubrication and noted that vegetable oils, viz., castor, soybean, maize, peanut, sunflower and palm oil archives lower value of specific energy and friction coefficient. Vegetable oils also inculcate better lubrication characteristics, and better surface quality has been observed under the application of the same. Bhople et al. [10] found that feed rate and cutting speed have made most significant contribution to surface roughness. Jadhav et al. [11] observed that better surface finish can be obtained with lower feed rate, smaller point angles and higher spindle speeds. Eker et al. [12] performed sustainable machining of magnesium alloy to compare dry and MQL machining techniques with the help of Taguchi design. In comparison to dry machining, MQL leads to improved machined surface quality and productivity as the latter helps in longer tool life by the virtue of reduced cutting temperature. Bhattacharya et al. [13] estimated the cutting parameters effect on surface finish during high-speed machining of AISI 1045 steel. With the help of Taguchi method and analysis of variance (ANOVA), they noted that cutting speed and feed rate contribute most to reduce average surface finish of the material under consideration.

Park et al. [14] noted that MQL and cryogenic machining gives almost similar tool wear and cutting force. However, tool wear under cryogenic conditions is prone to increase as the cutting time increases. As expected, they observed that MQL with nanoparticles (MQLN) shows the lowest tool wear among all the machining techniques. Sharma et al. [15] stated the effective penetration of oil mist in the machining zone along with reduced built-up edge formation under MQL application. Gajrani et al. [16] developed the new class of vegetable-based green cutting fluid (GCF) that is used under the application of MQL. Results show better anti-corrosion and emulsion stability, which shows the path for cleaner production practices. Lawal et al. [17] reported 31.6% enhancement in surface integrity under MQL vegetable-based lubricants over dry and wet machining techniques during turning operation of AISI 9310 steel. Rahim et al. [18] noted the reduction in cutting temperature by 10–30% over dry machining which helps in increasing tool life and ultimately the sustainable machining practice. Pereira et al. [19] performed an innovative attempt of combining MQL and cryogenic technique during turning of AISI 304 material and noted the 50% improvement in tool life. Further, cutting speed can be increased to 30% than normal range with the combination they concluded. Thakur et al. [20] found superior performance of MQL over dry machining during turning of Inconel 718. MQL outperformed dry machining in terms of reduction in cutting forces, improved surface characteristics, dimensional accuracy, reduced microchipping and uniform tool wear.

Nizamuddin et al. [21] noted the significant reduction in chip thickness by 11% and improvement in tool life during turning process of AISI 1045 steel using Karanja-based soluble cutting fluid over conventional cutting fluid. Gunjal et al. [22] found that canola oil performance is much closer to synthetic oil in terms of tool life during turning of AISI 4340 hardened steel under MQL. Gunjal et al. [23] in their extended experimental work of turning of AISI 4340 hardened steel observed that coconut oil gives minimum chip thickness which is turn achieves maximum shear angle and lower value of cutting forces and specific energy required for machining subsequently. The performance of coconut oil was differed by less than micron value than that of synthetic oil. This literature survey shows that bio-cutting fluids are the most prominent alternative to conventional cutting fluid to answer the issues

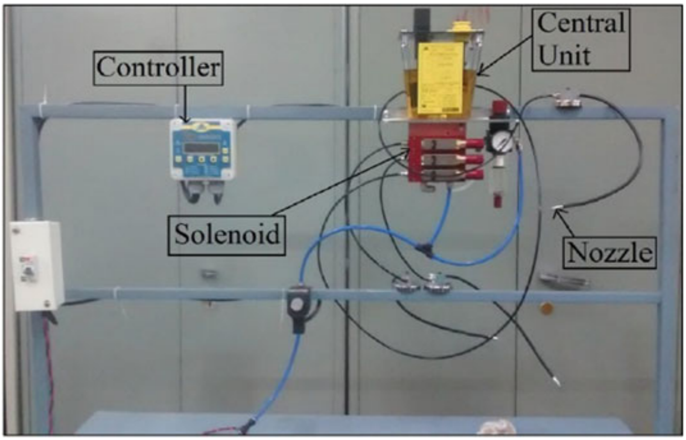


Fig. 1 Setup used for MQL application during experimentation

of health and environment concerns. At the same time, these bio-cutting fluids are heading toward the sustainable machining path of modern industrial requirements.

3 Experimental Procedure

3.1 Optimum Parameters of MQL

MQL is a highly reliable process when its parameters are kept optimal. In MQL, quality of droplets, which are finely atomized cutting fluid particles, defines the effectiveness of entire system. Optimum spraying distance, droplets quality and nozzle position are determined through experiment successively. In this, the droplets were sprayed on acrylic sheet, whereas to measure the force exerted by spray weighing machine has been used. With 10 mm interval, at each distance, the standoff distance varied from 10 to 350 mm. Variations are noted in force along with standoff distance. Figure 1 shows the MQL setup used during experimentation.

Table 1 indicates the optimum values of MQL parameters.

3.2 Experimental Details

CNC lathe machine has been used in order to conduct a series of experiments for evaluation of surface roughness and influence of parameters on it. AISI 316 stainless steel with Brinell hardness of 175 BHN was used as workpiece material. The dimensions of the material were 32 mm diameter and 60 mm length.

Table 1 Observations for optimum MQL parameters

S. No.	Oil	Flow rate (ml/h)	Air pressure (bar)	Nozzle distance (cm)	Maximum force (mg)	At contact surface circle dia. (cm)	Spray angle (°)
1	Palm	120	4	2.2	18	1.2	13
2	Cotton seed	120	4	3.1	20	1.64	15
3	Canola	120	4	2.9	25	1.54	15.5

3.3 Planning of Experiment

Experiment is done on AISI 316 turning operation under MQL conditions by using cutting fluids by considering L9 orthogonal array for number of trials for each oil, and after doing experiment separately all measurements of Ra values are tabulated in L27 orthogonal array to carry out analysis of variance (ANOVA). From ANOVA analysis the most significant factors are recognized. For reducing number of trials during preliminary experiment, Taguchi optimizing technique is used. During preliminary experiment two bio-lubricants (canola oil and palm oil) are used for which L9 orthogonal is used, for getting number of trials for three factors and three levels as mentioned in Table 2.

[Units: cutting speed (m/min), feed rate (mm/rev), depth of cut (mm)].

After trial, we obtain the Ra values by measurement of three different oils; L9 arrays for three oils with Ra values for respective oils are tabulated in Table 3.

For comparison of cotton seed oil, canola oil and palm oil, Taguchi orthogonal array is used. ANOVA of all 27 trials has been undertaken.

Figure 2 shows the plot of Ra for cutting fluids used during experimentation. We can say that observed roughness value (Ra value) in case of canola oil shows better results as compared to cotton seed oil and palm oil as cutting fluids.

Table 2 Level and parameters

S. no.	Input factors	Level 1	Level 2	Level 3
1	Cutting speed	180	240	300
2	Feed rate	0.08	0.16	0.24
3	Depth of cut	0.6	0.8	1

Table 3 Ra values for cotton seed, canola and palm oil

Trial no	Cutting speed	Feed rate	Depth of cut	Ra value-cotton seed	Ra value-canola	Ra value-palm
1	180	0.08	0.6	0.88	0.31	0.44
2	180	0.16	0.8	1.52	0.62	1.1
3	180	0.24	1	2.44	1.52	1.88
4	240	0.08	0.8	0.86	0.22	0.35
5	240	0.16	1	1.65	0.63	0.6
6	240	0.24	0.6	2.22	1.53	1.65
7	300	0.08	1	0.62	0.13	0.43
8	300	0.16	0.6	0.97	0.75	1.22
9	300	0.24	0.8	1.88	1.81	1.75

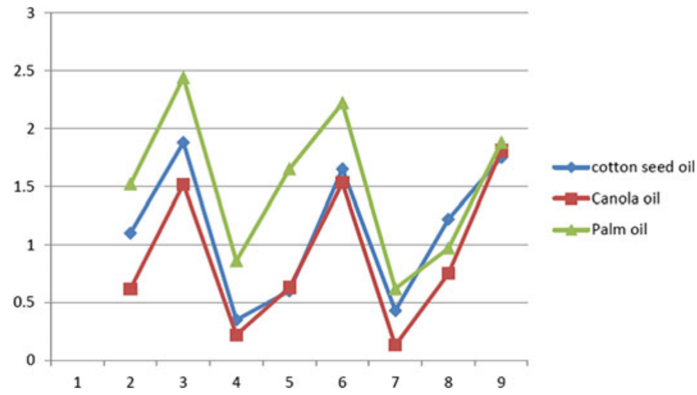


Fig. 2 Comparison of surface roughness values of cotton seed oil, canola oil and palm oil

4 Results and Discussion

4.1 Optimum Parameters for MQL Turning

Following are the summarized optimum parameters for the MQL system under consideration:

- Nozzle standoff distance: 2.9 cm for canola oil, 2.2 cm for palm oil and 3.1 cm for cotton seed oil
- Air pressure: 4 bar
- MQL flow rate: 120 ml/h
- Nozzle position: angular position (15° approx.)

4.2 ANOVA for Ra Value

From Table 4, it is noted that feed rate is the most significant parameter which has more influence on the surface. Its contribution is 77.29% and the next significant parameter is cutting fluid with 15.45% contribution. From the ANOVA analysis we can say that cutting fluid 2 (canola) gives best surface finish as compared to cutting fluids 1 and 3 (palm and cotton seed). Hence for final experimentation canola oil is used for optimizing turning process parameters.

Table 5 shows the response for signal-to-noise ratios for surface roughness. It gives delta rank for each parameter, and from delta rank we decide the most significant parameter. In this table delta rank one is given to feed rate and delta rank two is given to cutting fluid.

Figure 3 shows the main effect plot for Ra value at three different levels and for four parameters, viz., speed, feed, depth of cut, and cutting fluid. From the plot we can see that the depth of cut and speed do not have steepest slope, hence they are not as significant as feed and cutting fluid. But in this experiment our main interest is to find best cutting fluid among three. From the above plot, we can conclude that cutting fluid 2 will give us best possible value of surface finish. As feed rate increases, roughness also increases. Figure 4 shows the interaction plots of different

Table 4 Analysis of variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Speed	2	0.0869	0.08685	0.04343	229	0.182	0.768272
Feed	2	8.7426	8.74261	4.3713	230.65	0	77.29222
DoC	2	0.0025	0.00254	0.00127	0.07	0.936	0.022102
Cf	2	1.7476	1.74759	0.87379	46.11	0	15.45031
Speedxcf	4	0.4629	0.46293	0.11573	6.11	0.026	4.09244
Feedxcf	4	0.0306	0.03064	0.00766	0.4	0.8	0.270531
DoCxcf	4	0.1242	0.12424	0.03106	1.64	0.28	1.098036
Residual error	6	0.1137	0.11371	0.01895			1.005207
Total	26	11.3111					100

(Analysis based on level of significance = 5%, i.e., level of confidence = 95%)

Table 5 Signal-to-noise ratios (smaller is better)

Level	Speed	Feed	DoC	Cf
1	0.1371	7.9109	0.4977	1.1965
2	1.4122	0.536	0.8634	4.3584
3	1.6381	−5.2592	1.8263	−2.3675
Delta	1.501	13.1705	1.3286	6.7259
Rank	3	1	4	2

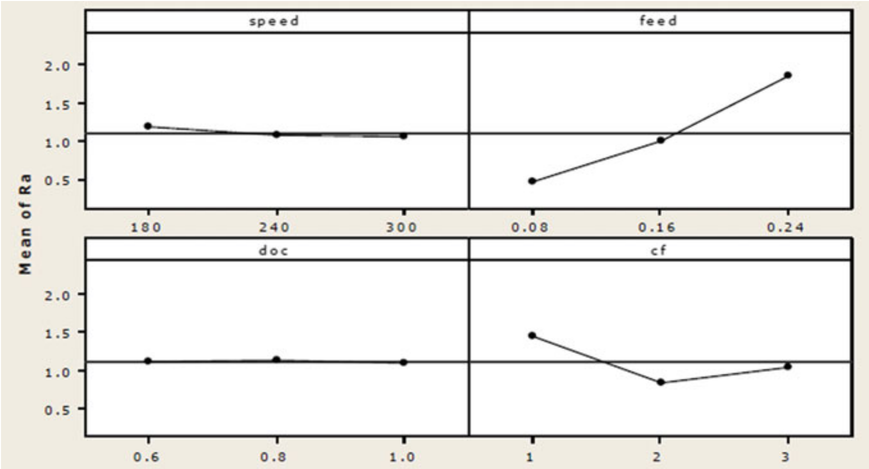


Fig. 3 Main effects plot (data means) for Ra

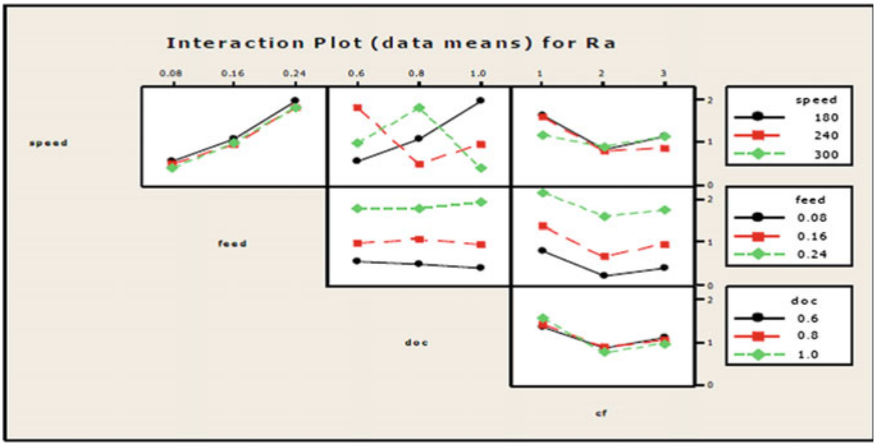


Fig. 4 Interaction plot (data means) for Ra

combination for Ra value. From interaction plots we can say that cutting speed and feed are major parameters that control surface roughness. Cutting fluid 2 shows good result against every machining parameter, hence from this discussion on interaction plot we can say that canola oil gives good results.

4.3 Chip Thickness

In this section, the measured chip thicknesses for canola and palm oil have been presented. Minimum thickness is 147.4 μm for canola oil which gives less energy investment, and for palm oil is 117.2 μm, which means this thickening should be as less as possible or the value of zeta should be as small as possible but not at the cost of productivity and hence keeping the productivity as the same. Chip thicknesses have been measured using optical microscopy. Table 6 and Fig. 5 present the shear angle calculations based on chip thickness and microscopic view, respectively, under the application of canola oil. However, Fig. 6 and Table 7 present the microscopic view of chip thickness and shear angle calculations, respectively, under the application of palm oil.

Table 6 Calculation of shear angle for canola oil

S. no	Speed	Feed (t)	Cut chip thickness (t_c μm)	Ra	$r = t/t_c$	Chip reduction coefficient = $1/r$	Shear angle (Φ) $\alpha = 6°$
K1	180	0.08	152.4	0.31	0.52	1.92	28.67°
K2	180	0.16	237.4	0.62	0.67	1.49	35.62°
K3	180	0.24	227.4	1.52	1.05	0.95	49.55°
K4	240	0.08	173	0.22	0.46	2.17	25.67°
K5	240	0.16	170.4	0.63	0.938	1.066	45.97°
K6	240	0.24	342.4	1.53	0.70	1.42	36.91°
K7	300	0.08	147.4	0.13	0.54	1.85	29.65°
K8	300	0.16	212.8	0.75	0.75	1.33	38.33°
K9	300	0.24	318.6	1.81	0.753	1.32	39.11°

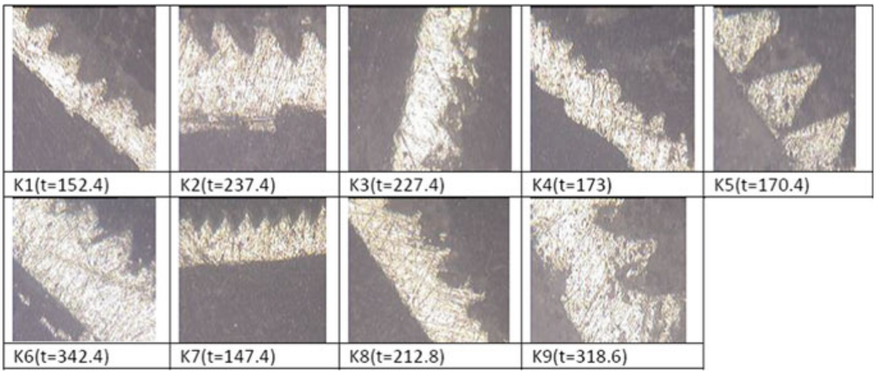


Fig. 5 Microscopic view of chip thickness under the application of canola oil

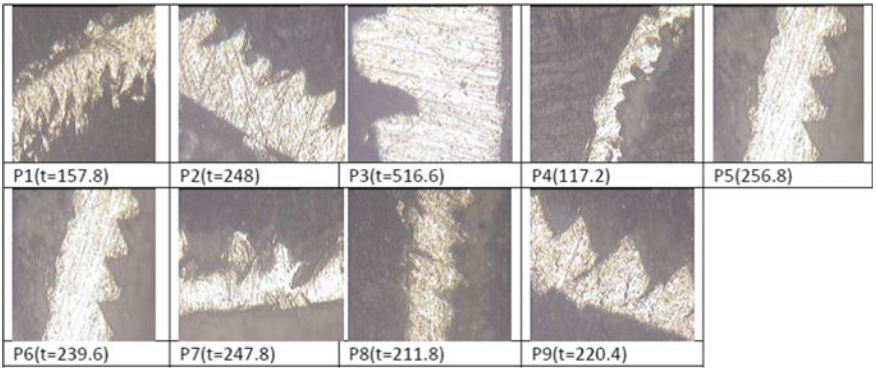


Fig. 6 Microscopic view of chip thickness under the application of palm oil

Table 7 Calculation of shear angle for palm oil

S. No.	Speed	Feed (t)	Cut chip thickness (t_c μm)	Ra	$r = t/t_c$	Chip reduction coefficient = $1/r$	Shear angle (Φ) $\alpha = 6°$
P 1	180	0.08	157.8	0.4	0.507	1.97	28.03°
P 2	180	0.16	248	1	0.645	1.55	34.52°
P 3	180	0.24	516.6	2	0.464	2.155	25.87°
P 4	240	0.08	117.2	1.4	0.682	1.466	36.15°
P 5	240	0.16	256.8	1.9	0.623	1.6	33.53°
P 6	240	0.24	239.6	2	1	1	48.00°
P 7	300	0.08	247.8	0.5	0.322	3.1	18.33°
P 8	300	0.16	211.8	1.9	0.755	1.32	39.19°
P 9	300	0.24	220.4	2	1.088	0.919	50.67°

Based on the above data and its analysis, the following observations are noted, which denoted the decrease in specific energy required for machining:

- Canola oil—Max. shear angle = 49.55° at cutting speed = 180 m/min.
- Palm oil—Max. shear angle = 50.67° at cutting speed = 300 m/min.

From Fig. 7, we can easily identify that canola oil gives least values of chip thickness as compared to that of palm oil which subsequently leads to maximum shear angle, respectively, which ultimately reduces the specific energy required for machining.

Surface finish and chip thickness play vital roles in defining the overall machining performance in industrial application in terms of quality control and specific energy required, respectively. The present work is an attempt toward knowledge contribution in the respective field.

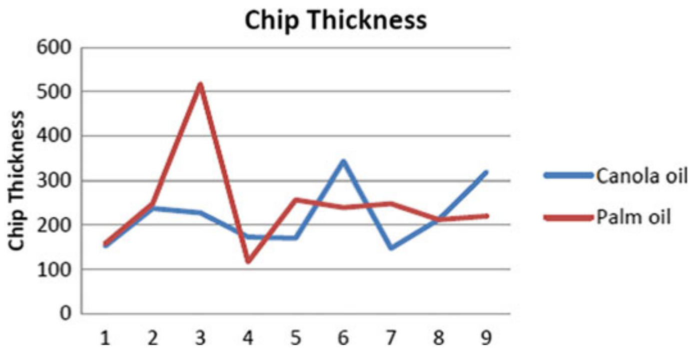


Fig. 7 Comparison of chip thickness under the application of canola and palm oil

5 Conclusions

During experimentation the effect of various machining parameters on surface roughness and chip thickness is studied with the help of full factorial design of experiments, and the best combination of machining parameters such as depth of cut, feed and cutting speed is determined. From the series of experimentation, it is concluded that cutting speed and depth of cut did not affect the surface roughness prominently as that of feed rate. Canola and palm oil have shown notable impact on chip thickness at varying cutting speed under consideration.

Based on the experimental investigations, the following conclusions can be drawn:

- From the ANOVA analysis, it has been found that feed rate (77.29%) is a significant parameter affecting surface roughness, followed by cutting speed, whereas depth of cut played an insignificant role in affecting surface roughness. This was true for all conditions of lubrication, viz., MQL (120 ml/h).
- Canola oil was found to be superior to cotton seed and palm oils.
- The optimum levels for canola oil are: speed = 300 m/min, feed = 0.08 mm/rev and depth of cut is obtained as 1.0 mm.
- Maximum shear angle with canola oil is noted as 49.55° at cutting speed of 180 m/min.

References

1. National Oil seeds and Vegetable Oils Development Board, Ministry of Agriculture, Government of India, https://www.novodboard.com/Index.htm. Last accessed 2019/07/15
2. Agrawal, S.M.,Lahane, S.,Patil, N.G.,Brahmankar, P.K.: Experimentalinvestigationsintowearcharacteristicsof M2steel usingcotton seedoil. In: 12th GlobalCongress On ManufacturingAnd Management, GCMM (2014)
3. Ioan, S.N.: On the future of biodegradable vegetable lubricants used for industrial tribo systems. Gal I Fascicie VIII, Issue No. 1221–4590 (2002)

4. Machado, A.R., Wallbank, J.: The effect of extremely low lubricant volumes in machining. Int. J. Sci. Technol. Frict. Lubric. Wear **210**, 76–82 (1997)
5. Mia S., Ohno N.: Prospectof mustardandcoconutoilasenvironmentfriendly lubricantfor-Bangladesh. (ICEAB10),Japan(2010)
6. Gajrani, K.K.., Sankar, M.R.: Sustainable machining with self-lubricating coated mechanical micro-textured cutting tools. In: Reference Module in Materials Science and Materials Engineering. Elsevier (2018)
7. Revuru, R.S., Posinasetti, N.R., VSN, V.R., Amrita, M.: Application of cutting fluids in machining of titanium alloys—a review. Int. J. Adv. Manuf. Technol. **91**(5–8), 2477–2498 (2017)
8. Agrawal, S.M., Patil, N.G.: Experimental study of non-edible vegetable oil as a cutting fluid in machining of M2 Steel using MQL. Procedia Manuf. **20**, 207–212 (2018)
9. Wang, Y., Li, C., Zhang, Y., Yang, M., Li, B., Jia, D., Mao, C.: Experimental evaluation of the lubrication properties of the wheel/workpiece interface in minimum quantity lubrication (MQL) grinding using different types of vegetable oils. J. Cleaner Prod. **127**, 487–499 (2016)
10. Bhople, N., Patil, N., Mastud, S.: The experimental investigations into dry turning of austempered ductile iron. Procedia Manuf. **20**, 227–232 (2018)
11. Jadhav, S.S., Kakde, A.S., Patil, N.G., Sankpal, J.B.: Effect of cutting parameters, point angle and reinforcement percentage on surface finish, in drilling of AL6061/Al2O3p MMC. Procedia Manuf. **20**, 2–11 (2018)
12. Eker, B., Ekici, B., Kurt, M., Bakır, B.: Sustainable Machining of the magnesium alloy materials in the CNC lathe machine and optimization of the cutting conditions. Mechanics **20**(3), 310–316 (2014)
13. Bhattacharya, A., Das, S., Majumder, P., Batish, A.: Estimating the effect of cutting parameters on surface finish and power consumption during high speed machining of AISI 1045 steel using Taguchi design and ANOVA. Prod. Eng. **3**(1), 31–40 (2008)
14. Park, K.H., Suhaimi, M.A., Yang, G.D., Lee, D.Y., Lee, S.W., Kwon, P.: Milling of titanium alloy with cryogenic cooling and minimum quantity lubrication (MQL). Int. J. Precis. Eng. Manuf. **18**(1), 5–14 (2017)
15. Sharma, A.K., Tiwari, A.K., Dixit, A.R.: Effects of Minimum Quantity Lubrication (MQL) in machining processes using conventional and nanofluid based cutting fluids: a comprehensive review. J. Cleaner Prod. **127**, 1–18 (2016)
16. Gajrani, K.K., Suvin, P.S., Kailas, S.V., Sankar, M.R.: Hard machining performance of indigenously developed green cutting fluid using flood cooling and minimum quantity cutting fluid. J. Cleaner Prod. **206**, 108–123 (2019)
17. Lawal, S.A., Choudhury, I.A., Nukman, Y.A.: Critical assessment of lubrication techniques in machining processes: a case for minimum quantity lubrication using vegetable oil-based lubricant. J. Cleaner Prod. **41**, 210–221 (2013)
18. Rahim, E.A., Ibrahim, M.R., Rahim, A.A., Aziz, S., Mohid, Z.: Experimental investigation of minimum quantity lubrication (MQL) as a sustainable cooling technique. Procedia CIRP **26**, 351–354 (2015)
19. Pereira, O., Rodríguez, A., Fernández-Abia, A.I., Barreiro, J., de Lacalle, L.L.: Cryogenic and minimum quantity lubrication for an eco-efficiency turning of AISI 304. J. Cleaner Prod. **139**, 440–449 (2016)
20. Thakur, D.G., Ramamoorthy, B., Vijayaraghavan, L.: Influence of minimum quantity lubrication on the high speed turning of aerospace material superalloy Inconel 718. Int. J. Mach. Mach. Mater. **13**(2–3), 203–214 (2013)
21. Nizamuddin, M., Agrawal, S.M., Patil, N.: The effect of Karanja based soluble cutting fluid on chips formation in orthogonal cutting process of AISI 1045 steel. Procedia Manuf. **20**, 12–17 (2018)
22. Gunjal, S.U., Patil, N.G.: Experimental investigations into turning of hardened AISI 4340 steel using vegetable based cutting fluids under minimum quantity lubrication. Procedia Manuf. **20**, 18–23 (2018)

23. Gunjal, S.U., Sanap, S.B., Patil, N.G.: Role of cutting fluids under minimum quantity lubrication: An experimental investigation of chip thickness. Mater. Today Proc. (2020). https://doi.org/10.1016/j.matpr.2020.01.090

Optimization of Inconel Die-In EDD Steel Deep Drawing with Influence of Punch Coating Using RSM

Naveen Anand Daniel, Umesh Kumar Vates, Bhupendra Prakash Sharma, Nand Jee Kanu, and Sivarao Subramonian

Abstract In the present industrial applications, conventional methods of metal forming and deep-drawn components of various metals and alloys are uneconomical, and the degree of accuracy, as well as responses, is not reported up to the mark. As far as the modern development and challenges are concerned, the present research has aimed to perform the efficient deep-drawing process for the difficult-to-draw materials by applying different coatings on punch materials. The appropriate Inconel 600 material is selected for the die and punches to perform deep drawing on extra deep-drawn (EDD) steel blank. Deep-drawing process performance is reported quite better using tetrahedral amorphous carbon coating on Inconel punch. In the present research, the selected coating exhibits the best choice among coating of molybdenum disulfide and brycoat titanium nitride. Clearance, blank thickness, and blank holding force are selected as critical input parameters to get the desired deep-drawing responses as limiting draw ratio (LDR), surface roughness, residual stress, and thinning. During the tetrahedral amorphous carbon coating on the punch, responses LDR, surface roughness, residual stress, and thinning are optimized as 1.8586, 0.8934, 268.1440, and 2.7201 by selecting the clearance as 2.7899, blank thickness 4.40, and blank holding force 11.00 using response surface methodology (RSM).

Keywords EDD steel · Inconel punch · Deep-drawing process · Response surface methodology (RSM)

N. A. Daniel (✉) · U. K. Vates · B. P. Sharma
Amity University Uttar Pradesh, Noida, Uttar Pradesh, India
e-mail: nadaniel@amity.edu

N. J. Kanu
Sardar Vallabhbhai National Institute of Technology, Surat, India

S. Subramonian
Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_64

1 Introduction

Deep drawing is a metal-shaping procedure used for producing measurable drawing depth of the axisymmetric part. At the point where the depth of component is essentially more than its diameter, then such component can be effectively framed to an ideal shape using deep-drawing process. This sheet-metal-forming process is favored in aerospace industries, automobile industries, and kitchen utensil producing enterprises.

The adhesive nature of the EDD material toward tool steel gives rise to challenging tri-biological conditions in sheet metal forming. Therefore, lubricants are applied to separate the tool and the workpiece to reduce friction and wearing in the conventional deep-drawing process. To increase sustainability and to achieve efficient usage of resources, abandonment of environmental-enemy lubricants is encouraged. Hydraulic pressure-assisted and conventional deep-drawing processes are selected, through which the cup may be manufactured. The conventional deep-drawing process is concerned with the formability of rigid materials into the desired shape and size using a rigid punch, rigid die, and rigid blank up to the macro level. This technology is used for drawing the cylindrical-shaped cups as per the dimensions of punch.

It has been reported that the possibility of improving the drawing ability of DIN EN 10130-91 sheet with 1 mm thickness over deep-drawing processes varies the geometrical features of the forming tools [1]. Inconel die and punch were selected for the deep-drawing process in EDD cup manufacturing due to the specific weight to strength ratio demanded as per the current industrial need. Micro deep drawing is also the other aspect where the performance and formability depend on material behaviors. It is very fact that process parameters of the conventional deep drawing are needed to get the best quality of the deep-drawn product so that the most significant effects of the influencing parameters may be observed on the deep drawing. Selection of the influencing critical independent parameters for the specific responses is a challenging task during the hydraulic pressure-assisted deep-drawing process. The classification of hydraulic pressure-assisted deep-drawing processes is based on the method of exploitation of fluid pressure into hydro-mechanical drawing, counter-pressure drawing, hydro-forming, and hydraulic pressure-augmented drawing [2–4]. Apart from the capability of the hydraulic pressure-assisted deep-drawing processes of producing components with complex shape, this technology also has several essential advantages, such as good surface quality, improvement of the sheet formability, reduction of the spring-back effect, accurate dimensions, and uniform ability of product wall thickness. Moreover, since the process is adopted to apply with simple configurations, the energy shall be saved [4, 5]. It has also been reported that to obtain the maximum 4.2 N, blank holding force (BHF) using lubricant as polyethylene film in the micro conical–cylindrical cup with an LDR of 2.1 was well-formed. There were only a few wrinkles in the rim of the cups when the drawing ratio was large [6, 7]. Depending on the design of experiments and available hydraulic press setup, clearance, blank thickness, and BHF are critically selected for the responses like

LDR, surface roughness, residual stress, and thinning. According to few researches the wall thickness of square cup lies between the punch radius and the matrix radius.

Punch coating with suitable materials gives a better result in the deep-drawing process [8–10]. It was evident from the results that the selection of high friction levels between the blank and the die led to an increase in the wall thickness. The increase in the frictional shear forces led to an increase in the axial stresses excited in the blank material which enhanced elongation and led to further thinning of the cup wall. The cup is drawn using the emulsion without oil, which resulted in a reduction in the thickness of the cup with the increase of maximum punch force as sustainability, and to achieve efficient usage of resources, the abandonment of environmental-enemy lubricants is encouraged.

The present investigation is given to choose the basic free parameters that play out the deep-drawing process according to the RSM plan of examinations. RSM demonstration is to be accomplished for the examination of the deep procedure connected to a genuine industrial component, in particular, bowl manufacturing of EDD using Inconel 600 punch and die materials along with different coating on it. The surface nature of the deep-drawn segments will be estimated with the assistance of the Surftest SJ-210 (Mitutoyo), a surface roughness measuring instrument. Ra parameter is used to examine the surface quality. In this study, we will calculate force to deep drawn a piece of sheet metal based on the drawing ratio, sheet thickness, and the ultimate tensile strength of the material. The measure of the draw can likewise be spoken to as the percent decrease of the blank diameter. The determined tonnage can be used for the determination of a machine to perform the deep-drawing operation. So, a benchmark strategy is, in this manner, fundamental to approve the distinctive measurement methods. The connection between the input and output of the deep-drawing process was resolved with the assistance of RSM displaying and advancement strategies. Figure 1 shows the systematic diagram of the deep-drawing process.

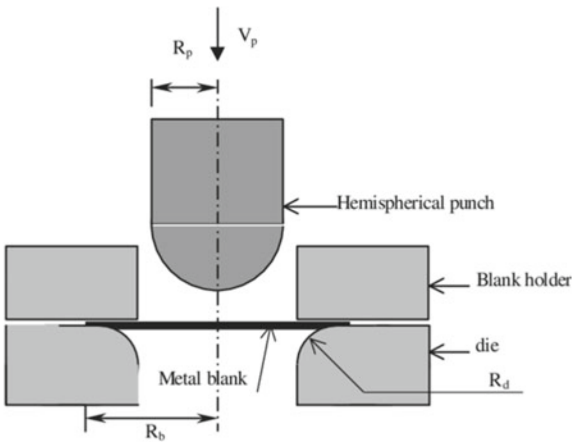


Fig. 1 Systematic diagram of deep-drawing process

In Fig. 1 R_b is the radius of blank, R_p radius of punch, V_p velocity of punch, and R_d is the radius of the die.

2 RSM Modeling

In measurements, response surface methodology (RSM) investigates the connections between a several explanatory variables and one or more response variables.

In RSM, the relation between performance and process parameters connects with algorithm as per the desired quality characteristic. By plotting the expected responses for a set of input parameters will be very complicated, but it has the ability to get a mathematical relationship. Thus, RSM aims at approximating a suitable lower-order polynomial in some region of the input process parameters.

3 Material Selection

EDD steel of BH-270 grade is selected as blank material because of its better formability as well as high resistance against thinning in deep drawing and also contains around 0.005% carbon, 0.25% manganese, 0.02% sulfur, and 0.02% phosphorus in its composition. Production of EDD steel is done by using vacuum-degassed process to minimize the carbon content and stabilized chemically through titanium and niobium (columbium). EDD steel (BH-270) selected as blank material has better mechanical properties, such as yield strength 310 MPa, tensile strength 270 MPa, and percentage elongation 32%.

As per the graph shown in Fig. 1, a significant variation in mechanical properties such as ultimate tensile strength, yield strength, corresponding strain rate, and percentage elongation in EDD (BH-270) steel is observed at elevated temperature ranges from room temperature to 4500 °C. Therefore, an understanding of the formability of adopted sheet metal is intended to produce the quality cups for industrial applications. Process variables play an important role in the overall formability of EDD during optimized design aspects.

Inconel 600 (ASTM B168 AMS 5540 Din 17,750) has been adapted for punch and die. It is very clear from Fig. 2 that a very less amount of thermal expansion is recorded for a wide variation of cryogenic to very high temperature. It is evident that temperature at punch and die interface increases with respect to forming time. Therefore, the selected punch and die materials are much suited for an efficient deep-drawing process. Despite a very large run, the quality of manufactured bowl deteriorates up to some instants due to the combined effect of elevated temperature and mechanical properties of materials. The effect of three material coatings [(MoS_2), (TAC-ON), and brycoat titanium nitride (TiN)] are to be observed to find the most suitable path for better production quality.

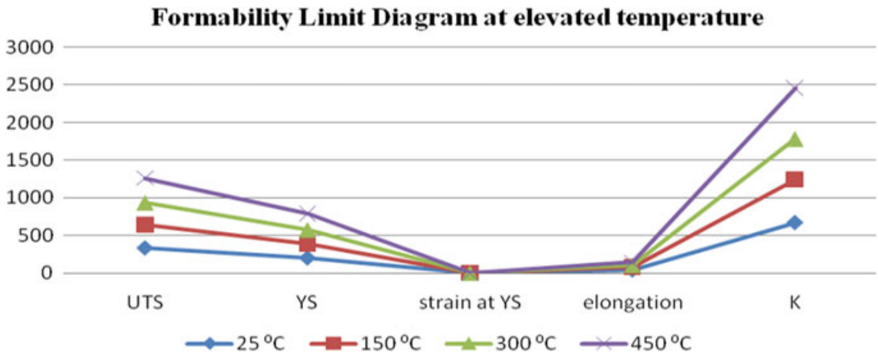


Fig. 2 Change in mechanical properties of EDD BH-270

4 Experimental Investigation

Deep drawing is one of the best metal-forming process through which bowl is being manufactured by applying hydraulic pressure on Inconel 600 (ASTM B168 AMS 5540 Din 17750) die punch set. Clearance, blank thickness, and blank holding force are critically adapted to perform the process for 20 runs as per the design of the experiment by considering LDR, surface roughness, residual stress, and thinning as performance characteristics (Table 1). Three different coatings [(MoS_2), (TAC-ON), and brycoat titanium nitride (TiN)] are provided on punch and the corresponding data collected during the deep-drawing process is presented in Tables 2, 3 and 4. Inconel 600 punch material is being used to perform the deep-drawing operation on EDD steels. Researchers have already used regression analysis, genetic algorithms, expert systems, or artificial neural networks (ANN) for analyzing the different process parameters [11, 12]. In particular, RSM offers a new and intelligent alternative for relating input variables of the deep-drawing process to its output parameters. An RSM has the capability to learn the entire effects of this process on account of

Table 1 Maximum wall angle and thinning limit with different geometries

Part description	Part number	Depth of fracture (mm)	Wall angle (θ_p)	Max. thinning
Circular generatrix	1	62.5	77.18	0.235
Circular generatrix	2	63.4	77.82	
Elliptical generatrix	1	62.0	74.56	0.240
Elliptical generatrix	2	65.0	76.21	
Parabolic generatrix	1	50.0	73.12	0.288
Parabolic generatrix	2	53.0	73.41	
Exponential generatrix	1	70.3	74.70	0.241
Exponential generatrix	2	75.0	75.31	

Table 2 Process parameters and levels of variations

Process parameter	Levels and their range		
	−1	0	1
(A) Clearance (mm)	1.8	2.8	3.8
(B) Blank thickness (mm)	3.6	4.0	4.4
(C) Blank holding force (BHF) (kN)	3	7	11

Table 3 Specification of die and punch setup

Size of die	20 mm
Size of punches	18 mm with different coating
Die material	Inconel 600 with 200 GPa
Sheet metal material	EDD
Thickness of blank	1.0, 0.8, 0.6 mm
Machine tonnage	30 Tonne

Table 4 Tetrahedral amorphous carbon coating (TAC-ON) on Inconel 600 punch materials

Clearance (mm)	Blank thickness (mm)	BHF (kN)	LDR at TAC-ON	SR (μm) at TAC-ON	Residual Stress (MPa) at TAC-ON	Thinning (mm) at TAC-ON
2.8	4.0	7	1.57	1.14	302	3.5
1.8	3.6	11	1.75	0.18	386	3.2
2.8	4.0	7	1.60	0.56	311	3.6
2.8	4.0	11	1.76	0.51	402	2.9
3.8	4.4	3	1.42	0.94	389	3.2
2.8	4.0	7	1.58	0.95	332	3.5
3.8	3.6	11	1.88	0.22	294	3.0
3.8	3.6	3	1.58	0.95	313	3.8
1.8	4.4	11	1.69	0.32	406	2.8
2.8	4.0	7	1.65	0.54	387	3.3
2.8	3.6	7	1.52	0.17	362	3.4
2.8	4.4	7	1.93	0.33	373	3.5
2.8	4.0	7	1.58	0.77	355	3.6
3.8	4.0	7	1.63	0.50	286	3.3
2.8	4.0	7	1.57	0.56	346	3.4
1.8	4.0	7	1.54	0.37	391	3.0
3.8	4.4	11	1.80	1.07	304	2.8
1.8	3.6	3	1.56	0.57	413	3.3
1.8	4.4	3	1.73	0.88	428	3.9
2.8	4.0	3	1.59	0.53	395	3.2

its robustness, its ability to incorporate nonlinear dependencies between input and output variables, as well as its power of generalization [13].

The present study is devoted to the selection of critical independent parameters and to perform the deep-drawing process as per the RSM design of experiments. RSM modeling is done for the analysis of deep-drawing process applied to an actual industrial component, namely bowl manufacturing of EDD blank using Inconel 600 punch and die materials along with different coating on it. The surface quality of the deep-drawn components is measured with the help of the Surftest SJ-210 (Mitutoyo) surface roughness measuring instrument. Ra parameter is used to analyze the surface quality [14].

To obtain the maximum wall angle, the varying wall angle conical frustums are formed on the CNC milling machine till the fracture occurs [15–19]. The maximum formable angle is given below, which is calculated using Eq. (1) [20–22].

In the present investigation, parabolic generatrix is used to conduct the deep-drawing process in EDD steels.

In incremental forming trial, the wall angle generatrix for parabolic part 1 case (in Table 1) is adapted to perform the deep-drawing process as discussed in Figs. 3 and 4. The working of the deep-drawing process is shown in Figs. 1 and 5 presents the deep-drawn process and the manufactured cups at the different blank holding force at the trial basis, respectively. Actual setup and performance as per the design of experiments are shown in Figs. 6 and 7, respectively.

Design of Experiments Three factors at three-level L 20 RSM design is selected to perform the experiments. Tables 4, 5 and 6 give the deep-drawing experimental details under the coatings of tetrahedral amorphous carbon coating, brycoat titanium nitride and solid lubricant coating of molybdenum disulfide, respectively.

The formula for calculating LDR is shown below:

$A = 0.7849 \times D^2$, Area of flat blank.

$D_b = \sqrt{\frac{A}{0.7849}}$, Diameter of flat blank,

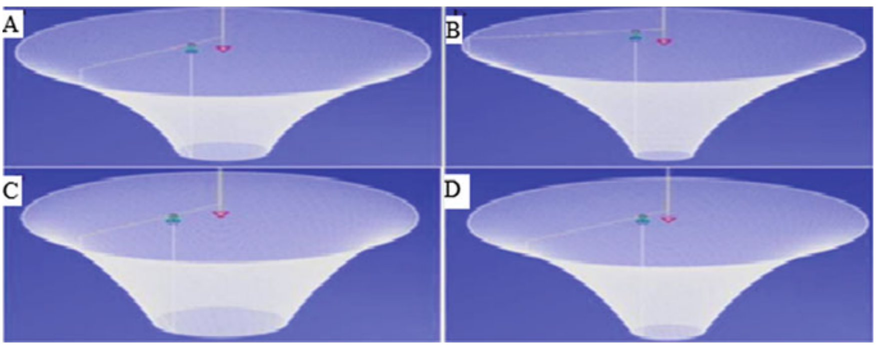


Fig. 3 Generated tool paths for different geometries **a** circular generatrix **b** elliptical generatrix **c** parabolic generatrix **d** exponential generatrix

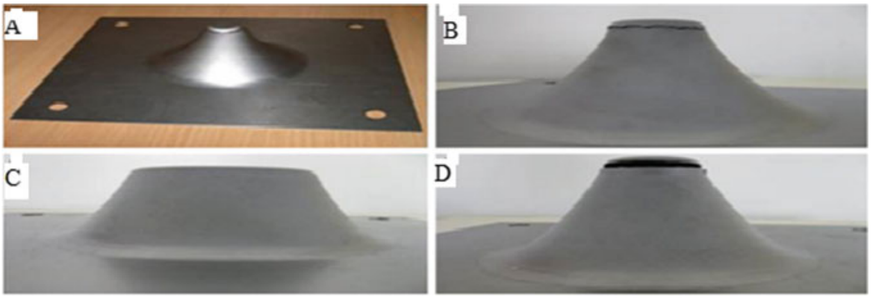


Fig. 4 Parts formed in incremental forming **a** circular generatrix **b** elliptical generatrix **c** parabolic generatrix **d** exponential generatrix

Fig. 5 Deep drawing setup

LDR = $\frac{D_p}{D_p}$, where D_p is the diameter of punch.

In Fig. 8, with the increase in clearance, thinning reduces till the clearance value is 2.5 mm. Beyond this thinning shows slight increase. With the increase in clearance value, the residual stress is reduced. The residual stress is increased with the increase in blank thickness and again the residual stress is decreased with the blank holding force. With the increase in clearance and blank thickness, surface roughness is improved. Whereas with the increase in blank holding force, surface roughness is reduced up to a point where BHF is 7 kN; after that it slightly increases. LDR is constant up to a point when clearance is equal to 2.5 mm, after which it reduces

Fig. 6 Drawn component at different BHF

Fig. 7 Deep-drawn components

gradually. The LDR increases with the increase in blank thickness and blank holding force.

In Fig. 9, thinning reduces with the increase in clearance until the value of clearance is 2.8 mm. After that, it increases gradually. The thinning reduces gradually with the increase in blank thickness and also with an increase in BHF. With the increase in clearance and BHF, there is a reduction in residual stress and residual stress increases with the increase in blank thickness. Surface roughness increases with the increase in clearance and blank thickness and reduces with the increase in BHF. LDR increases with the increase in clearance till the clearance value is 2.8 mm,

Table 5 Bry coat titanium nitride (TiN) coatings on Inconel 600 punch materials

Clearance (mm)	Blank thickness (mm)	BHF (kN)	LDR at TiN coating on punch	SR (μm) at TiN coating on punch	Residual stress (MPa) at TiN coating on punch	Thinning (mm) at TiN on punch
2.8	4.0	7	1.52	1.05	311	3.1
1.8	3.6	11	1.76	0.19	382	3.2
2.8	4.0	7	1.60	0.58	315	3.5
2.8	4.0	11	1.78	0.62	408	2.8
3.8	4.4	3	1.41	0.44	382	3.3
2.8	4.0	7	1.35	0.91	323	3.5
3.8	3.6	11	1.91	0.27	291	3.1
3.8	3.6	3	1.48	0.85	331	3.9
1.8	4.4	11	1.61	0.32	401	2.8
2.8	4.0	7	1.71	0.51	382	3.4
2.8	3.6	7	1.57	0.19	368	3.8
2.8	4.4	7	1.83	0.35	374	3.3
2.8	4.0	7	1.67	0.71	358	3.5
3.8	4.0	7	1.63	0.40	281	3.4
2.8	4.0	7	1.52	0.52	343	3.4
1.8	4.0	7	1.51	0.38	391	3.1
3.8	4.4	11	1.78	0.97	308	2.6
1.8	3.6	3	1.54	0.54	418	3.4
1.8	4.4	3	1.71	0.89	462	3.9
2.8	4.0	3	1.55	0.52	383	3.3

after which there is a gradual reduction. Also, LDR increases with the increase in blank thickness and BHF.

In Fig. 10, thinning reduces with the decrease in clearance, blank thickness, and BHF. Residual stress decreases with the decrease in clearance and BHF and increases with the increase in blank thickness. Surface roughness increases with the increase in clearance and blank thickness and reduces with BHF. LDR increases with the increase in clearance, blank thickness, and BHF.

5 Optimal Prediction of Responses Through RSM

As per the desired condition of responses, optimizations were performed in each case of materials coating at the Inconel punch using the RSM technique followed by Minitab 17.

Table 6 Solid lubricant coating of molybdenum disulfide (MoS_2) on Inconel 600 punch materials

Clearance (mm)	Blank thickness (mm)	BHF (kN)	LDR at MoS_2 coating on punch	SR (μm) at MoS_2 coating on punch	Residual stress (MPa) at MoS_2 coating on punch	Thinning (mm) at MoS_2 coating on punch
2.8	4	7	1.67	1.02	315	3.2
1.8	3.6	11	1.71	0.18	383	3.1
2.8	4	7	1.8	0.17	321	3.2
2.8	4	11	1.67	0.19	409	2.8
3.8	4.4	3	1.4	0.91	382	3.2
2.8	4	7	1.78	0.85	338	3.4
3.8	3.6	11	1.26	0.25	299	3.1
3.8	3.6	3	1.02	0.94	413	3.5
1.8	4.4	11	1.31	0.22	436	2.8
2.8	4	7	1.52	0.44	306	3.4
2.8	3.6	7	1.56	0.17	364	3.1
2.8	4.4	7	1.29	0.21	333	3.2
2.8	4	7	1.48	0.41	342	3.2
3.8	4	7	1.44	0.35	277	3.1
2.8	4	7	1.17	0.19	318	3.4
1.8	4	7	1.07	0.31	351	3.1
3.8	4.4	11	1.2	1.01	310	2.7
1.8	3.6	3	1.43	0.27	385	3.2
1.8	4.4	3	1.38	0.18	403	3.4
2.8	4	3	1.31	0.29	365	3.1

Figures 11, 12 and 13 presents the optimization of responses at various conditions which are listed as follows:

(1) Process optimization during solid lubricant coating of molybdenum disulfide (MoS_2) on Inconel 600 punch materials (Fig. 11).
(2) Process optimization during tetrahedral amorphous carbon coating (TAC-ON) on Inconel 600 punch materials (Fig. 12).
(3) Process optimization during brycoat titanium nitride (TiN) coatings on Inconel 600 punch materials (Fig. 13).

Validation of Optimized Data

Deep-drawing operations were further conducted on the predicted response parameters with a separate coating of materials on the punches as shown in Table 7. From Tables 8 and 9 we conclude that percentage error between experimental data and simulated data for LDR, SR, and thinning was lower than 10%. This value proves

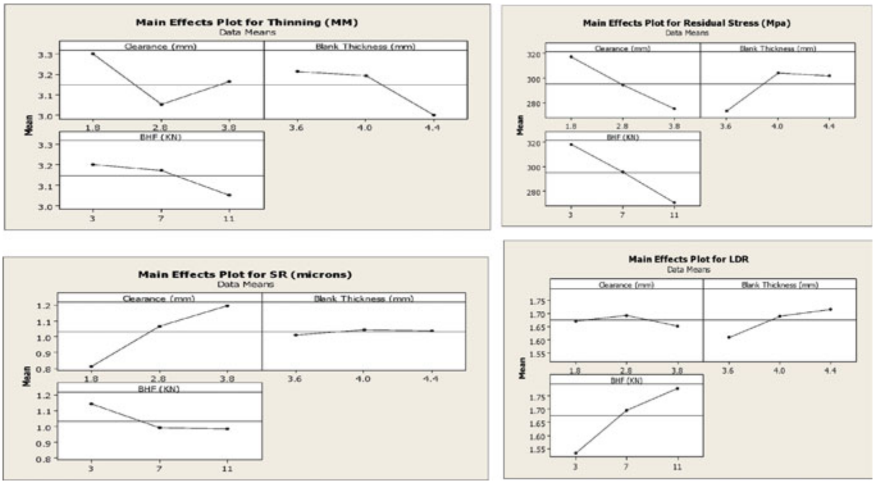


Fig. 8 Main effect plot for solid lubricant coating of tetrahedral amorphous carbon coating on Inconel 600 punches materials

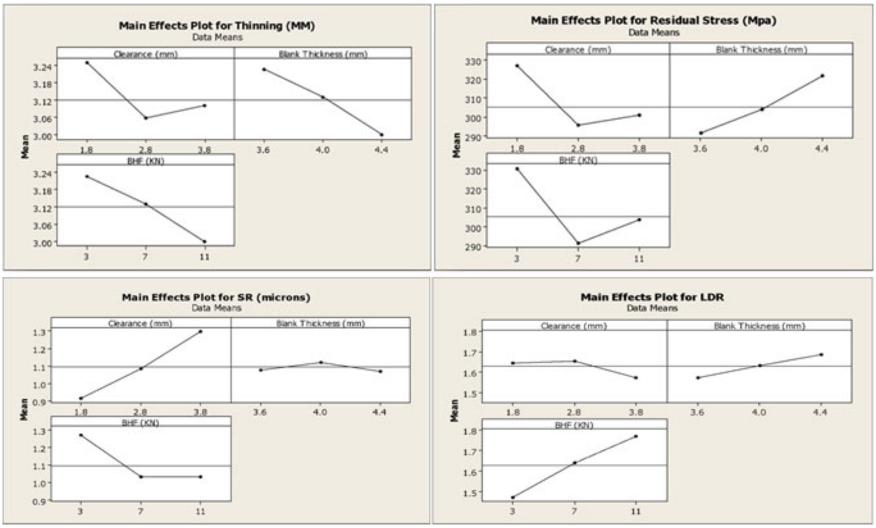


Fig. 9 Main Effect Plot for solid lubricant coating of bry coat titanium nitride on inconel 600 punches materials

good agreements between the results and verifies the validity of the model. An error was also estimated for the corresponding responses in each coating conditions. It reveals that error is very low in case of TAC-ON, which is also depicted in Table 8. TAC-ON coating is best suited for EDD steel forming under Inconel 600 die and punch.

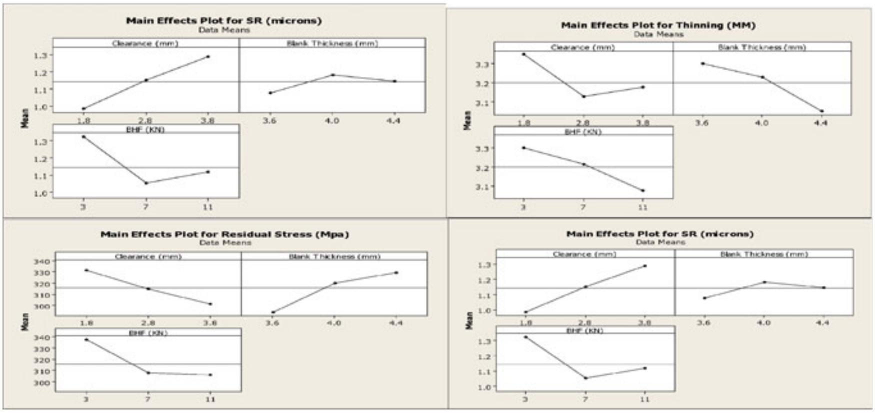


Fig. 10 Main effect plot for MoS_2 on Inconel 600 punch materials

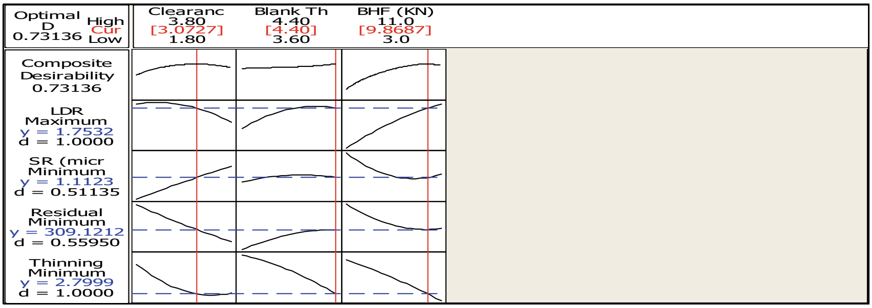


Fig. 11 Response optimization plot in molybdenum disulfide (MoS_2) coated punch

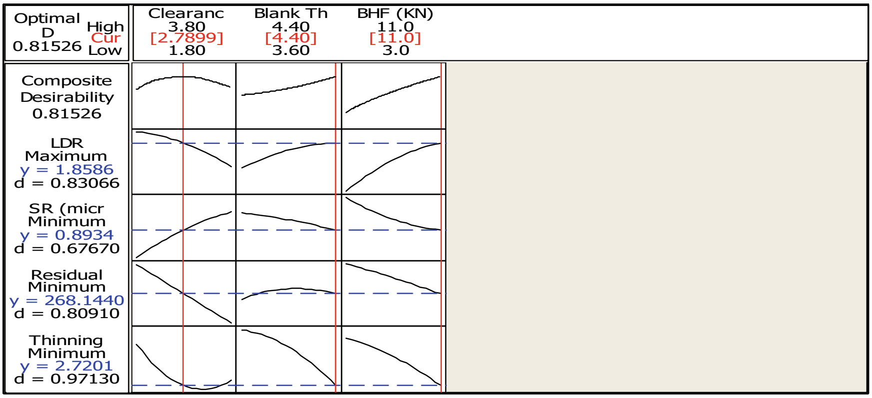


Fig. 12 Response optimization plot in tetrahedral amorphous carbon coating (TAC-ON) coated punch

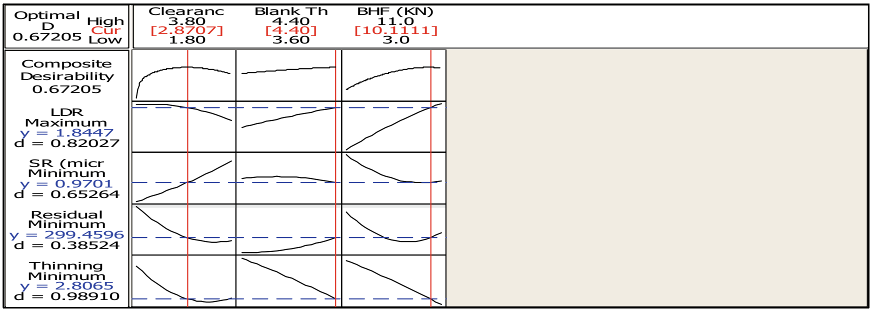


Fig. 13 Response optimization plot in brycoat titanium nitride (TiN) coated punch

Table 7 Optimal prediction of responses for material coating

Punch coating	Input parameters			Optimal responses			
	Clearance (mm)	Blank thickness (mm)	BHF (KN)	LDR	SR (μm)	Residual stress (MPa)	Thinning (mm)
MoS_2	3.0727	4.4	9.8687	1.7532	1.1123	309.121	2.7999
TAC-ON	2.7899	4.4	11	1.8586	0.8934	268.144	2.7201
Brycoat titanium nitride (TiN)	2.8707	4.4	10.1111	1.8447	0.9701	299.46	2.8065

Table 8 Experimental responses for material coating

Punch coating	Input parameters			Experimental responses			
	Clearance (mm)	Blank thickness (mm)	BHF (kN)	LDR	SR (μm)	Residual stress (MPa)	Thinning (mm)
MoS_2	3.0727	4.4	9.8687	1.7374	1.1648	322.855	2.7673
TAC-ON	2.7899	4.4	11	1.8597	0.8827	266.194	2.6904
Brycoat titanium nitride (TiN)	2.8707	4.4	10.1111	1.8744	1.0673	292.665	2.8922

6 Results and Discussion

A schematic diagram of SEM images for the non-coated punch and tetrahedral amorphous carbon-coated punch is given in Figs. 14 and 15, respectively.

Table 9 Percentage error estimation for material coating (%)

Punch coating	Input parameters			Percentage error in responses			
	Clearance (mm)	Blank thickness (mm)	BHF (kN)	LDR	SR (μm)	Residual stress (MPa)	Thinning (mm)
MoS_2	3.0727	4.4	9.8687	0.9	4.7199	4.4427	1.1643
TAC-ON	2.7899	4.4	11	0.05	1.1976	0.7272	1.0918
Brycoat titanium nitride (TiN)	2.8707	4.4	10.1111	1.61	10.0195	2.269	3.0536

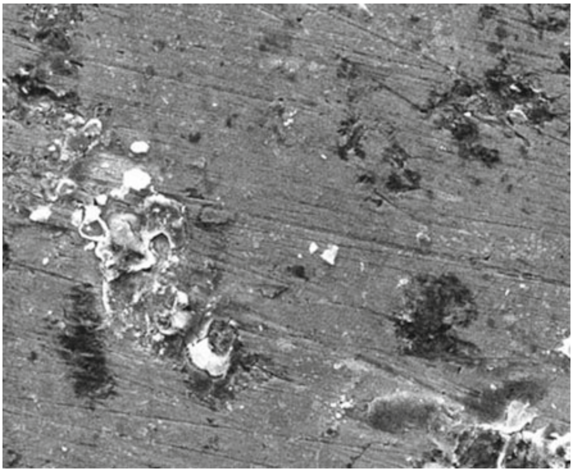


Fig. 14 SEM image of cup for non-coated punch

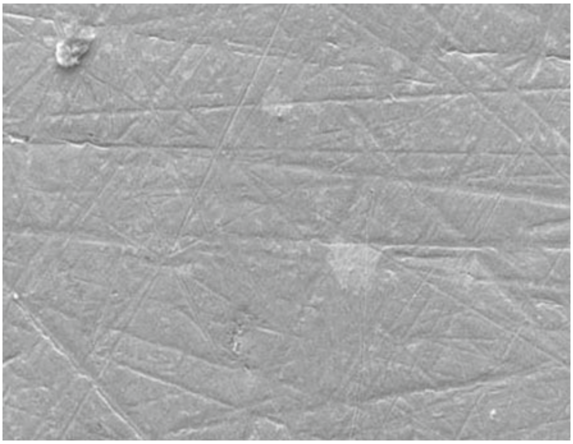


Fig. 15 SEM image of cup after Tetrahedral Amorphous Carbon Coating punch

Solid lubricant coating of tetrahedral amorphous carbon coating has been applied on punch material to obtain low wear; the microstructure and chemical compositions are also examined [15]. Thermal evaporation is a promising technique to deposit solid lubricant on selected areas of deep-drawing punch surfaces, to improve their tri-biological performance and eliminate oil lubrication. Change of elemental composition in the surface-modified layer of tetrahedral amorphous carbon coating is detected in the EDX analysis. A well-adherent surface coating is deposited on deep-drawing die steels by controlling the coating process parameters, coating properties, and coating film thickness (Figs. 16 and 17).

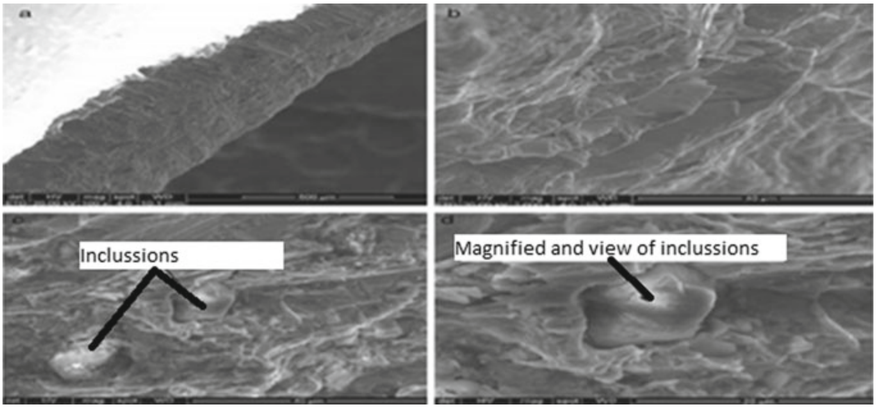


Fig. 16 SEM micrograph of EDD steels after processing

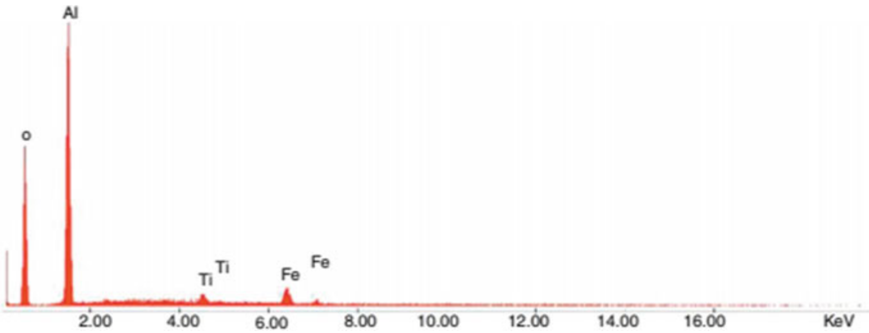


Fig. 17 EDX analysis of inclusion after processing

7 Conclusion

The present work is based on the modeling of the deep-drawing process carried out on EDD steel BH-270 grade blank using three different materials coating, like molybdenum disulfide (MoS_2), tetrahedral amorphous carbon coating (TAC-ON), and brycoat titanium nitride (TiN) on Inconel 600 (ASTM B168 AMS 5540 Din 17,750) punch. Based on the exhaustive study, three critical input parameters as clearance (mm), blank thickness (mm), and blank holding force (kN) have been selected in a deep-drawing process to estimate the LDR, surface roughness, residual stress, and thinning using RSM. As per the RSM design experiment, in each case of material coatings on punch and optimal response (Table 6), it is very clear that tetrahedral amorphous carbon coating (TAC-ON) on Inconel 600 punch is more suitable than molybdenum disulfide and brycoat titanium nitride. In case of tetrahedral amorphous carbon coating on Inconel 600 punch, the optimal values of response parameters LDR, surface roughness, residual stress, and thinning are predicted as 1.8586, 0.8934, 268.1440, and 2.7201, respectively, at clearance (mm), blank thickness (mm), and blank holding force (kN) as 2.7899, 4.4, and 11.0, respectively. The limiting wall angle and allowable thinning for the EDD cup were found to be optimal values as 75.27° and 0.252 mm, respectively. A statistical test is also performed for all the responses, that is, LDR, surface roughness, residual stress, and thinning by using regression quadratics methods which indicates the experimental data is significant. Error in RSM predicted and experimental optimal responses was estimated for each set of coating conditions, and LDR, SR, residual stress, and thinning are found to be 0.8533%, 5.3123%, 2.4796, and 1.7699, respectively.

References

1. Cebeli, Ö., Bal, M.: The effect of die/blank holder and punch radiuses on limit drawing ratio in angular deep-drawing dies. Int. J. Adv. Manuf. Technol. **40**, 1077–1083 (2009)
2. Lal, G.K., Choudhury, S.K.: Fundamentals of Manufacturing Processes, pp 88–92. Narosa Publishing House, New Delhi (2005) (Chapter 3)
3. Hawkins, D.N.: J. Mech. Work. Technol. **11**, 5–21 (1985)
4. Allen, S.J., Mahdavian, S.M.: The effect of lubrication on die expansion during the deep drawing of axisymmetrical steel cups. J. Mater. Process. Technol. **199**, 102–107 (2008)
5. Vollertsen, F., Hu, Z.: Analysis of punch velocity dependent process window in micro deep drawing. Prod. Eng. **4**(6), 553–559 (2010)
6. Sresomroeng, B., Premanond, V., Kaewtatip, P., Khantachawana, A., Kurosawa, A., Koga, N.: Performance of CrN radical nitrided tools on deep drawing of advanced high strength steel. Surf. Coat. Technol. **205**(17–18), 4198–4204 (2011)
7. Takagi, S., Toji, Y., Yoshino, M., Hasegawa, K.: Hydrogen embrittlement resistance evaluation of ultra high strength steel sheets for automobiles. Iron Steel Inst. Jpn. Int. **52**(2), 316–322 (2012)
8. Toji, Y., Takagi, S., Hasegawa, K., Seto, K.: Influence of low-temperature heattreatment after deformation on hydrogen entry into steel sheets. Iron Steel Inst. Jpn. Int. **52**(2), 274–280 (2012)
9. Bernados, P.G., Vosniako, G.C.: Predicting surface roughness in machining: a review. Int. J. Mach. Tools Manuf. **43**, 833–844 (2003)

10. Feng, C.-X., Wang, X.: Neural networks modeling of turning surface roughness parameters defined by ISO 13565. Transactions of NAMRI/SME. Technical paper no. MSO3-202, Society of Manufacturing Engineers, Dearborn, MI, pp. 467–474 (2003)
11. Ozel, T., Nadgir, A.: Prediction of flank wears by using back propagation neural network modeling when cutting hardened H-13 steel with chamfered and honed CBN tools. Int. J. Mach. Tools Manuf. **42**, 287–297 (2002)
12. Wang, M.Y., Chang, H.Y.: Experimental study of surface roughness in slot end milling. Int. J. Mach. Tools Manuf. **44**, 51–57 (2004)
13. Jeswiet, J., Micari, F., Hirt, G., Bramley, A., Duflou, J., Allwood, J.: Asymmetric single point incremental forming of sheet metal. CIRP Ann. Manuf. Technol. **54**, 88–114 (2005)
14. Justinger, H., Hirt, G., Witulski, N.: Analysis of cup geometry and temperature condition in the miniaturized deep drawing. In: Proceedings of the 8th ICTP (2005)
15. Luisa Garcia-Romeu, M., Pérez-Santiago, R., Bagudanch, I.: Fabrication of a biopsy meso-forceps prototype with incremental sheet forming variants. Int. J. Mechtron. Manuf. Syst. **6**, 242–253 (2013)
16. Emmens, W.C., Van den Boogaard, A.H.: An overview of stabilizing deformation mechanisms in incremental sheet forming. J. Mater. Process. Technol. **209**, 3688–3695 (2009)
17. Kim, Y.H., Park, J.J.: Effect of process parameters on formability in incremental forming of sheet metal. J. Mater. Process. Technol. **130**, 42–46 (2002)
18. Filice, L., Fratini, L., Micari, F.: Analysis of material formability in incremental forming. CIRP Ann. Manuf. Technol. **51**, 199–202 (2002)
19. Young, D., Jeswiet, J.: Forming limit diagrams for single point incremental forming of aluminum sheet. Proc. Inst. Mech. Eng. B J. Eng. Manuf. **219**, 1–6 (2005)
20. Fratini, L., Ambrogio, G., Di Lorenzo, R., Filice, L., Micari, F.: Influence of mechanical properties of the sheet material on formability in single point incremental forming. CIRP Ann. Manuf. Technol. **53**, 207–210 (2004)
21. Silva, M.B., Nielsen, P.S., Bay, N., Martins, P.A.F.: Failure mechanisms in single-point incremental forming of metals. Int. J. Adv. Manuf. Technol. **56**, 893–903 (2011)
22. Takuda, H., Mori, K., Masuda, I., Abe, Y., Matsuo, M.: J. Mater. Process. Technol. **120**, 412–418 (2002)

Effect of Current on the Hardness of Weld Bead Generated by TIG Welding on Mild Steel

Moazzam Mahmood, Vijay K. Dwivedi, and Rajat Yadav

Abstract TIG welding is the most common metal-joining process widely used in all manufacturing industries. The welder strikes an arc at the start of the weld, and creates a puddle, holding the electrode at a 10°–15° angle from the vertical. The electrode is pointed in the direction of the weld, and the welder "pushes" the molten metal forward by moving the electrode and the arc in the same direction. The quality of weld bead decides the reliability of the structure. The quality of weld mainly enhances the mechanical properties of the weld. In this paper the authors propose the correct welding parameter to get good weld bead quality. It is observed that the bead quality effect of welding speed and welding current on the hardness has been investigated, and that the hardness of welded joint has increased with the increase in current up to 110 A for 6 mm thick plate; then the hardness is reduced with increase in current. Higher current can lead to splash and workpiece damage. Due to thinner workpiece, high current can lead to widening of the material gap. This can also lead to heat damage and a much larger weld-affected area, and longer period of time to deposit the same amount of filling materials. Inverted microscopic analysis has been done on the weld zone to evaluate the effect of welding parameters on weld quality. To enhance the property of TIG quality of weld bead, dye penetration test is also performed.

Keywords TIG welding · Hardness test · HAZ test · Dye penetration test

1 Introduction

TIG welding is a liquid state homogeneous welding process. In this welding non-consumable tungsten electrode, inert gas such as helium or argon, or mixture of both are used as a shielded gas. An arc is produced between the workpiece and the non-consumable tungsten electrode. During the welding process the tungsten electrode,

M. Mahmood (✉) · V. K. Dwivedi · R. Yadav
Department of Mechanical Engineering, GLA University, Mathura, Uttar Pradesh 281406, India
e-mail: mech_moazzam@rediffmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_65

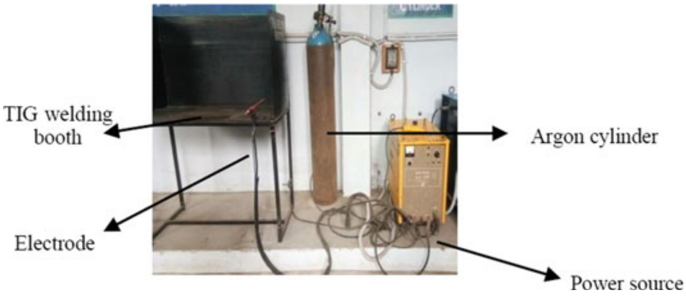


Fig. 1 Experimental setup

the arc and the weld pool are protected against the damaging effects of the atmospheric air by an inert shielding gas. TIG welding differs from the other arc welding due to short arc length generation and non-consumable electrode. Automation of the TIG welding increases production due to precision [1–3].

Different types of material can be welded in TIG welding by preparing V or U notch to increase the hardness of the specimen at different angles. Some researchers used Taguchi and ANOVA technique for optimization of process parameter [4–7]. In this paper the authors have investigated hardness and microstructure of the welded specimen by using TIG welding.

1.1 Working of TIG Welding

Figure 1 shows the experimental setup of TIG welding. The generation of the spark is started at very high temperature near about 5890 °C. At this temperature weld pool is generated due to melting of workpiece. Argon and helium gases are used as shielding gas. Argon gas is heavy and produces good shield around the weld bead.

2 Experimental Procedure

The specimen of the mild steel plate with dimensions 55 mm × 50 mm × 6 mm is prepared with V-notch and then join with tungsten inert gas welding.

2.1 Specimen Preparation for Welding

Initially, the mild steel specimen of dimensions 55 mm × 50 mm × 6 mm) is prepared and then it is cut into two pieces of dimensions 55 mm × 25 mm × 6 mm. Then the

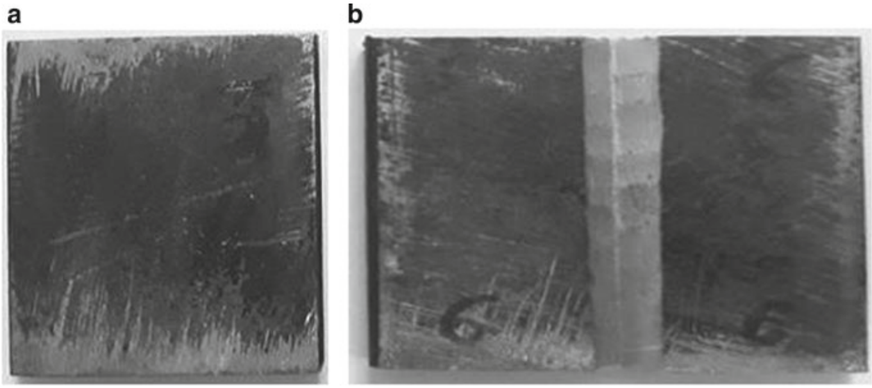


Fig. 2 **a** Specimen without notch. **b** Specimen with V-notch at 30°

V-notch is prepared by filing one edge of both the pieces at 30° angles. The filing is done with the help of 12″ flat rough file. Figure 2a, b presents the specimen without grove and with groove, respectively.

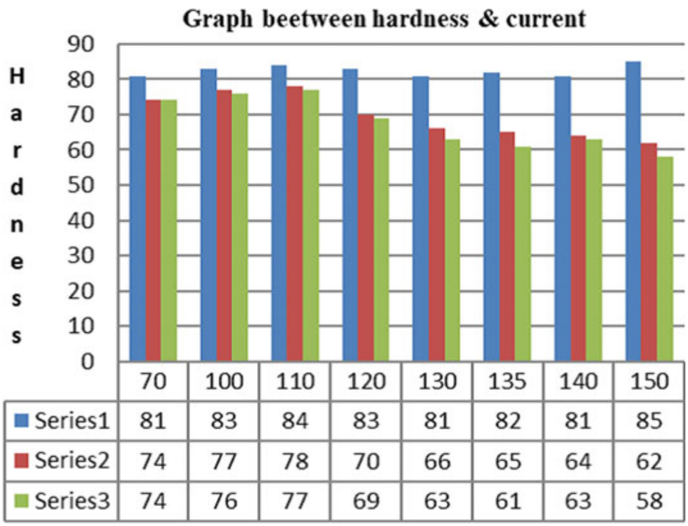
3 Results

3.1 Hardness of the Specimen

The hardness of the specimen is measured by Rockwell hardness testing machine, and is measured at weld bead and heat-affected zone area. The hardness test is performed for eight specimens prepared by selecting different welding parameter as mentioned in Table 1. It is observed that the increment in hardness results in increase in current

Table 1 Welded specimens at various current and voltage

S. no.	Workpiece no.	*I* (A)	*V* (V)	*T* (S)	Hardness of unaffected zone series 1	Hardness of HAZ area series 2	Hardness on weld bead series 3
1	4	70	12.5	2.52	81	74	74
2	5	100	12.5	1.38	83	77	76
3	8	110	12.4	0.35	84	78	77
4	2	120	12.4	1.18	83	70	69
5	1	130	12.4	0.50	81	66	63
6	7	135	12.6	1.04	82	65	61
7	6	140	12.5	0.38	81	64	63
8	3	150	12.4	0.42	85	62	58



	70	100	110	120	130	135	140	150
Series1	81	83	84	83	81	82	81	85
Series2	74	77	78	70	66	65	64	62
Series3	74	76	77	69	63	61	63	58

Fig. 3 Effect of current on the hardness of HAZ and weld bead generated by TIG welding

up to 110 A at unaffected zone, heat-affected zone (HAZ) area and on weld bead. The hardness of the specimens prepared at high amps, that is, decreased more than 110 A. This decrement in hardness is because of inter-granular crack propagation at higher currents, especially 120 and 150 A as shown in Fig. 3.

3.2 Specimen Preparation for Microstructure

For the microstructure study, initially the specimen is prepared by using etchant Nital. The composition of Nital etchant is 1 ml nitric acid, 10 ml ethanol and 89 ml distilled water. Dryer is used for removing the water droplet on the weld surface. The inverted microscope is used to get the micrograph on 100 μm scale. Figure 4 shows the mild

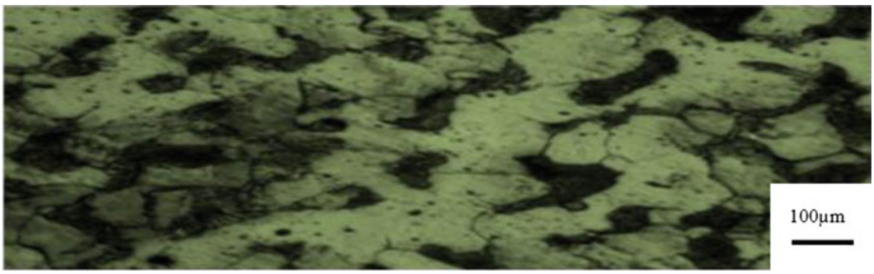


Fig. 4 Mild steel specimen without welding

steel microstructure without welding. Figures 5, 6 and 7 are the microstructure of welded specimen at 100, 130 and 150 A, respectively.

Measurements of average grain size were carried out in different parameter of welding. Small black spot is clearly seen in the microscopic image of the mild steel specimen in Fig. 5. This black spot is called as α-Mg phase. After increasing the current from 100 to 130 A β-phase is also visible. The dendrite grain and spline grain are obtained at 130 A, which is clearly seen in Fig. 6. The crack propagation was initiated at 130 A. But it is clearly seen in Fig. 7 at 150 A.

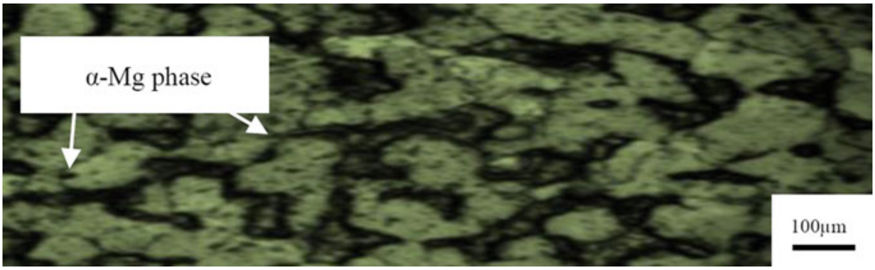


Fig. 5 Mild steel specimen with welding

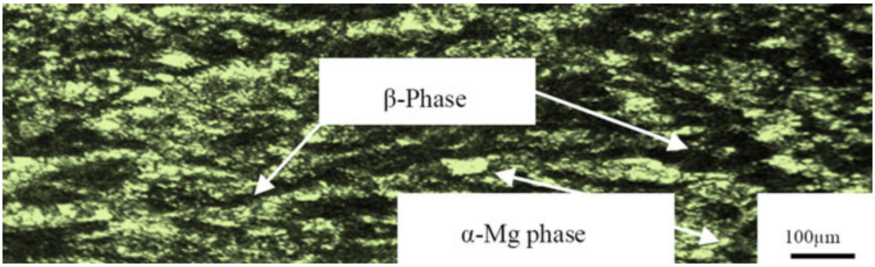


Fig. 6 Microstructure of specimen at 130 A

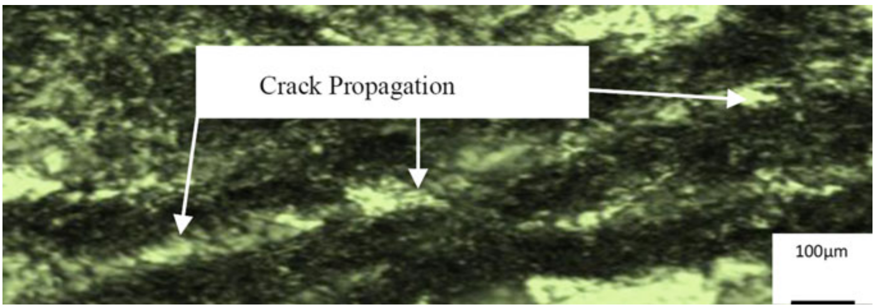


Fig. 7 Microstructure of specimen at 150 A

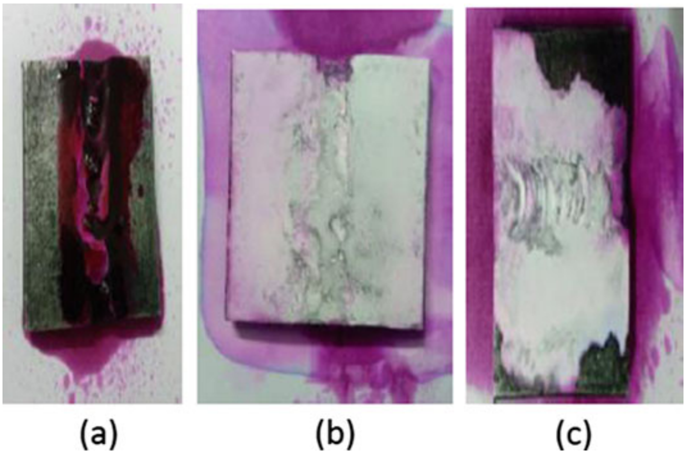


Fig. 8 Dye penetration test; **a** Applied cleaner. **b** Applied penetrate. **c** Applied developer

3.3 Dye Penetration Test

It is used to detect the welding surface, casting defects such as cracks and porosity, and fatigue crack in the welded specimen. In this inspection, five steps are done on the specimen to find cracks and porosity. Firstly, the specimen surface is cleaned by cleaner to remove the dirt, oil and paint. The cleaning step may include solvent and vapor degreasing. It is used in surface finishing process. It involves solvent in vapor form to cleanse the specimen made for further finishing process. The removal of excessive penetrate is done only in one direction, either vertically or horizontally. After the removal of extra penetrate, the developer is applied on the surface of the specimen.

It draws penetrate from defects on the surface which can be easily seen from a naked eye. Interpreting the results and characterizing defects from the specimen required expertise. This test steps are shown in Fig. 8.

4 Conclusions

The hardness of weld bead is initially increasing up to 110 A and then decreases. It is because of increment in the welding heat input due to high current [8]. With high energy input, grain size in welded microstructure increases and grain boundaries are concentrated. Lessening in grain boundaries as locks for movement of dislocations increases possibility and amount of dislocation movement as line defects in structure. It will cause a reduction in hardness of welded metal. It is also seen that the hardness of HAZ is less as compared to base material because evaporation of Mg during welding process. It is clearly seen from the microstructure that the crack propagation is visible after 110 A. It is also supported from Table 1 that the hardness of the weld bead is maximum at 110 A. After that the crack is initiated and propagated up to 130 A. Dye penetration test reveals more crack propagation visible at higher current.

References

1. Thakur, Y., Kumar, K., Kumar, K.: Influences of TIG welding parameters on tensile and impact behaviour of aluminium alloy joints: a review. IOSR J. Mech. Civ. Eng., Special Issue, AETM'16, 54–58 (2016)
2. Randhawa, V.J., Suri, N.M.: Effect of a TIG welding process parameters on penetration in mild steel plates. J. Mech. Ind. Eng. **3**(2), 27–30 (2013)
3. Jeyaprakash, N., Haile, A., Arunprasath, M.: The parameters and equipments used in TIG welding: a review. Int. J. Eng. Sci. **4**(2), 11–20 (2015)
4. Singh, G., Bansal, A., Gupta, A.K., Singh, A.: Study the parametric optimization of TIG welding. Int. Res. J. Eng. Technol. **3**(5), 412–417 (2016)
5. Bhavsar, A.N., Patel, V.A.: Influence of process parameters of TIG welding process on mechanical properties of SS304L welded joint. Int. Res. J. Eng. Technol. **3**(5), 977–984 (2016)
6. Gopinath, V., Manojkumar, T., Sirajudeen, I., Yogeshwaran, S., Chandran, V.: Optimization of process parameters in TIG welding of AISI 202 stainless steel using response surface methodology. Int. J. Appl. Eng. Res. **10**(13), 11053–11057 (2015)
7. Vijayan, D., Rao, V.S.: Process parameter optimization in TIG welding of AISI4340 low alloy steel welds by genetic algorithm. IOP Conf. Ser. Mater. Sci. Eng. **90**, 012066 (2018)
8. Singh, P., Singh, V.: Experimental investigation of weld bead hardness of tig welding of grade ss316. Glob. J. Eng. Sci. Res. **1**(3), 42–48 (2014)

Hot Corrosion Study on Dissimilar Weld Joints of Austenitic Stainless Steel and High Strength Low Alloy Steel

B. P. Agrawal and Ramkishor Anant

Abstract Amalgamation of austenitic stainless steel (ASS) and high strength low alloy steel (HSLA) as tube is used in many applications of boiler and heat exchanger where high temperature occurs. Owing to the availability of welding, weld joint faces high temperature. Keeping in view, weight gain studies have been carried out on weld joints assembled with shielded metal arc welding (SMAW), pulse current gas metal arc welding (P-GMAW) and tungsten inert gas welding (TIG) under the environment of Na_2SO_4 and V_2O_5 (60%) in melted condition at 600 and 650 °C for 1 h heating and 20 min cooling as cycle. It has been found that the specimen layered with this mixture obeys the parabolic rate law. The thickness of scale on HSLA steel side was higher and more liable to spalling. The impact of coating of melted salt atmosphere on hot corrosion behaviour of weld is further explained. It was observed that the higher the temperature of exposure, the greater will be the corrosion and weight gain by the weld joint.

Keywords Hot corrosion · ASS · HSLA steel · SMAW · P-GMAW · TIG welding

1 Introduction

The combination of ASS and HSLA steel has been applied in many cases of boilers, heat exchangers, coal-based power plants and offshore oil rigs in as-welded condition. This is due to its good weldability along with low cost and high resistance to stress corrosion cracking. The weld joints face high temperature in service and corrosive environments [1–3]. These are normally joined by commonly used welding process of SMAW, TIG and P-GMAW welding [4–6]. These welded joints are getting corroded and degraded at high temperature to various extent depending upon the method

B. P. Agrawal (✉)
School of Mechanical Engineering, Galgotias University, Yamuna Expressway, Greater Noida, Uttar Pradesh 201309, India
e-mail: banshiprasad@gmail.com

R. Anant
Department of Materials and Metallurgical Engineering, Maulana Azad National Institute of Technology, Bhopal, Madhya Pradesh, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_66

of welding. The various methods of joining through their effect on heat input and thermal cycles generate microstructures of different grain sizes. Accordingly, these are corroded to various extent [7–9].

Hot corrosion is an accelerated corrosion, resulting from the occurrence of salt impurities like Na_2SO_4, NaCl and V_2O_5, which may lead to the formation of liquid. It occurs in two ways [10, 11]. In one case, it occurs at relatively greater temperature, where deposited salt remains in unsolidified condition. The corrosion occurs at very rapid rate and kinetics remain rectilinear with the occurrence of Na_2SO_4 next to higher temperature of 900 °C [11, 12]. As Na_2SO_4 gets melted at about 880 °C, corrosion is relatively faster from the start of the corrosion itself. In another case, corrosion is very slow at the starting of corrosion, and after certain time it enhances all of a sudden and follows linear kinetics [13, 14]. This corrosion occurs at lower temperature as compared to temperature at which salt is getting converted into liquid [15, 16]. Further, the fuels used by thermal power plant or heat exchanger may be of low grade as coal or oil can contain high concentration of sulphur, vanadium and sodium. These elements may form alkali metal sulphates and vanadium penta-oxide (V_2O_5) vapours that may get associated with other ash ingredients and may deposit on surfaces [17, 18]. At higher temperature, certain salt remains as fluid or get changed in complicated mix of salt in contact with gases containing sulphur. Corrosion in the presence of such salts as liquid gets accelerated.

Sędek et al. observed that the relieving technique used for thermal stress for assembled joints was not very much effective and can give rise to residual stresses. This may be because of differing coefficient of thermal expansion of steels used [19]. Klueh and King examined the dissimilar alloy weld failure problem in fossil-fired boilers for joints between ferritic and austenitic stainless steel. The microstructure developed at the interface of weld metal and ferritic steel was examined in the as-welded and tempered, besides as-welded and aged conditions, and developed a mechanism by which the interface microstructure form during welding [20].

Considering all, it can be said that the corrosion behaviour of dissimilar assembled joints of ASS and HSLA joined using various methods in eutectic mixture of Na_2SO_4–60%V_2O_5 at different temperatures have not been considered in the literature thoroughly. Therefore, it is planned to study the corrosion behaviour of weld joints joined using SMAW, P-GMAW and TIG welding. The study was performed in molten salt environment of Na_2SO_4 and V_2O_5 (60%) at 600 and 650 °C in cyclic condition of 1 h heating and 20 min cooling because these conditions are most prevalent conditions where frequent breakdown occurs in industry.

2 Experimentation

The plates of ASS and HSLA steel were joined using SMAW, P-GMAW and TIG welding processes. Different elements present in both ASS and HSLA steel plates are shown in Table 1. The parameters of welding used in joining of plates have been given in Table 2. The heat input was kept at 14–16 kJ/cm. The parameters of P-GMAW of

Table 1 Compositions of ASS and HSLA steel plates used in the study

Material	Source	Chemical analysis (wt%)									
		Carbon	Chromium	Nickel	Manganese	Nitrogen	Molybdenum	Silicon	Copper	Sulphur	Phosphorus
γ-SS (304LN)	Supplier test certificate[a]	0.024	18.8	9.3	1.7	0.15	–	0.55	–	0.001	0.022
		0.022	19	9.1	1.8	0.16	0.19	0.57	0.3	0.002	0.021
HSLA Steel	Supplier test certificate[a]	0.14	0.023	0.04 (v)	1.46 (v)	0.02 (Ti)	0.04 (Nb)	0.28	0.02	0.008	0.02
		0.154	0.014	0.08 (v)	1.5	0.02 (Ti)	0.04 (Nb)	0.31	0.03	0.02	0.022

[a]Indicates testing by spark emission optical spectroscopy

Table 2 Parameters of different welding process applied for joining the plates

Welding processes	Arc voltage (V)	Heat input (Ω) (kJ/cm)	Welding speed (S) (cm/min)	Mean current $I/(I_{\mathrm{m}})$ (A)	Pulse parameters				
					I_{p}	I_{b}	f (Hz)	t_{b} (s)	t_{p} (s)
SMAW	28	13.4	14.8	160	–	–	–	–	–
P-GMAW	28 ± 2	13.3	19.5	220	295	164	105	3.5	4.08
TIG	28	13.4	23	200	–	–	–	–	–

peak current (I_p), base current (I_b), frequency (f), base current duration (t_b) and peak current duration (t_p) are also given in table. During SMAW and P-GMAW, electrode is kept as positive and plates as negative. In P-GMAW, joining is done in shield of commercial argon gas with flow rate of 18 L/min. In GTAW electrode is connected to negative. The dimension of plate was 25 mm × 10 mm × 6 mm and so multi-pass welding was used. Samples are made by cutting from central part of weld. Samples were coated with salt mixture of Na_2SO_4 and V_2O_5 (60%). The samples were heated along with salt coating up to 250 °C for 2.5 h to remove moisture, and the weight is taken. Hot corrosion study was done for 50 cycles at temperature of 600 and 650 °C with the help of silicon carbide tubular furnace with built-in PID controller. In each cycle specimen were heated for 1 h and then cooling for 20 min at room temperature. Then samples were visually inspected and the weight was measured after every cycle. Total of 50 cycles was done for each sample.

3 Results and Discussions

3.1 Study on Macrostructures of Weld Prepared by Using SMAW, TIG and P-GMAW Processes

The macrostructures of weld joints prepared by using SMAW, TIG and P-GMAW processes (Fig. 1) show that all welds are free from any defects of porosity, lack of fusion between weld bead and base metal and inter-bead deposits. It also gives analytically different portion of weld joints of base metal, heat affected zone (HAZ) on both sides and weld. It clearly shows that macrostructures are dendritic.

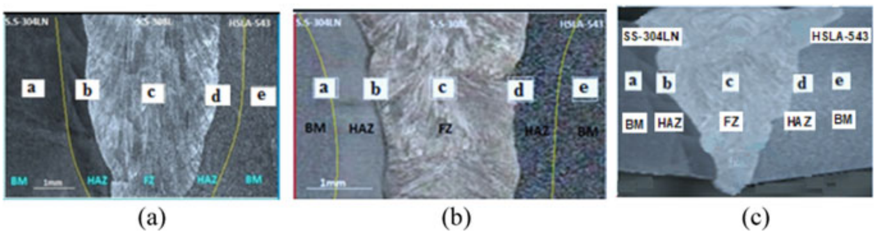


Fig. 1 Macrostructures of welds of **a** SMAW, **b** TIG and **c** P-GMAW processes

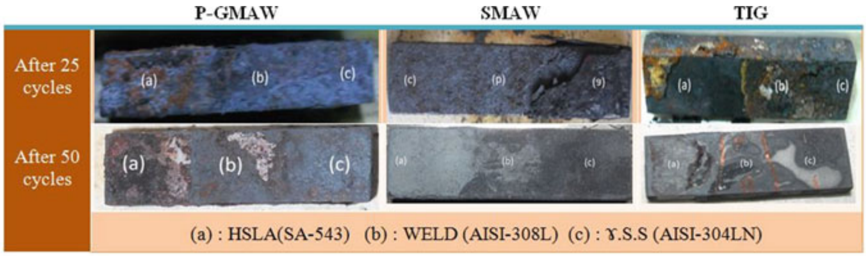


Fig. 2 Macro snapshot of various weld joints after exposing in Na_2SO_4 and V_2O_5 (60%) environment at 600 °C

3.2 *Effect of Na_2SO_4 and V_2O_5 (60%) Salt Coating on Weld Joints at 600 °C*

The macro photograph of different weld joints joined using P-GMAW, SMAW and TIG welding processes after exposure in Na_2SO_4 and V_2O_5 (60%) environment at 600 °C are shown in Fig. 2. A light scale with rough surface with brown blotches has been found in few early cycles afterwards. The blotches have been observed mainly on HSLA side and not on ASS 304LN side. Upon further heating the specimen, the thickness of spallation goes on increasing, especially on HSLA side due to its lower Cr content. With increase in Cr content the resistant to hot corrosion enhances due to shift of structure towards austenite structure side. ASS side offers much resistance to oxidation, chloridation and sulphidation. After 25 cycles, the scale breaks down over the surface of all welded specimens due to the formation of subsequent oxide layer beneath the sputtered oxide layer. Colour of scale turns to greyish colour after the completion of 30 cycles. The colour of scale becomes dark with enhancement of cycle numbers. The colour of scale and texture of joint is found diverse as compared to metals assembled.

3.3 *Effect of Na_2SO_4 and V_2O_5 (60%) Salt Coating on Weld Joints at 650 °C*

Figure 3 depicts the effect of Na_2SO_4 and V_2O_5 (60%) salt coating on weld joints at relatively higher temperature of 650 °C joined with various welding processes of P-GMAW, SMAW and TIG welding. The colour of scale on HSLA steel side has been found as light purplish grey for the duration of some of the starting cycle and converting to dark grey after subsequent cycle number six. However, on ASS side, the presence of blue colour patch has been observed after fifth cycle. Consequently, the weld was seen as light grey colour only after ninth cycle. Subsequently, on finishing 10 cycles, the scale was becoming thicker and more dark brown in colour on HSLA steel side and was mostly spalled out, while on ASS side it seems to be light brown

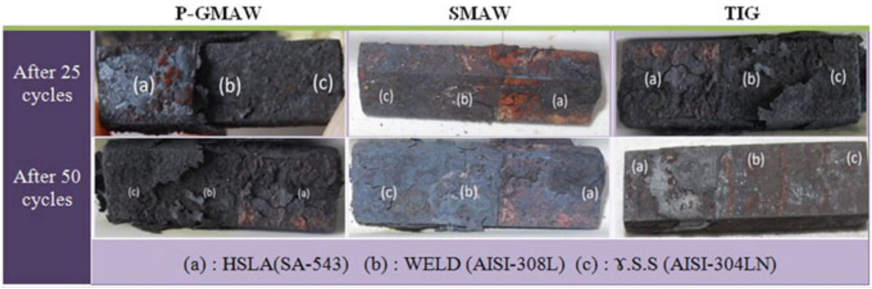


Fig. 3 Macro snapshot of various weld joints after exposing in Na_2SO_4 and V_2O_5 (60%) environment at 650 °C

and adheres to the joint. No significant variation in colour was observed during other subsequent cycles. The thickness of scale has been found to enhance on the HSLA steel side as temperature increases from 600 to 650 °C, along with substantial spalling and deep noise. On completion of 25 cycles, the scales have been observed to be becoming extra brittle and substantial spalling is observed as shown in Fig. 3.

3.4 Corrosion Kinetics

The plots of weight gain/area versus time (number of cycles) and (weight gain/area)^2 versus number of cycles are given in Fig. 4. These plots show the corrosion kinetics of samples that are deposited with molten salt. The plots shown in Figs. 4b and 5b are used for establishing rate law for hot corrosion. Parabolic rate constant Kp has been found with the help of slope of line obtained by fitting linear regression of the plot between (weight gain/area)^2 versus number of cycles. So, it can be found by equation $(\delta W/\mathrm{A})^2 = \mathrm{Kp.t}$, where $\delta W/\mathrm{A}$ represents the weight gain per unit surface

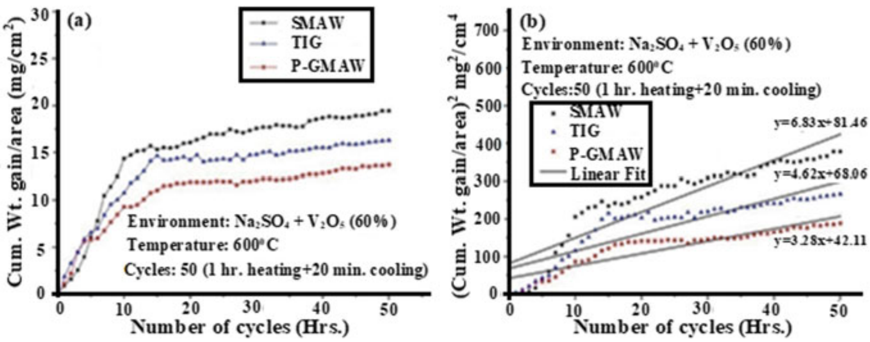


Fig. 4 **a**, **b** Plot of weight gain for various weld joints with corrosion of 50 cycles in Na_2SO_4 and V_2O_5 (60%) on 600 °C

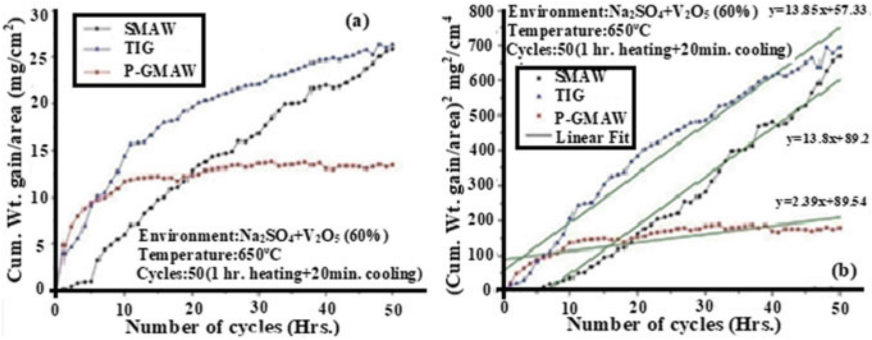


Fig. 5 **a**, **b** Plot of weight gain for various weld joints with corrosion for 50 cycles in Na_2SO_4 and V_2O_5 (60%) at 650 °C

area (mg/cm^2) and t number of cycles. It deals with the comparison between hot corrosion performance of different weld joints subjected to a given environment and temperature of exposure.

Specimen shows rapid rate of weight gain in starting cycles, while rate of weight gain reduces for the period of later cycles at both temperatures of 600 and 650 °C. This is because a substantial portion of thick oxide layer is formed on the specimen. Only thick and fragmented scale remained after 50 cycles. The weight gain is lowest for P-GMAW weld joint, while in case of TIG it lies between SMAW and P-GMAW weld joints at both temperatures of 600 and 650 °C. Accordingly, the corrosion is lowest in P-GMAW weld joint, and the TIG weld joint shows medium corrosion. The lowest corrosion in P-GMAW weld joint may be due to its association of finer microstructure as compared to others [15]. Higher temperature is found to be more corrosive and higher weight gain rate is noted.

Kp is an intrinsic property of the alloy-resisting corrosion. Figure 6 shows comparison between hot corrosion performance of various weld joints at different temperatures. The value of parabolic rate constant Kp is relatively lower for all weld joints joined using P-GMAW, SMAW and TIG welding processes at 600 °C as compared to 650 °C. Further, it is observed that the parabolic rate constant Kp is lowest for P-GMAW weld joint, while it is highest for SMAW weld joints at both temperatures of 600 and 650 °C, respectively. The parabolic rate constant Kp in case of TIG weld joints lies in between SMAW and P-GMAW weld joints. This shows again that the P-GMAW weld joint gives highest resistance to corrosion and has been attacked least by molten salt environment. This further confirms that hot corrosion in P-GMAW weld joint is lowest. The highest value in case of SMAW weld joint shows least resistance to corrosion. This again shows that SMAW weld joints are very severely attacked by corrosion and so has highest corrosion attack, while TIG weld joints give medium value of Kp.

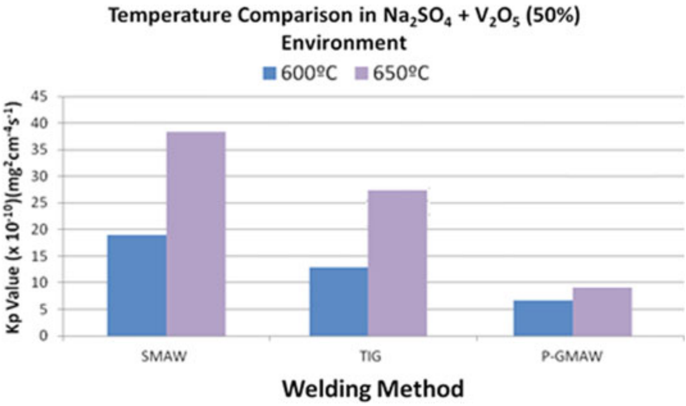


Fig. 6 Comparison of hot corrosion performance of a particular weldment at different temperatures in Na_2SO_4 and V_2O_5 (60%) environment

4 Conclusion

The results of investigation on weld joints of SMAW, TIG and P-GMAW welding process subsequent to corrosion in the presence of Na_2SO_4 and V_2O_5 (60%) are concluded as follows:

1. P-GMAW weld joints as compared to other weld joints of SMAW and TIG gives better hot corrosion resistance at both working temperatures of 600 and 650 °C.
2. Significant weight gain has been found in all weld joints of ASS and HSLA steel which may be due to galvanic type of attack owing to heterogeneous composition because of welding process. The galvanic type of attack is corrosion damage induced in dissimilar welding of ASS and HSLA steel.
3. Initial cycles show relatively higher rate of oxidation and later cycles give slower rate of oxidation because the scales generated in initial cycles can protect metals below it.
4. The weld joints of dissimilar metals show rapid hot corrosion in molten salt environment as substantial spalling and sputtering of scale.
5. Weight gain of specimen coated with salt follow parabolic rate law all through period of corrosion in hot condition.

References

1. Davoodi, A., Esfahani, Z., Sarvghad, M.: Microstructure and corrosion characterization of the interfacial region in dissimilar friction stir welded AA5083 to AA7023. Corros. Sci. **107**, 133–144 (2016)

2. Kulkarni, S.G., Agrawal, B.P., Ghosh, P.K., Ray, S.: Critical aspects of pulse current GMA welding of stainless steel influencing metallurgical characteristics. Int. J. Microstruct. Mater. Prop. Indersci. **12**(5/6), 363–390 (2017)
3. Agrawal, B.P., Chauhan, A.K., Kumar, R., Anant, R., Kumar, S.: GTA pulsed current welding of thin sheets of SS304 producing superior quality of joint at high welding speed. J. Braz. Soc. Mech. Eng. **39**(11), 4667–4675 (2017)
4. Agrawal, B.P., Ghosh, P.K.: Influence of thermal characteristics on microstructure of pulse current GMA weld bead of HSLA steel. Int. J. Adv. Manuf. Tech. **77**(9–120), 1681–1701 (2015)
5. Agrawal, B.P., Ghosh, P.K.: Assembling of thick section HSLA steel with one seam per layer multi pass PC-GMA welding producing superior quality. J. Braz. Soc. Mech. Eng. **39**(12), 5205–5218 (2017)
6. Agrawal, B.P., Ghosh, P.K.: Thermal modelling of multi pass narrow gap pulse current GMA welding by single seam per layer deposition techniques. Math. Manuf. Proc. **25**(11), 1251–1268 (2010) (Taylor and Francis)
7. Agrawal, B.P., Ghosh, P.K.: Characteristics of extra narrow gap pulse current gas metal arc weld of HSLA steel produced by single seam per layer deposition technique. J. Math. Eng. Perform. **26**(3), 1365–1381 (2017)
8. Kumar, R., Anant, R., Ghosh, P.K., Kumar, A., Agrawal, B.P.: Influence of PC-GTAW parameters on micro structural and mechanical properties of thin AISI 1008 steel joints. J. Math. Eng. Perform. **25**(9), 3756–3765 (2016)
9. Kumar, R., Chattopadhyaya, S., Agrawal, B.P., Kumar, S., Devkumaran, K., Arvindan, S.: Effects of types of GTAW including superior GTAW-PC with superimposed HF current on mechanical and metallurgical properties of super duplex stainless steel weld joints. Mater. Res. Exp. **6**(7), 076572 (2019) (IOP Science)
10. Anant, R., Dahiya, J.P., Agrawal, B.P., Ghosh, P.K., Kumar, R., Kumar, A., Kumar, S., Kumar, K.: SMA, GTA and P-GMA dissimilar weld joints of 304LN stainless steel to HSLA steel; part-2: hot corrosion kinetics. Mater. Res. Exp. **5**(9), 096503 (2018) (IOP Science)
11. Yamada, K., Tomono, Y., Morimoto, J., Sasaki, Y., Ohmori, A.: Hot corrosion behaviour of boiler tube materials in refuse incineration environment. Vacuum **65**, 533–540 (2002)
12. Mortezaie, M.: Shamanian, An assessment of microstructure, mechanical properties andcorrosion resistance of dissimilar welds between Inconel 718 and 310S austenitic stainless steel. Int. J. Press. Vessels Pip. **116**, 37–46 (2014)
13. Eliaz, N., Shemesh, G., Latenision, R.M.: Hot corrosion in gas turbine components. Eng. Fail. Anal. **9**, 31–43 (2002)
14. Niraj, B., Harpreet, S., Prakash, S.: Accelerated hot corrosion studies of cold spray Ni 50Cr coating on boiler steels. Mater. Des. **31**, 244 (2010)
15. Anant, R., Dahiya, J.P., Agrawal, B.P., Ghosh, P.K., Kumar, R., Kumar, A., Kumar, S., Kumar, K.: SMA, GTA and P-GMA dissimilar weld joints of 304LN stainless steel to HSLA steel; part-1: thermal and microstructure characteristics. Mater. Res. Exp. **5**(9), 096503 (2018) (IOP Science)
16. Moteshakker, A., Danaee, I.: Microstructure and corrosion resistance of dissimilar weld joints between duplex stainless steel 2205 and austenitic stainless steel 316L. J. Mater. Sci. Techol. **32**, 282–290 (2016)
17. Mohammed, A.M., Kulkarni, A.S., Sathiya, P., Goel, S.: The impact of heat input on the strength, toughness, microhardness, microstructure and corrosion aspects of friction welded duplex stainless steel joints. J. Manuf. Proc. **18**, 92–106 (2015)
18. Hurdus, M.H., Tomlinson, L., Tichmarsh, J.M.: Observation of oscillating reaction rates during the isothermal oxidation of ferritic steels. Oxid. Met. **34**(5–6), 429–464 (1990)
19. Sędek, P., Brózda, J., Wang, L., Withers, P.J.: Residual stress relief in MAG welded joints of dissimilar steels. Int. J. Press. Vessels Pip. **80**(10), 705–713 (2003)
20. Klueh, R.L., King, J.F.: Austenitic stainless steel-ferritic steel weld joint failures. Weld. J. Res. Suppl. **61**, 302s–311s (1982)

Quality Improvement in Assembly of 'Head Lamp Leveling Switch (HLLS)' by Continuous Improvement Methods Utilization

Anil Kumar and Rakesh Giri

Abstract The automotive industry is the world's largest manufacturing industry with an activity that is frequently impacted by trade, investment regulation, manufacturing process, and environmental standards. In order to compete in such an industry, manufacturing managers have to put their efforts in motivating their personnel to increase their efficiency and improve the processes to achieve a common successful goal of improved productivity and quality. In the context of the above, focus was made to implement the lean concepts (Kaizen and Poka-yoke) to improve the quality of one of its products 'head lamp leveling switch (HLLS)' in the assembly line by reducing cycle time, lead time, and rejection. In this research five steps of the DMAIC cycle were used to synchronize the findings and their effects throughout the manufacturing cycle. After implementing the solutions switch rejection gap has been reduced from 6 to 0 in a shift of 7.5 h.

Keywords Lean manufacturing · Kaizen · Synchronization · HLL switch · Minimizing rejection

1 Introduction

Nowadays, around the world the companies are realizing the importance of being a part of the global market and are searching for operational methods to increase their productivity and competitive power through the use of innovative production systems. Traditional manufacturing systems are being challenged and new manufacturing principles are being developed. In the journey of improving the manufacturing processes, Toyota coined the term 'Lean' to describe the outcomes associated with

A. Kumar (✉)
MAE Department, G. B. Pant Engineering College, New Delhi, India
e-mail: anilapmae@gmail.com

R. Giri
SRM University, Sonipat, Haryana, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_67

the Toyota production system (TPS) management philosophy. Since then, lean manufacturing has evolved beyond automotive into all types of manufacturing in many other industries.

1.1 Project/Concerned Place Introduction

The company Mindarika is chosen for solving a new type of problem related to the quality improvement. Making its mark in the International Grid of Automobile Components manufacturing, MINDA steers ahead as a leading Tier 1 supplier of proprietary automotive solutions to original equipment manufacturers (OEMs). Incepted way back in 1958 with a meagre start-up capital and now notching up a group turnover beyond US$ 1150 million speaks volumes of the conglomerate that it is today. The company manufactures and assembles a number of products, such as lever combination switches, panel switches, head lamp leveling switch, HVAC switch, and so on.

1.2 Product Introduction

The function of head lamp leveling switch is to control on/off function of light and to adjust the inclination angle of the optical system in the head lamp in such a way that the focus of light beam remains in the prescribed and garage-adjusted base position irrespective of the state of load. In manual system the angle of inclination is adjusted by Knob detent (refer Fig. 1). Here in our case the inclination angle can change up to 24° in four steps. Its main components are:

1. Knob head lamp
2. Knob detents

Fig. 1 Head lamp leveling switch

3. Back cover and housing
4. PCB.

2 Literature Review

Around the entire world, automotive and its related industries are facing numerous challenges toward capturing larger market share to earn more and more profit. This can be achieved only by maximizing productivity with minimum production wastes. To achieve minimum rejection rate, improved quality, and higher productivity various continuous improvement methods such as lean tools have to be used. Many of the scientists and engineers have done a lot of research in these field such as:

In Pool et al. [1], a case study implementing lean planning in a semi-process industry describes that lean approach is an idealizing improvement approach that has an enormous impact in the field of operations management. It started in the automotive industry and has since been widely applied in discrete manufacturing. Lean elements—cyclic schedule, production regularity, process improvement, coordination simplicity, and so on help to improve production and production quality. Demeter and Matyusz [2] studied that the inventory turnover performance as a visible and concrete marker of world-class performance and also as an indicator of effort and from the most typical measures (rejects and scrap, reworking, labor and machine productivity, product quality, inventory levels and turnover, unit manufacturing cost, manufacturing cycle time, delivery speed, and reliability) of manufacturing performance can be improved by the implementation of lean practices in the companies.

Kumar [3] used the CIP method and removed the problem of locking not good. The study reveals the different methods used to bring the rejection of lever combination switch to zero. Losonci et al. [4] examined workers' perceptions regarding the success of the lean implementation and identified the critical intrinsic factors (commitment, belief) and external factors (lean work method, communication) affecting the success of lean implementation from workers' point of view and found positive long-term impact on the shop floor level. Eroglu and Hofer [5] investigated the effect of inventory leanness on firm performance. A total of 54 U.S. manufacturing firms were studied over a 6-year time period and found that the effect of inventory leanness on firm performance is mostly positive and generally nonlinear. In most instances, the effect of inventory leanness is concave implying and that there is an optimal degree of inventory leanness beyond which the marginal effect of leanness on financial performance becomes negative.

Faye and Falzon [6] focused on the automotive industry production, based on assembly line work, which is now characterized by lean manufacturing and customization. This results in greater flexibility and increased quality demands, including worker performance self-monitoring, and results in the construction of a variety of cars on the same assembly line. Lockstorm et al. [7] presented that supplier integration is an important concept for improving supply chain performance. The data was collected through 30 detailed case interviews with subsidiaries of foreign automotive companies operating in China. The results indicate that buyer-side leadership is an important antecedent for building motivation, trust, and commitment among suppliers and shaping their mindsets.

Shahin and Ghasemaghaei [8] describe Poka-yoke as one of the effective quality design techniques in manufacturing, which is developed for fail-safing services. For this purpose, service Poka-yoke has been demonstrated and its solutions have been classified. They also proposed a framework by which the common and uncommon elements of service Poka-yoke and service recovery solutions have been classified and addressed schematically. Saurin and Fabricio Ferreira [9] studied the impacts of lean production on working conditions of a harvester assembly line in Brazil, and the results indicated that workers considered their working conditions had improved after the introduction of lean production. It was also reported that the most dramatic health and safety changes were in terms of culture of safety. Kumar et al. [10] made an investigation on needle missing in bearing. Initially the case of needle missing in bearing was found to be 30%, but when they implemented the Poka-yoke tool, the case of needle missing is totally decreased and found that no complaint has been raised by the customers. This leads to an increased customer satisfaction, increased sales, enhanced productivity, and profit. Premanand et al. [11] studied the impact of Poka-Yoke on the company's quality maintenance system. The found that the horns which the industry is using, as a Poka-Yoke tool, have 100% effectiveness in reducing the rejection rates.

From these studies it can be concluded that the CI methodologies can be used for almost all problems which leads to poor quality, more rejection, or less productivity.

3 Problem Identification

Recently, Mindarika Pvt. Ltd. has reported a considerable shortfall in production and poor quality of one of its products 'head lamp leveling switch (HLSS)' in assembly line. In order to improve the status in assembly line, the company has raised few issues in consolidation on which focus is to be made to improve the condition of assembly line, which is listed as follows:

1. Line production variates due to different reasons.
2. A considerable rejection rate of 13 switches due to quality problem in line during the shift at different workstations, in which six switches in average are rejected while performing caulking process.
3. Actual line production is less than required.

4 Experimental Methodology

An experimental methodology, the DMAIC strategy in combination of 5S, Kaizen, and Poka-yoke was used to describe steps to solve the problems in assembly line to improve productivity and quality by minimizing the waste at different workstations by using lean tools. Problems were observed in the line, and the related data were collected and analyzed to reach at the optimal solution. For data collection the major processes were broken up into subprocesses or work elements and placed in sequence. The following steps will be used to analyze and improve the assembly line condition:

- Step 1: Selection of crucial variables which may create waste.
- Step 2: Focusing on root cause analyses for the parameters, which are responsible for waste or rejection of switch.
- Step 3: Proposing the solutions and ideas to the various problems/parameters found during root cause analysis step.
- Step 4: Development and implementation of proposed solutions and ideas online.
- Step 5: Collection of new results/data on various workstations under consideration.
- Step 6: Comparison 'before and after' improvement condition.
- Step 7: Making recommendations about moving with proposed solutions or for any further improvements.

5 Objectives

In order to improve quality and productivity performance in assembly line, the following may be considered as objectives of the study:

1. To note down the latest working performance of the company regarding the specified product.
2. To identify the problems leading to quality issues in assembly line, 'which leads to rejection'.
3. To develop and implement the possible solutions of the various identified problems and their analysis.

6 Experimental Work

Head lamp leveling switch (HLSS) is produced on assembly line where workers and machinery are arranged strategically in straight line, and it moves down from one station to the next until product is finally assembled. Presently, seven operators are arranged to perform the different activities in line, shown in process flow diagram (refer Fig. 2).

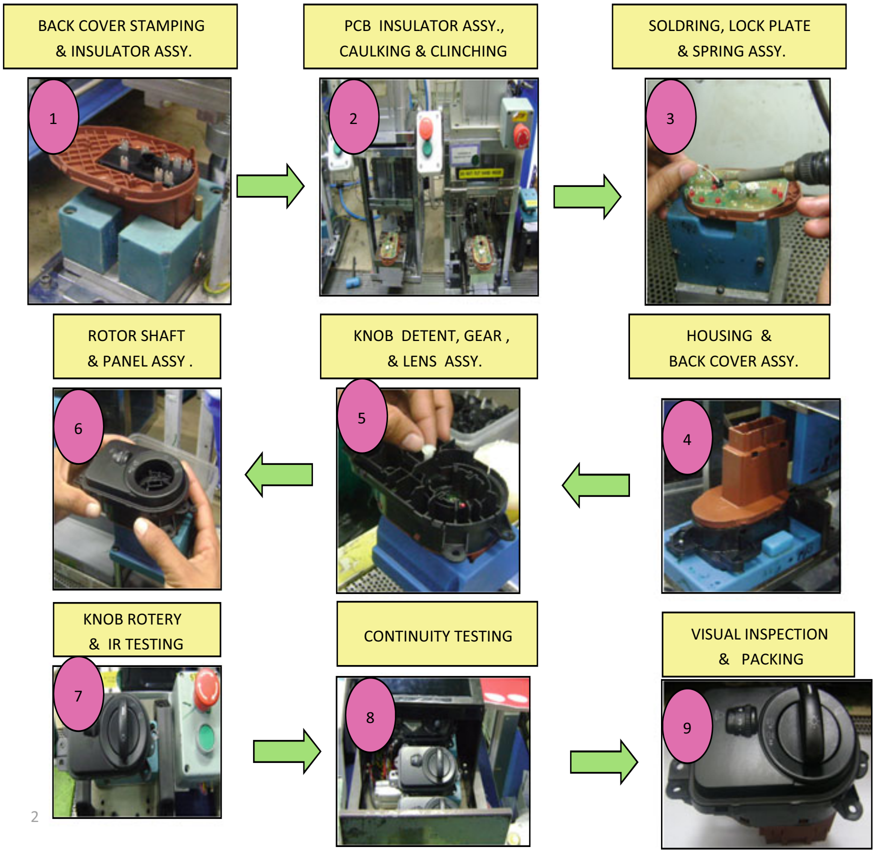


Fig. 2 Process flow diagram

7 Measurement Phase

7.1 Objective 1: To Note Down the Latest Working Performance of the Company Regarding the Specified Product

Accurate data collection is essential to maintain the integrity of research and to reduce the occurring errors. In the context of the above, the following may be listed as outcome of this phase:

- 1* Line production: 450 switches/shift.
- 2* Number of operators in line: 7
- 3* Rejection: average 13 switches in a shift at all locations, in which six switches are rejected while performing caulking process.

- 4* So, the actual line production is less than 450 switches.

7.2 Objective 2: To Identify the Problems Leading to Quality Issues in Assembly Line, 'Which Leads to Rejection'

Problem identified during analysis phase: Skipping of caulking process, which leads to rejection of 'head lamp leveling' switch (HLSS) in assembly line.

Root Cause Analysis Phase for the Problem: Skipping of Caulking Process
After critical examination of the data collected from different sources, it was found that the sequence of operations is:

1. Caulking process
2. Clinching process.

For these two processes the two fixtures are used which work independently. But, if due to any reason if the caulking process skips, then there is no facility to identify this problem. Owing to this reason the faulty product keeps moving ahead in the assembly line covering different working stations. Finally, during quality check it gets rejected. Therefore, root causes of the problems are as follows:

- Fatigue of the worker
- No checking facility after the caulking process.

7.3 Objective 3: To Develop and Implement the Possible Solutions of the Various Identified Problems

In order to eliminate the problem of operation skip, a lean technique prevention Poka-yoke can be used. Poka-yoke is one of the tools that use the zero-defect principle. The goals of Poka-yoke lean technique are:

- To identify the defective parts immediately at the source itself,
- To detect the reason/cause of the defect, and
- To stop the motion of the defective parts to the next workstation of the assembly line.

Examples of Common Mistake-Proofing Methods

- Color or shape coding
- Use of symbols and/or icons
- Use of computerized checklists
- Use of flags and counters.

So, taking the reference of the above table and above examples, for achieving the zero-defect condition, that is, 'No operation skip', we will use a PLC program, which will *synchronize* the fixtures. If the caulking operation is performed as per the requirement, the product will move for the clinching operation, but if the caulking operation is missing, then the component will not move to the next stage for operation. This will remove the problem of missing of caulking operation.

Now the effects of the solution can be explained with the help of two diagrams taken from the assembly line. One diagram explains the condition before implementing the solution, while the other diagram explains the condition after implementing the solution.

Operation Sequences Before Synchronization of the Fixtures

Before synchronization of the fixtures, operations are performed independently on both the fixtures. The sequences are given as follows:

1. Locater will go inside below the tool.
2. Tool will go down for operation.
3. Tool will go up after completion of the operation.
4. Locater will go outside for holding next piece.

These sequences are common for both the fixtures. This assembly line diagram shows the condition before implementing the solution. This diagram explains nicely the condition of skipping of the caulking process during the assembly of head lamp leveling switch. In this condition caulking and clinching fixture works independently. So, the possibility of skipping the operation is there (refer Fig. 3).

Operation Sequences After Synchronization of the Fixtures

The sequences after synchronization of caulking and clinching fixtures are given below:

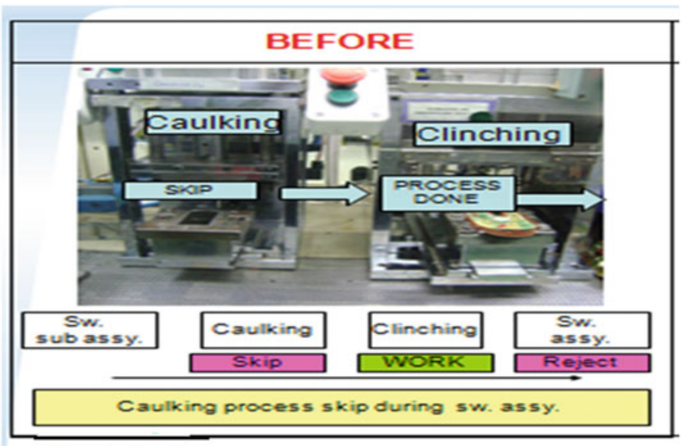


Fig. 3 Caulking and clinching process (before condition)

At caulking fixture, four designated sequences A^-, B+, B^-, and A+ are performed, which are explained below:

1. First sequence, locater will go inside with PCB below the caulking tool. This condition or sequence is designated by A^-.
2. Second sequence, caulking tool will go down for caulking operation. This condition or sequence is designated by B+.
3. Third sequence, caulking tool will go up after performing the caulking operation. This condition or sequence is designated by B^-.
4. Fourth sequence, locater after completion of the operation will go outside. This condition or sequence is designated by A+.

After completion of the caulking process at caulking fixture, the same sequences will be repeated for clinching operation at clinching fixture. These are explained below:

1. First sequence, locater will go inside with PCB below the clinching tool. This condition or sequence is designated by A^- at clinching fixture.
2. Second sequence, clinching tool will go down for clinching operation. This condition or sequence is designated by B+ at clinching fixture.
3. Third sequence, clinching tool will go up after performing the clinching operation. This condition or sequence is designated by B^- at clinching fixture.
4. Fourth sequence, locater after completion the operation will go outside. This condition or sequence is designated by A+ at clinching fixture.

Now after synchronization the fixtures clinching process can be performed only if caulking process has completed at caulking fixture. This will help in prevention of skipping of caulking process (refer Fig. 4).

This assembly line diagram shows the condition after implementing the proposed solution. This diagram explains that when CI method of Poka-yoke technique (PLC program) is implemented, the problem of skipping the caulking process has been removed.

8 Conclusion

This research was focused on emphasizing the elimination of waste in all forms. When waste elimination is the goal, the results are an improvement in customer service, efficiency, and the quality of the products. Lean concepts were used to explore the problems in assembly line and by using tools like Kaizen, 5S, and Poka-yoke, delay time and rejection has reduced to lower value. A successful lean effort has a significant impact on the organization performance. The graph given below shows the rejection per shift before and after implementing the solution. After implementing the solutions switch rejection gap has been reduced from 6 to 0 in a shift of 7.5 h (refer Fig. 5).

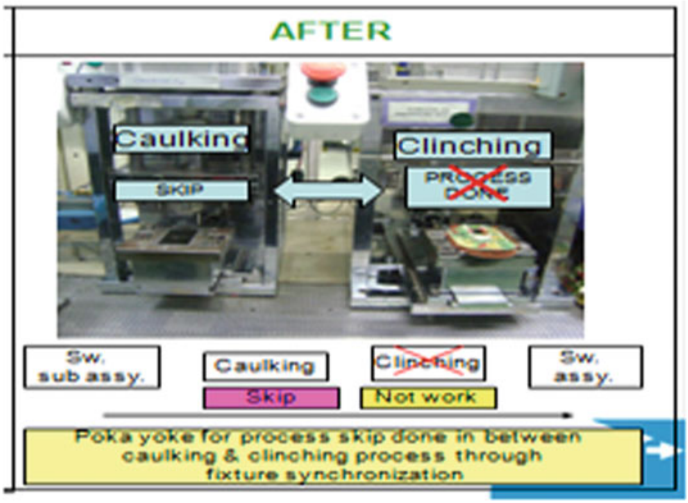
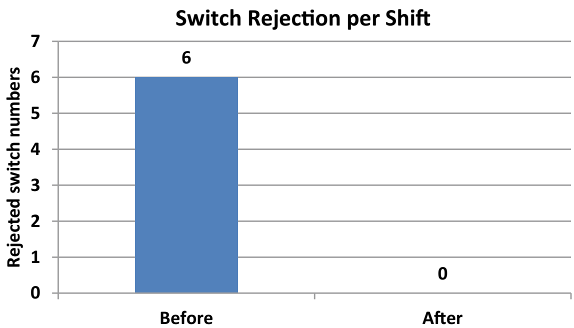


Fig. 4 Caulking and clinching process (after condition)

Fig. 5 Rejection before and after improvement



References

1. Pool, A., Wijngaard, J., Van der Zee, D.J.: Lean planning in the semi-process industry—a case study. Int. J. Product. Econ. **131**, 194–203 (2011)
2. Demeter, K., Matyusz, Z.: The impact of lean practices on inventory turnover. Int. J. Product. Econ. **133**, 154–163 (2011)
3. Kumar, A.: Removing the problem of locking not good in assembly of lever combination switch using continuous improvement process. Int. J. Manuf. Technol. Manage. **31**(5), 424–435 (2017)
4. Losonci, D., Demeter, K., Jenie, I.: Factors influencing employee perceptions in lean transformations. Int. J. Product. Econ. **131**, 30–43 (2011)
5. Eroglu, C., Hofer, C.: Lean, linear, too lean, the inventory-performance link revisited. J. Oper. Manage. **29**, 356–369 (2011)
6. Faye, H., Falzon, P.: Strategies of performance self-monitoring in automotive production. Appl. Ergon. **40**, 915–921 (2009)

7. Lockstorm, M., Schadel, J., Harrison, N., Moser, R., Malhotra, M.K.: Antecedents to supplier integration in the automotive industry: a multiple case study of foreign subsidiaries in China. J. Oper. Managag. **28**, 240–256 (2010)
8. Shahin, A., Ghasemaghaei, M.: Service Poka Yoke. Int. J. Market. Stud. **2**(2), 190–201 (2010)
9. Saurin, T.A., Ferreira, C.F.: The impacts of lean production on working conditions: a case study of industry a harvester assembly line in Brazil. Int. J. Ind. Ergon. **39**, 403–412 (2009)
10. Bhawesh Kumar, R., Kumar, P.: Implementation of Poka Yoke in needle bearing assembly process. Int. J. Eng. Sci. Invent. **6**(11), 01–10 (2017). ISSN (Online): 2319–6734
11. Premanand, N., Kannan, V., Sangeetha, P., Umamaheswari, S.: A study on implementation of Poka–Yoke technique in improving the operational performance by reducing the rejection rate in the assembly line. Int. J. Pure Appl. Math. 119(17), 2177–2191 (2018). ISSN: 1314–3395

Modeling and Control of Arc Welding Processes Using Artificial Neural Networks

Rudra Pratap Singh, Aman Singh, Somil Dubey, and Subodh Kumar

Abstract The strength of artificial neural networks (ANN) for prediction of output welding process parameters for given input welding process parameters is shown in this work. Some important concepts of ANN are discussed. A model for weld bead geometry relating to input process parameters is made with the help of a computer program in C++. Feed-forward back propagation algorithm of ANN is used in this work. Real TIG welding data are used for the evaluation of the performance of the ANN. After comparison of the experimental dimensions with the predicted dimensions of the weld bead geometry, it is concluded that the ANN model is capable of forecasting the output parameters accurately if the input welding parameters are known.

Keywords Artificial neural networks · TIG welding · C++ · Weld · Model · Data · Back propagation · Feed forward

1 Introduction

The arc welding processes are nonlinear and have multi-variables. There is no formula that expresses exact relationship between the input and output welding parameters [1, 2]. In several cases the welding variables that can affect the output structure and properties of the weld are not recognized. The variables are mainly welding current, welding voltage, speed of welding, environmental conditions, structure of the work pieces, electrode or wire feed rate, electrode angle, electrode diameter and so on. All these variables cannot be controlled in efficient way simultaneously [2]. All these factors make the welding process a difficult one. There is no equation that can represent the exact relationship between the input and output welding parameters [3]. The experience and the knowledge of the human welder can provide the effective way of proper welding. Artificial neural networks approach which is used in this work is helpful for the optimum or required output. Real welding data of gas tungsten

R. P. Singh · A. Singh (✉) · S. Dubey · S. Kumar
Department of Mechanical Engineering, GLA University, Mathura 281406, India
e-mail: aman.singh_me17@gla.ac.in

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_68

arc welding (GTAW) are used for modeling purpose using artificial neural networks in this work. In GTAW a tungsten electrode is used for arc initiation and handling. Tungsten is non-consumable and additional consumable wire is externally supplied using a torch. Inert gases like argon or helium are used as shielding gases to safeguard the weld from the atmospheric gases. It has been shown that dimensions of weld bead are related to its mechanical properties [4]. The main dimensions of bead are depth of penetration, weld width and reinforcement height, whereas the main mechanical properties of weld are hardness, tensile strength and impact strength. The dimensions of weld bead are primarily governed by input welding process parameters in which current, voltage, feed rate of wire and speed of welding are very important. The effect of individual welding parameter on output parameters is very important but the degree of effect of any parameter is unknown as it varies differently in different conditions [5–9]. All these conditions make the relation between the input and output parameters as multi-variable. To find the solution of unknown multi-variable-type relations, artificial neural networks are used. The model of artificial neural networks is framed with the help of a program in C++. This model can predict the values of output variables if the values of input variables are supplied to this model.

2 Artificial Neural Networks

The artificial neural networks technology was developed to fulfill the desire of performing intelligent tasks as a human brain works [6–10]. ANN works in the same manner as the brain of a person works. A large number of interconnected processing elements like neurons work together to solve a problem. A set of inputs are fed to obtain output values. This output may be input for some other processing. Each input neuron is multiplied by some weight as its synaptic strength. All the weighted inputs are added to know the strength of output variable. The calculation of weights for neurons is difficult but necessary for the formulation of the model. The artificial neural networks acquire knowledge through some learning and the knowledge is stored in the same way as human neurons store information [7]. ANN has a quality of adaptive learning, self-organization and real-time operation, which may be supervised or unsupervised. During the learning process, global information is required. In this work feed-forward back propagation is used to predict the structure of the weld. In feed-forward system signals travel in one direction but feedback system travels in both the directions. Input layers receive the input parameters, the hidden layers are like black boxes and output layers obtain the values of bead geometry and mechanical properties. The performance of neural networks depends upon the number of hidden layers and number of neurons in the hidden layers which forces us to obtain optimized structure [8–12]. According to the generalized delta rule the back propagation is a form of supervised learning in the case of multi-layered networks [9]. During training the data must be normalized. The artificial neural networks work better in the range of 0 and 1, hence the normalized value X_n, actual input or output value X and maximum value of the inputs or output $X_{\max}$ are related as

$$X_n = (X)/(X_{\max}) \tag{1}$$

3 Formulation of Artificial Neural Networks Program Using Back Propagation Algorithm

The algorithm for feed-forward back propagation is given in the following:

I In the first step normalize the inputs and outputs with respect to their maximum values. Assume that there are 'l' inputs and n outputs in normalized forms.

II The number of neurons in the hidden layer is considered in between l and $2l$. Here x_i and y_i represent the neurons to input and output layers, respectively, y_{is} represents the sigmoidal output of input layer which may be input to the first hidden layer, Y_i represents the neurons of output of first hidden layer and Y_{is} represents that of sigmoidal output of first hidden layer which may be the input to the second hidden layer. $Z_{i,}$ and Z_{is} represent the neurons of output and sigmoidal output layers, respectively.

III The weights of synapses connecting input neurons to first hidden neurons, first hidden neurons to second hidden neurons and second hidden neurons to output neurons are represented by $[W]$, $[V]$ and $[U]$, respectively. Sigmoidal gain 'λ' is assumed as 1 and threshold value 'θ' is taken as zero. Momentum coefficient 'α' is assumed to be zero.

$$\text{Here } [W] = [V] = [U] = \left[\text{any random number}\right] \tag{2}$$

IV Training of data is done by using one set of inputs and outputs. Then present the inputs to the input layer. The output of the input layer may be evaluated.

V Calculation of inputs to the first hidden layer is done by multiplying corresponding weights of synapses as

$$y_i = \sum X_i W_{ij} \tag{3}$$

VI The output of the first hidden layer is written as a sigmoidal function as

$$y_{is} = 1/\left(1 + e^{-yi}\right) \tag{4}$$

This is actually the input for the second hidden layer.

VII Calculation of output to the second hidden layer is done by multiplying corresponding weights of synapses as

$$Y_i = \sum y_{is} V_{ij} \tag{5}$$

VIII Output of the second hidden layer is written as a sigmoidal function as

$$Y_{is} = 1/\left(1 + e^{-Yi}\right) \quad (6)$$

This is taken as the input for output layer.

IX Calculation of the outputs to the output layer is done by multiplying corresponding weights of synapses as

$$Z_i = \sum Y_{is} U_{ij} \quad (7)$$

X The sigmoidal function is used to evaluate the output by output layer units as

$$Z_{is} = 1/\left(1 + e^{-Zi}\right) \quad (8)$$

This is the network output.

XI The difference between network output and the desired output for the *i*th training set is expressed as

$$e_i = Z_{is}(1 - Z_{is})(Z_{it} - Z_{is}) \quad (9)$$

In the second hidden layer this error is used for the calculations.

XII Calculation of error for output and second hidden layer for the *i*th training set is done as

$$t_i = Y_{is}(1 - Y_{is}) \sum e_i U_{ij} \quad (10)$$

This error is used for back propagation calculation work in the second hidden layer.

XIII Calculation of the error for second hidden layer and input layer for the *i*th training set is done as

$$T_i = y_{is}(1 - y_{is}) \sum t_i V_{ij} \quad (11)$$

The error for back propagation calculation work in the first hidden layer can be done by this equation.

XIV Calculation of small changes in weight values is done as

$$\delta U_{ij} = \beta Y_i e_i \quad (12)$$

$$\delta V_{ij} = \beta y_i t_i \quad (13)$$

and

$$\delta W_{ij} = \beta X_i T_i \quad (14)$$

In the above equation β is known as learning rate coefficient.

XV Calculation of new values of weights is done as.

$$\text{New } U_{ij} = \text{Old} U_{ij} + \delta U_{ij} \quad (15)$$

$$\text{New } V_{ij} = \text{Old} V_{ij} + \delta V_{ij} \quad (16)$$

$$\text{New } W_{ij} = \text{Old } W_{ij} + \delta W_{ij} \quad (17)$$

XVI Checking is done whether the required number of iterations have been completed or not. If it is yes, then this indicates that the modified weights are obtained, and the training of data is completed. If it is no, then follow step number V.

4 Construction of Computer Program

The main computer program is made with the help of C++. Multi-layered feed forward network is developed and trained using back propagation algorithm. The program is trained with 16 sets of experimental input–output data. Input data are current, voltage, speed of welding and feed rate but the output data are weld width, depth of penetration and reinforcement height. Figure 1 shows the weld obtained by TIG welding process. From the experiments these values are obtained and fed to the program to train it. Seven other such sets obtained from experimental data are used to verify the program. In verification the result of experiments is compared with that of the program and an error is seen. If the error is negligible the program is verified.

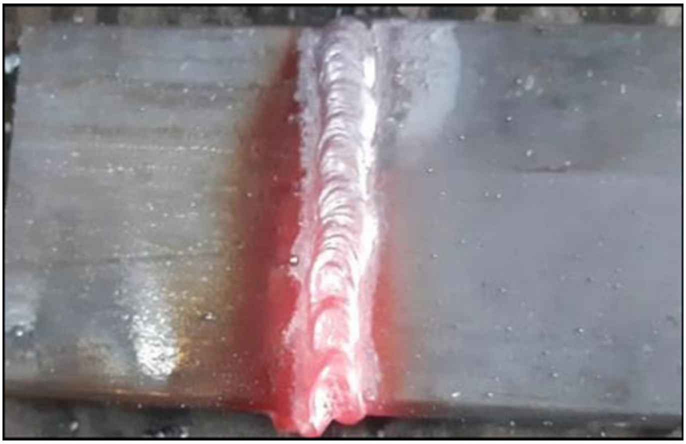


Fig. 1 Weld obtained by TIG welding process

The assumed artificial neural network contains one input layer with four neurons, one output layer with four neurons and two hidden layers each with five neurons. Every neuron of input layer has relation with every neuron of the first hidden layer. This relationship can be represented by some weight. These weights are represented by W11, W12, W13, W14 and W15. In the same way, second neuron has weights with the neurons of first hidden layer as W21, W22, W23, W24 and W25. Similarly, the weights for third and fourth neurons of the input layer with the neurons of the first hidden layer can be written as W31, W32, W33, W34, W35; W41, W42, W43, W44 and W45. Similarly, the neurons of the first hidden layer will have weights with the neurons of the second hidden layer in terms of V and the neurons of the second hidden layer will have weights with the neurons of the output layers in U terms. This indicates that every neuron has relation with other neurons in the program. Initial weights are taken randomly which are refined with iterations. In this work a sigmoidal function is used whose value varies in between the two asymptotic 0 and 1 or −1 and is given by Eq. (18), where λ is the sigmoidal gain which is used to adjust the abruptness of the function.

$$y_{is} = 1/\left(1 + \mathrm{e}^{-\lambda yi}\right) \tag{18}$$

The small changes in weight values can be adjusted by coefficient of learning rate β. The size of weight adjustments made in iterations is determined by β. This also influences the rate of convergence. We have considered its value as 0.9.

5 Training and Validation of ANN Program for Weld Bead Structure

Forty-six mild steel plates of 75 mm × 50 mm × 6 mm were cut with the help of a hack saw to weld 23 pairs with TIG welding machine. The values of current, voltage, speed of welding and feed rate were noted in every case. Clamp meter was used to measure current but the multi-meter was used to measure voltage. Every weld bead was sectioned transversely to have a 10 mm thick welded portion in the middle. Grinding of these portions was done with emery belt grinder with 0, 2 and 3 grade emery papers. A double-disk polishing machine was used for polishing purpose. The etching of polished surfaces was done using a mixture having 2% nitric acid and 98% ethyl alcohol solution. The weld width, depth of penetration and reinforcement height were measured using a digital slide caliper. These values were noted for every weld. Sixteen such sets as shown in Table 1 were used to train the program. Another seven set of such sets were used for testing and verification of the program. If the error in prediction by ANN program is negligible, the program is verified.

Table 1 Welding data for training the ANN program

S. no.	*I* (A)	*V* (V)	*W* (mm/s)	*F* (mm/s)	BW (mm)	DOP (mm)	RH (mm)
1	150	9.5	1.90	2.10	6.96	2.61	0.38
2	150	9.5	1.90	4.20	7.05	2.71	0.65
3	150	9.5	1.90	6.30	6.94	2.64	0.87
4	150	9.5	1.90	8.40	6.89	2.48	1.03
5	150	9.5	2.80	4.20	6.82	1.94	0.48
6	150	9.5	2.80	6.30	7.24	2.01	0.61
7	150	9.5	2.80	8.40	7.06	1.84	0.79
8	150	9.5	1.40	2.10	7.46	3.22	0.43
9	200	10.0	2.10	16.90	11.10	1.12	1.19
10	200	10.0	2.70	12.70	9.46	1.59	0.84
11	200	10.0	2.70	16.90	9.59	0.89	1.06
12	200	10.0	2.70	8.40	9.32	2.29	0.64
13	100	9.0	1.10	8.40	5.36	1.44	1.89
14	100	9.0	1.80	4.20	5.71	1.74	0.69
15	150	9.5	2.80	10.50	6.07	1.95	0.98
16	150	9.5	1.40	6.30	7.56	2.87	0.96

6 Results and Discussion

Artificial neural networks program in C++ was framed. This program has a quality of self-improvement by correcting the weight in required number of iterations. Current, voltage, speed of welding and feed rate can be fed in this program as input data and at the same time weld width, depth of penetration and reinforcement height can be fed as output data. The initial weights can be taken randomly of any value from 0 to 1. The training can be done using some sets of such input–output data. After training, the program can be used to predict the output values if input values are fed. The strength of this program depends upon the quality of training performed. The present developed program is a powerful program which can predict correctly as shown in Table 2.

1. If input current is 150 A, voltage is 9.5 V, speed of welding is 1.40 mm/s and wire feed rate is 4.28 mm/s, the error in prediction of weld width is only 0.39%, error in prediction of depth of penetration is only 0.64% and the error in prediction of reinforcement height is only 3.17%.
2. If input current is 100 A, voltage is 9.0 V, speed of welding is 1.90 mm/s and wire feed rate is 2.10 mm/s the error in prediction of weld width is only 7.69%, error in prediction of depth of penetration is only 1.55% and the error in prediction of reinforcement height is only 4.54%.
3. If input current is 100 A, voltage is 9.0 V, speed of welding is 1.90 mm/s and wire feed rate is 4.20 mm/s, the error in prediction of weld width is only 1.06%, error

Table 2 Welding data for testing and verification of the ANN program

S. no.	*I* (A)	*V* (V)	*W*	*F*	BW (mm)			DOP			RH		
					E	*P*	PE	*E*	*P*	PE	*E*	*P*	PE
1	150	9.5	1.40	4.23	7.58	7.61	0.39	3.10	3.08	0.64	0.63	0.65	3.17
2	100	9.0	1.90	2.10	5.59	6.02	7.69	1.29	1.31	1.55	0.66	0.69	4.54
3	100	9.0	1.90	4.20	5.66	5.60	1.06	1.85	1.89	2.16	1.09	1.13	3.66
4	100	9.0	1.90	8.40	5.78	5.75	-0.5	5.78	5.99	3.63	2.13	2.15	0.93
5	200	10.0	2.80	6.30	7.80	7.77	-0.3	7.80	7.20	7.69	0.44	0.47	6.81
6	200	10.0	2.80	8.40	8.09	8.54	5.56	8.09	8.45	4.44	0.53	0.56	5.66
7	200	10.0	2.80	14.80	8.27	8.34	0.84	8.27	8.37	1.20	0.75	0.77	2.66

I current (A), *V* voltage (V), *W* travel speed (mm/s), *F* feed rate (mm/s), *BW* bead width (mm), *DOP* depth of penetration (mm), *RH* reinforcement height (mm), *E* experimental value (mm), *P* predicted value by ANN (mm), *PE* percentage error in prediction

in prediction of depth of penetration is only 2.16% and the error in prediction of reinforcement height is only 3.66%.

4. If input current is 100 A, voltage is 9.0 V, speed of welding is 1.90 mm/s and wire feed rate is 8.40 mm/s, the error in prediction of weld width is only −0.51%, error in prediction of depth of penetration is only 3.63% and the error in prediction of reinforcement height is only 0.93%.
5. If input current is 200 A, voltage is 10.0 V, speed of welding is 2.80 mm/s and wire feed rate is 6.30 mm/s, the error in prediction of weld width is only −0.38%, error in prediction of depth of penetration is only 7.69% and the error in prediction of reinforcement height is only 6.81%.
6. If input current is 200 A, voltage is 10.0 V, speed of welding is 2.80 mm/s and wire feed rate is 8.40 mm/s, the error in prediction of weld width is only 5.56%, error in prediction of depth of penetration is only 4.44% and the error in prediction of reinforcement height is only 5.66%.
7. If input current is 200 A, voltage is 10.0 V, speed of welding is 2.80 mm/s and wire feed rate is 14.80 mm/s, the error in prediction of weld width is only 0.84%, error in prediction of depth of penetration is only 1.20% and the error in prediction of reinforcement height is only 2.66%.

From the above discussion it is clear that the framed ANN program is capable of prediction of almost exact bead dimensions.

7 Conclusion

The maximum error in prediction of weld bead was 7.69%, in depth of penetration was also 7.69% and that in reinforcement height was 6.81%. The other errors were less than these values. This shows the strength of this program for prediction. This program can also be used for any input–output system, which has four types of inputs that affect the values of three outputs. The program can predict the bead dimensions as weld width, reinforcement height and depth of penetration accurately if the current, voltage, welding speed and feed are known in tungsten inert gas welding or any other similar welding processes.

References

1. Cook, G.E.: Feedback and adaptive control in automated arc welding systems. Metal Constr. **13**(9), 551–556 (1981)
2. Andersen K., Barnett, R.J., Cook, G.E., Ramaswamy, K., Prasad, T.: Intelligent gas tungsten arc welding control. In: Phase I SBIR including arc welding control and robotics for final report to NASA-MSFC, Sept 1987
3. Prasad, T., et al.: Computer implementation and study of a weld model. In: Proceedings of the IEEE Southeastcon 89, vol. 2, pp. 517–521. Columbia, SC, 9–12 Apr 1989
4. Bates, B.E., Hardt, D.E.: A realtime calibrated thermal model for closed loop weld bead geometry control. Trans. ASME J. Dyn. Syst., Meas. Contr. 25–33 (1985)
5. Hardt, D.E., Garlow, D.A., Weinert, J.B.: A model of full penetration arc welding for control system design. Trans. ASME, J. Dyn. Syst. Meas. Contr. 40–46 (1985)
6. Eraslan, A.H., Zacharia, T., Aidun, D.K.: WELDER: a computer code for simulating fast-transient, three-dimensional, three-phase, flow, temperature and material composition conditions during welding. Department of MIE, Clarkson University, Potsdam, NY, Report MIE-142, Oct 1986
7. Hopfield, J.J.: Neural networks and physical systems with emergent collective computational abilities. Proc. Natl. Acad. Sci. **79**, 2554–2558 (1982)
8. Lippmann, R.P., Gold, B., Malpass, M.L.: A comparison of Hamming and Hopfield neural nets for pattern classification. MIT Lincoln Laboratory, Technical report, TR-769. Rumelhart, D.E., Hinton, G.E., Williams, R.J.: Parallel Distributed Processing, vol. 12. MIT Press, Cambridge, MA (1986)
9. Karsai, G., Andersen, K., Cook, G.E., Ramaswamy, K.: Dynamic modeling and control of nonlinear processes using neural network techniques. In: Proceedings of the IEEE'89 Symposium on Intelligent Control, pp. 280–286. Albany, NY, Sept 25–26 (1989)
10. Kumar, D., Phanden, R.K., Thakur, L.: A review on environment friendly and lightweight magnesium-based metal matrix composites and alloys. Mater. Today Proc. (2020)
11. Kataria, R., Singh, R.P., Sharma, P., Phanden, R.K.: Welding of super alloys: a review. Mater. Today: Proc. (2020)
12. Phanden, R.K., Gupta, R., Gorrepati, S.R., Patel, P., Sharma, L.: ANN based robust bidirectional charger for electric vehicles. Mater. Today Proc. (2020)

Influence of Process Parameters on Reinforcement Height of Tungsten Inert Gas Welded Joints for Low Carbon Steel AISI 1010 Plates

Rudra Pratap Singh, Ashu Kumar Verma, Abhishek Mishra, and Abhishek Chauhan

Abstract In the present work, tungsten inert gas welding process was used to analyze the effects of input process parameters on reinforcement height of weldment. The input process parameters were used as current, voltage, speed of welding and the feed rate. Low carbon steel AISI 1010 plates of dimensions 75 mm × 50 mm × 5 mm were used to obtain the weld. Totally, 16 pairs of plates were welded to obtain 16 welds using tungsten inert gas welding process. At first, current, voltage and speed of welding were kept at constant values and the feed rate was varied one by one as 2.12, 4.23, 6.35 and 8.47 mm/s, respectively, for four welds. In each case the reinforcement height was measured. This was used to investigate the effect of feed rate on reinforcement height. In the similar manner, other three sets, each having four welds were used to investigate the effect of welding speed, welding voltage and welding current on reinforcement height, respectively, by keeping other variables at some fixed values. The results were tabulated and were expressed in four diagrams to investigate the effect of feed rate, welding speed, welding voltage and welding current on reinforcement height in each case. It is concluded that the reinforcement height increased with increase of current, voltage and feed rate and decreased with welding speed.

Keywords Tungsten inert gas welding · Reinforcement height · Weld bead · Input process parameters · Travel speed · Welding torch

1 Introduction

Welding is used to join different materials permanently in which at the interface of the workpieces, melting and solidification take place. There are several methods of welding, in which some use and some do not use filler materials [1]. Tungsten inert gas welding is used to join the materials sometimes with and sometimes without filler materials [2]. The aim of formation of any joint is to make it strong enough to

R. P. Singh · A. K. Verma (✉) · A. Mishra · A. Chauhan
Department of Mechanical Engineering, GLA University, Mathura, Uttar Pradesh 281406, India
e-mail: ashu.verma_me17@gla.ac.in

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_69

sustain the loads applied on it. If we consider different joining processes, welding is the cheapest of all [3]. All the materials cannot be welded by a single method as the weldability of different materials differs with the applied welding process. Therefore, the different welding processes are used in the manufacturing and general machine repair work [4]. During welding very high temperature is developed, so if non-consumable electrode is to be used a material having very high melting point is required [5]. Tungsten has very high melting point and will not melt during welding. The process in which tungsten is used as an electrode is known as tungsten inert gas welding process. In this process a mixture of argon and helium gases is used to form a shielding atmosphere to protect the weld metal from atmospheric gases. At high temperature the atmospheric gases may react with the hot weld metal and form contaminations [6]. Very sensitive materials which cannot be welded with other processes can be welded efficiently using tungsten inert gas welding process due to strong shielding atmosphere. During Second World War this process was developed to weld aluminum, magnesium, stainless steel and mild steel efficiently [7]. Tungsten inert gas welding process generally works on constant current characteristics as in manual welding the control over voltage is difficult, so constant voltage process becomes difficult [8]. If the tungsten electrode is connected to negative terminal of DC current supply, the heat received by the electrode is only 30% of total heat generated and life of electrode is more [9]. The main input welding parameters are welding current, voltage, speed of welding and feed rate. These parameters control the structural and mechanical properties of the weld. If voltage is increased the arc length increases and weld width also increases. The welding current has direct effect on heat supplied to the weld area and depth of penetration. Speed of welding reduces the heat input and feed rate affects the volume deposited on bead. The mechanical properties depend on the structure of the weld. The macroscopic structural output parameters of welding are weld width, depth of penetration and reinforcement height. Reinforcement height should be optimum. It should not be very large to reduce the stress concentration, but metallurgical concept allows the large value of the reinforcement height [10, 11]. In this way the determination of optimum reinforcement height is very important and should be researched.

2 Experimental Procedure

The experiments were performed in the welding science and technology lab of the GLA University, Mathura. The welding of specimens was done with the help of a tungsten inert gas welding process. The specimen pieces were cut from a large thin low carbon steel AISI 1010 plates having 50 mm width and 5 mm thickness, with the help of a power hack saw. The dimensions of the specimens were taken as 75 mm × 50 mm × 5 mm. The specimens were cleaned with the help of rough and hard papers to remove rust, dust and contaminated surface layers. The sensitivity analysis of the input parameters on the reinforcement height with four input welding parameters requires 16 welded pieces in this work. To obtain 16 welds, 32 pieces,

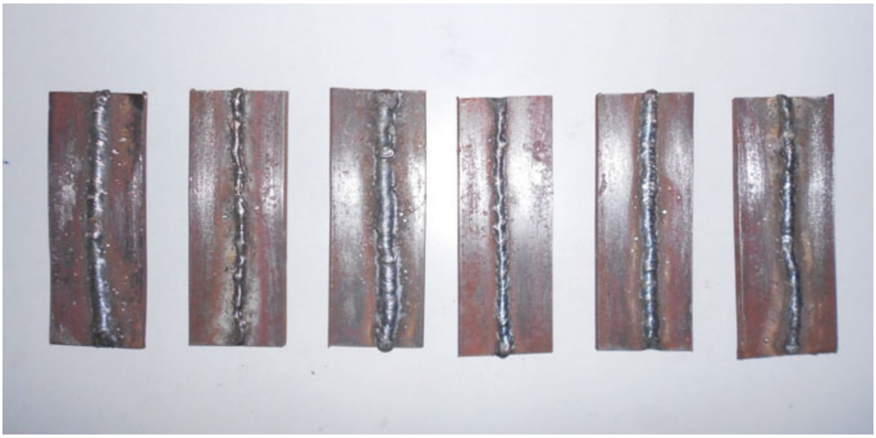


Fig. 1 Sample welded pieces

each of dimensions 75 mm × 50 mm × 5 mm were cut. Two pieces were welded in butt position to obtain the required bead. The used power source was a rectifier from which the power was supplied to the workpieces with the help of a system having torch and tungsten electrode. An electric arc was developed in between the workpiece and the tungsten electrode. The energy was supplied through the arc and a column of highly ionized gas and metal vapors. The temperature of more than 20,000 °C is developed in TIG welding process. The high amount of heat, so developed was used to melt the material and to form the joint. The schematic diagram of a TIG welding system is given in [4], and some welded pieces are shown in Fig. 1.

In this work, four input welding variables selected were current, voltage, speed of welding and feed rate. The sensitivity analysis can be done if all the input parameters are fixed and only one parameter is altered, and the effect of this alteration is analyzed. At first, four sets of welds were obtained by having welding current at 150 A, welding voltage at 9.6 V and welding speed at 1.91 mm/s. Only feed rate was altered as 2.12, 4.23, 6.35 and 8.47 mm/s, respectively, for the welding process. Four sets of welds were obtained by having welding current at 100 A, welding voltage at 9 V and feed rate at 2.12 mm/s. Only welding speed was altered as 1.19, 1.44, 1.82 and 1.91 mm/s, respectively, for the welding process. Four sets of welds were obtained by having welding current at 100 A, welding speed at 1.19 mm/s and feed rate at 8.47 mm/s. Only welding voltage was altered as 9, 9.6, 10 and 10.5 V, respectively, for the welding process. Other four sets of welds were obtained by having welding voltage at 9.6 V, welding speed at 1.44 mm/s and feed rate at 6.35 mm/s. Only welding current was altered as 100, 125, 150, and 200 A, respectively, for the welding process.

The data are arranged in Table 1. After welding, all the weld beads obtained were sectioned transversely at two surfaces in such a way that middle portion, 1 mm thick containing weld, heat-affected zone and base metal were selected for investigation. The welds are generally not proper at the start and at the end of the workpieces due to several reasons, so these portions are removed. The sectioned parts were ground

Table 1 Variation of reinforcement height with current, voltage, speed of welding and feed rate

S. no.	Current (A)	Voltage (V)	Welding speed (mm/s)	Feed rate (mm/s)	Reinforcement height (mm)
1	150	9.6	1.91	2.12	0.38
2	150	9.6	1.91	4.23	0.65
3	150	9.6	1.91	6.35	0.87
4	150	9.6	1.91	8.47	1.03
5	100	9	1.19	2.12	0.60
6	100	9	1.44	2.12	0.55
7	100	9	1.82	2.12	0.47
8	100	9	1.91	2.12	0.45
9	100	9	1.19	8.47	1.90
10	100	9.6	1.19	8.47	1.91
11	100	10	1.19	8.47	1.93
12	100	10.5	1.19	8.47	1.99
13	100	9.6	1.44	6.35	0.79
14	125	9.6	1.44	6.35	0.87
15	150	9.6	1.44	6.35	0.96
16	200	9.6	1.44	6.35	0.98

with the help of emery belt grinders of grades 0, 2 and 3 so that weld bead dimensions become clear and visible. The ground portions were polished with double-disk polishing machine. Etching process was done to the polished pieces with the help of a mixture of 2% nitric acid and 98% ethyl alcohol solution. The reinforcement height was measured for every weld with the help of digital sliding caliper and arranged. The effect of individual parameters on reinforcement height can be easily analyzed, as shown in Table 1.

3 Results and Discussion

The effect of individual parameter on the reinforcement height can be understood with the help of Figs. 2, 3, 4 and 5 and can be summarized as follows.

3.1 Effect of Feed Rate on Reinforcement Height

The measurements of reinforcement height for all the weld beads were done using a sliding digital caliper. The results are written in Table 1. From Table 1, the sensitivity analysis was done. If the input current, input voltage and welding speed were fixed

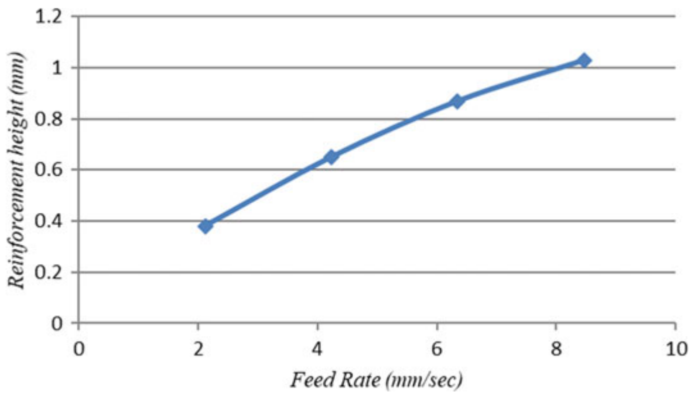


Fig. 2 Effect of feed rate on reinforcement height

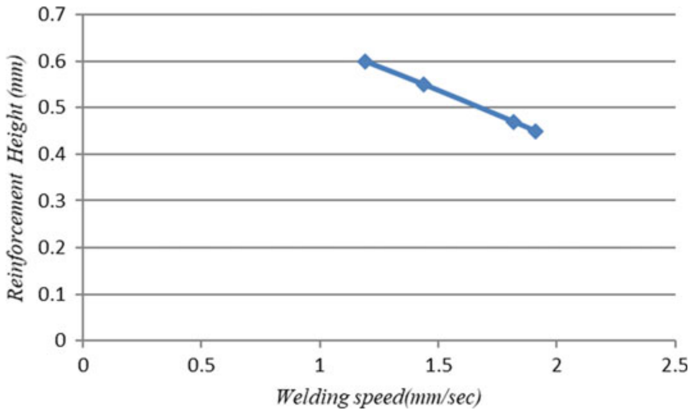


Fig. 3 Effect of welding speed on reinforcement height

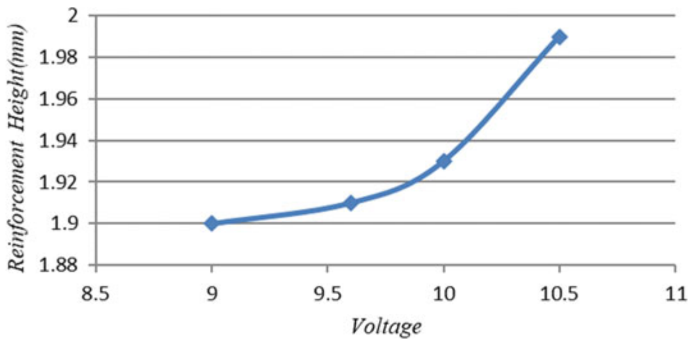


Fig. 4 Effect of voltage on reinforcement height

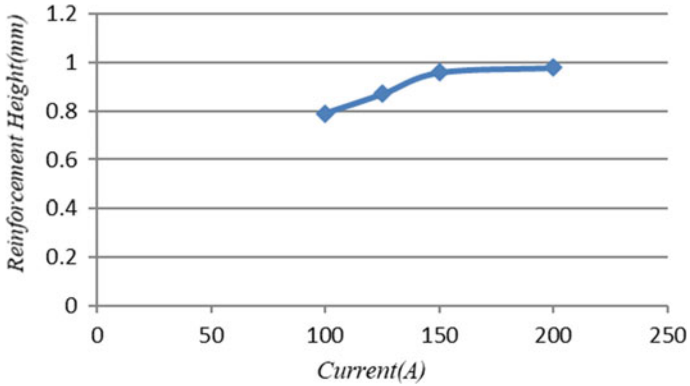


Fig. 5 Effect of current on reinforcement height

at 150 A, 9.6 V and 1.91 mm/s, respectively, and only feed rate was increased, then the general trend for all the experiments under our study is that the reinforcement height increased with increase of feed rate. If the feed rate was increased from 2.12 to 4.23 mm/s, the reinforcement height increased from 0.38 to 0.65 mm; if the feed rate was increased from 4.23 to 6.35 mm/s the reinforcement height increased from 0.65 to 0.87 mm; if the feed rate again increased from 6.35 to 8.47 mm/s, the reinforcement height again increased from 0.87 to 1.03 mm. These variations were shown in Fig. 2. Actually, when feed rate increases more electrodes melt per unit time, hence the volume of weldment increases. The input power is proportional to the product of current and voltage and reciprocal to speed of welding. In this case these three variables are fixed at some value, so the net heat per unit time is fixed. If feed rate increases then the same heat is used to melt more volume, hence the temperature of the molten volume becomes lower. Owing to this reason the heat is unable to penetrate to more depth. The volume of weld is the function of product of weld width, reinforcement height and depth of penetration. If the depth of penetration decreases this implies that the product of weld width and reinforcement height will increase, hence increase in reinforcement height is according to the convention.

3.2 Effect of Welding Speed on Reinforcement Height

If welding current, voltage and feed rate were fixed at 100 A, 9 V and 2.12 mm/s, respectively, and only speed of welding was varied, the general trend of change of reinforcement height was its reduction with increase of welding speed. Heat rate can be expressed by the equation:

$$H = \frac{VI}{v} \tag{1}$$

where

H = heat rate in J/mm,
V = welding voltage in Volts,
I = welding current in Amperes,
v = welding speed in mm/s.

This can be explained as if speed of welding increases then the heat rate decreases, and hence melted volume also decreases, which results in reduction of some dimensions of the bead as the volume of weld is proportional to the product of weld width, reinforcement height and depth of penetration. If the speed of welding was increased from 1.19 to 1.44 mm/s, the reinforcement height decreased from 0.60 to 0.55 mm/s; if welding speed was increased from 1.44 to 1.88 mm/s, the reinforcement height decreased from 0.55 to 0.47 mm; if the welding speed was further increased from 1.44 to 1.82 mm/s the reinforcement height further decreased from 0.47 to 0.45 mm. In our selected study range, the reinforcement height decreased with increase of welding speed. This is according to the convention as less volume and heat rate is possessed by the weld in this case resulting in small reinforcement height as the product of the three bead dimensions is proportional to the volume of the bead.

3.3 Effect of Welding Voltage on Reinforcement Height

If the welding current, welding speed and feed rate were fixed at 100 A, 1.19 mm/s and 8.47 mm/s, respectively, and only the value of welding voltage was increased, the change in reinforcement height increased with the increase of voltage for our study range of voltage. When voltage changed from 9 to 9.6 V, the reinforcement height increased from 1.90 to 1.91 mm; if voltage was increased from 9.6 to 10 V the reinforcement height increased from 1.91 to 1.93 mm; if the welding was again increased from 10 to 10.5 V the reinforcement height again increased from 1.93 to 1.99 mm. This can be explained with the help of Eq. (1), according to which as the voltage increases the input heat increases and the volume of melted material increases which results in increase of some dimensions of the bead. As due to the increase of voltage the distance between electrode tip and workpiece increases, hence same heat is distributed at larger area. Actually the arc is in the form of a cone whose vertex lies at the tip of the electrode; hence with the increase of distance between workpiece and the tip of electrode, the surface area covered by molten metal increases, thus depth of penetration does not increase if welding voltage is increased, so reinforcement height increases. This implies that the variation is according to the convention.

3.4 Effect of Welding Current on Reinforcement Height

If the value of welding voltage, speed of welding and feed rate were kept as fixed at 9.6 V, 1.44 mm/s and 6.35 mm/s, respectively, and only the value of welding current was changed, the reinforcement height changed every time. If the current was increased from 100 to 125 A, the reinforcement height increased from 0.79 to 0.87 mm; if current was increased from 125 to 150 A, the reinforcement height increased from 0.87 to 0.96 mm; if the current was further increased from 150 to 200 A, the feed rate again increased from 0.96 to 0.98 mm. This indicates that reinforcement height increases with increase of current for the range of our study. It can be explained that as the current is increased the input heat increases and melted volume increases, so some bead dimensions will increase as the product of the three bead dimensions is proportional to the volume of the bead. This can be explained by Eq. (1), due to increase of current heat rate increases but this heat is more utilized to increase the depth of penetration. The product of depth of penetration, reinforcement height and weld width is proportional to the volume of the weld, so reinforcement height increases, which may be smaller in some cases as in that condition the depth of penetration may increase more. This implies that the variation of reinforcement height with current is according to the convention.

4 Conclusions

From investigations and sensitivity analysis, it is clear that the welding process is a complicated one and there is no exact relationship between input and output variables. Only general trend can be observed. The volume of the weld bead is the function of weld width, reinforcement height and depth of penetration. If this volume increases, all the dimensions may not increase but some increase and some may decrease. The general trend can be concluded as:

(a) Reinforcement height increases if current of welding is increased.
(b) Reinforcement height increases if voltage of welding is increased.
(c) Reinforcement height decreases if speed of welding is increased.
(d) Reinforcement height increases if feed rate is increased.

The strength of any weld is dependent on its reinforcement height, if reinforcement height is very large and it will produce stress concentration, and the weld will be very weak if reinforcement height is very less. The metallurgical consideration says that due to the welding operation some metallic properties may degrade, so to bear larger load larger area is needed. The two different concepts compel us to search an optimum value of the reinforcement height. If optimum value of reinforcement height is obtained, the maximum strength of the weld can be achieved.

References

1. Juang, S.C., Tarng, Y.S.: Process parameter selection for optimizing the weld pool geometry in the tungsten inert gas welding of stainless steel. J. Mater. Process. Technol. **122**, 33–37 (2002)
2. Xi-he, W., Ji-tai, N., Shao-kang, G., Le-jun, W., Dong-feng, C.: Investigation on TIG welding of SiCp-reinforced aluminum–matrix composite using mixed shielding gas and Al–Si filler. Mater. Sci. Eng. A **499**(1), 106–110 (2009)
3. Qinglei, J., Yajiang, L., Puchkov, U.A., Juan, W., Chunzhi, X.: Microstructure characteristics in TIG welded joint of Mo–Cu composite and 18–8 stainless steel. Int. J. Refract. Metal. Hard Mater. **28**(3), 429–433 (2010)
4. Hussain, A.K., Lateef, A., Javed, M., Pramesh, T.: Influence of welding speed on tensile strength of welded joint in TIG welding process. Int. J. Appl. Eng. Res. **1**(3), 518–527 (2010) (Dindigul)
5. Sakthivel, T., Vasudevan, M., Laha, K., Parameswaran, P., Chandravathi, K.S., Mathew, M.D., Bhaduri, A.K.: Comparison of creep rupture behaviour of type 316L (N) austenitic stainless steel joints welded by TIG and activated TIG welding processes. Mater. Sci. Eng. A **528**(22), 6971–6980 (2011)
6. Tseng, K.H., Hsu, C.Y.: Performance of activated TIG process in austenitic stainless steel welds. J. Mater. Process. Technol. **211**(3), 503–512 (2011)
7. Narang, H.K., Singh, U.P., Mahapatra, M.M., Jha, P.K.: Prediction of the weld pool geometry of TIG arc welding by using fuzzy logic controller. Int. J. Eng. Sci. Technol. **3**(9), 77–85 (2011)
8. Karunakaran, N.: Effect of pulsed current on temperature distribution, weld bead profiles and characteristics of GTA welded stainless steel joints. Int. J. Eng. Technol. **2**(12), 1908–1916 (2012)
9. Li, D., Shanping, Lu., Dong, W., Li, D.: Yiyi Li Study of the law between the weld pool shape variations with the welding parameters under two TIG processes. J. Mater. Process. Technol. **212**, 128–136 (2012)
10. Kataria, R., Singh, R.P., Sharma, P., Phanden, R.K.: Welding of super alloys: a review. Mater. Today: Proc. (2020). https://doi.org/10.1016/j.matpr.2020.07.198
11. Kumar, D., Phanden, R.K., Thakur, L.: A review on environment friendly and lightweight magnesium-based metal matrix composites and alloys. Mater. Today Proc. (2020). https://doi.org/10.1016/j.matpr.2020.07.424

Effect of Process Parameters on Spark Energy and Material Removal Rate in Electro-Discharge Machining Process

Rudra Pratap Singh, Ashish Pal, and Deepak Raghuvanshi

Abstract Electro-discharge machining process is a very important non-traditional, cost-effective and non-contact technique of machining electrically conductive materials which are extremely tough, brittle and difficult-to-cut. The material removal takes place electro thermally with the help of several discrete discharges between the work and the electrode. It is used to manufacture complex geometries and intricate shaped sections with very high accuracy. The material removal rate and spark energy both depend on the input process parameters in this process. The efficiency of the machining process can be maximized by optimizing the input process parameters. The material selected for this study was Inconel-925. In this work the effects of input parameters like pulse on time, current and voltage were studied on the metal removal rate and spark energy by applying the sensitivity analysis. This was performed by taking two input parameters as fixed and the third one as varying for all the three input variables. The variations were tabulated, and the graphs were drawn to understand the effect of individual input parameters on the metal removal rate and spark energy. After the sensitivity analysis it was found that metal removal rate in electro-discharge machining process increases with increase in current, increases nonlinearly with increase in voltage and increases with an increment in pulse on time up to a certain limit and then keeps on decreasing.

Keywords Spark energy · Process parameters · Voltage · Current · Pulse on time · Discharge · Sensitivity analysis · Material removal rate

1 Introduction

The continuous increasing demand for advanced materials having special properties requires some advanced methods for machining purpose as these materials are very difficult to be cut. Non-traditional machining processes are generally used to achieve more efficient and accurate machining of workpieces in comparison to that

R. P. Singh · A. Pal (✉) · D. Raghuvanshi
Department of Mechanical Engineering, GLA University, Mathura 281406, India
e-mail: ashish.pal_me17@gla.ac.in

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_70

of the traditional processes. Electro-discharge machining (EDM) process is one of the several non-traditional machining processes which are used to machine very hard materials or to make precise and minute cavities and contours in the materials [1]. These operations are very difficult to be achieved by any conventional methods. This process came in picture after the Second World War in 1940s. Improvement and advancement in the process has continuously been done by the researcher since its inception. The process became more useful with the introduction of Wire EDM in 1970. The EDM process is capable of machining geometrically complex or hard materials such as heat-treated tool steels, composite materials, ceramics, carbides, and so on. EDM plays its vital role in improvement in various fields like sport, medical, aerospace, automotive, communication, biotechnological, optical and R&D. EDM is also known as spark machining and die-sinking. The electro-discharge machining process is used to machine an electrically conductive material with the sparks between the work and the EDM electrode tool [2]. There is no physical contact between the work and the tool, so no mechanical forces, chattering or vibrations are developed in this process. Very small, fragile and delicate products can be machined with the help of EDM without any damage, as due to the absence of any cutting force the induced residual stresses are absent. The workpiece and the electrode tool both are submerged in a dielectric fluid having insulating nature. The process uses both electrical and non-electrical parameters. Some important electrical parameters are peak current, discharge voltage, pulse duration and interval, electrode tool gap, pulse wave form and polarity, whereas the important non-electrical parameters are the flushing action of the dielectric fluid, rotation of electrode tool and properties of the workpieces. Generally, positive electrode polarity is applied in EDM processes to have minimum wearing of electrode tool [3]. If high metal removal rate is required, the negative polarity can be used at the cost of electrode tool wear. The inter-electrode gap of 0.005–0.1 mm is provided as if the two are in contact, so no spark generation will take place. The tool is moved up and down with the help of a servo mechanism as during down period the sparks are generated and during up period the flushing of debris takes place. The dielectric fluid should have flushing capability to flush out the debris; it reduces the temperature around the machined area and provides insulation against premature discharging. Some researchers used gas as dielectric fluid but some favored liquid in place of gas. This is because if spark is generated in the air the erosion is less as due to the electrical discharge some energy is lost [4]. Some researchers favor the use of oxygen as a dielectric fluid. As the oxidation due to the presence of oxygen is increased, it results in increase in the volume removed from the workpiece per discharge cycle. The optimum flushing pressure reduces density of cracks. The temperature rise is very sharp in the machined area where the temperature reaches to 8000–12,000 °C [5]. Nowadays, EDM has emerged as one of the most effective technologies which are widely used to achieve a fine surface finish, accuracy and complexity. A metal removal rate of 245.8 cm^3/h can be achieved using die-sinking EDM [6]. Many experimental researches came to a conclusion that with a significant increase in the discharge energy and the impulse, the metal removal rate keeps on increasing but the surface finish becomes relatively rough and the layer thickness increases [7]. The importance of metal removal rate increases if effectiveness and efficiency of EDM machining process is required. To achieve maximum benefits from the electro-discharge machining process the optimization of EDM parameters is required [4]. Though the MRR is affected by all process parameters but spark energy is mainly responsible for producing ample amount of heat which also affects the MRR indirectly. The EDM process has multiple industrial applications, like production of injection molds and dies for mass production of objects in electronic and telecommunication, domestic applications, watches and aeronautics [6]. For proper optimization of metal removal rate, the tool wear ratio, surface finish and the material removal should be carried out in several stages [8–10].

2 Experimental Procedure

Electro-discharge machining process is one of the several such machining processes in which the tool and the workpieces do not come in contact with each other while working. The electro-discharge machining setup used for experimental work in GLA University, Mathura is shown in Fig. 1. Different parameters of electro-discharge machining process, namely pulse on time, current and voltage, were used in this work for sensitivity analysis. These parameters were varied at different levels and were analyzed for their effects on MRR and spark energy. A dielectric fluid was used to create a non-conducting gap between the electrodes. This fluid was also used for flushing off the eroded solid debris and spark gap region during machining operation. The dielectric fluid also maintains the temperature well below the flash point. When an appropriate potential difference is applied across the tool electrode (which is mostly cathode) and the workpiece (which is mostly anode) on control panel of EDM, initially dielectric material resists the flow of electrons, but after a critical gap the breakdown of this dielectric medium occurs due to the growth of strong electrostatic field and cold emission of electros starts. Because of this strong electric field electrons start to move from anode (workpiece) to cathode (tool) on the surface of electrode through the shortest distance between them. The reason behind making tool as cathode and workpiece as anode is that if we take both the electrodes of the same material then the one which is attached to the anode erodes relatively at a faster rate. The electrons when impinge on dielectric molecules (insulating medium) break up into positive ions and electrons, creating an ionized column in the shortest spark gap between the anode and the cathode. Hence the resistance of the fluid column decreases and causes a discharge of electrons in the shortest distance point between the tool and the workpiece. Due to this electron discharge, a huge amount of energy is generated which melts and evaporates the material in the spark zone as shown in Fig. 2.

Inconel-925 cubical-shaped workpiece was taken for experimental analysis, as shown in Fig. 3. Workpiece was made smooth by using surface finishing process properly to make it free from rust, dust and scales. Composition of the workpiece is

Fig. 1 Electro-discharge machine setup

given on the basis of percentage, as shown in Table 1. In Fig. 3 gray color circular cavities are machined at various parameters.

The tool was prepared by taking a copper rod whose one end is tapered and fixed in the tool holder of the EDM. The circular cutting end of the tool has a diameter of 8.1 mm and cross-sectional area of 51.52 mm^2. The experiments were performed on *Z* numerically controlled (ZNC), oil die-sinking EDM machine, having pulsating DC supply. The electronic balance used for weighting has accuracy level upper and lower limits of 220 and 0.0001 g, respectively. During experiment the parametric details of the electro-discharge machine are as given in Table 2.

The metal removal rate and the spark energy both are very important for the performance of electro-discharge machining process. There are some mathematical relations among them. The relationships are expressed in Eqs. (1) and (2). The rate at which material is being removed from the workpiece is called as MRR. Its unit is

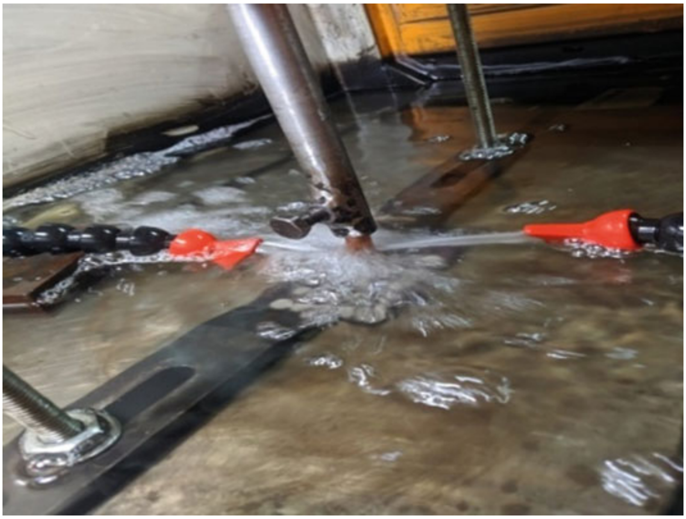


Fig. 2 Material cutting and fluid flow

Fig. 3 Workpiece for experimentation

Table 1 Composition of workpiece material

Elements	C	Si	Mg	Al	Cr	Mo	Ni	Cu	Fe
Percentage	0.04	0.5	1.0	0.3	20.13	2.68	42.95	1.54	30.86

Table 2 Parametric details of EDM process

S. no	Parameters	Details
1	Ton (μs)	50–40
2	Current range (A)	4–10
3	Voltage range (V)	30–120
4	Dielectric	Transformer oil
5	Machining time (min)	15
6	Polarity	Straight

mm^3/s. Material gets removed from the workpiece by spark erosion mechanism due to the series of recurring sparks between the tool and the workpiece. Mathematically, it is written as

$$\text{MRR} = \frac{(W_I - W_F)}{t \times \rho} \tag{1}$$

where

W_I = Initial weight of the workpiece material.
W_F = Final weight of the workpiece material.
t = Machining time = 10 min.
ρ = Density of the workpiece material = 8.05 g/cm^3 = 8.05×10^{-3} g/mm^3.

Spark energy is also one of the very important aspects which is responsible for melting and vaporization of the workpiece material. It has many effects on surface roughness, microstructure and heat-affected zone. The equation used to calculate spark energy is given by:

$$\text{Spark Energy} = I_D \times V_G \times T_{\text{ON}} \tag{2}$$

where I_D represents discharge current, V_G represents potential difference and T_{ON} represents pulse on time.

3 Results and Discussions

3.1 Effect of Pulse on Time on Metal Removal Rate and Spark Energy

To investigate the effect of pulse on time (T_{on}) on metal removal rate and spark energy, the current was fixed at 6 A and the voltage was fixed at 85 V. The metal removal rate and the spark energy were calculated at different pulse on times as 50, 75, 90, 100, 120 and 140 μs and were noted in Table 3.

Table 3 Variation of spark energy and MRR with respect to pulse on time

S. no.	Current (A)	Voltage (V)	T_{on} (μs)	Initial weight (g)	Final weight (g)	Weight loss (g)	Spark energy (J)	MRR (mm^3/s)
1	6	85	50	216.0122	215.6830	0.3292	0.0255	0.0469
2	6	85	75	215.6830	215.3131	0.3699	0.0383	0.0527
3	6	85	90	215.3131	214.9202	0.3929	0.0459	0.0559
4	6	85	100	214.9202	214.5113	0.4089	0.0510	0.0582
5	6	85	120	214.5113	214.1105	0.4008	0.0612	0.0571
6	6	85	140	214.1105	213.7128	0.3927	0.0714	0.0557

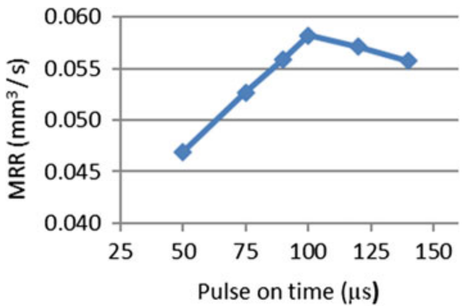


Fig. 4 MRR versus pulse on time

3.1.1 Effect of Pulse on Time on Metal Removal Rate (MRR)

Metal removal rate (MRR) increases in starting when we increase pulse on time up to a critical point, that is, 100 μs with increase in pulse on time, as indicated in Fig. 4. The rate of increase in MRR is higher in starting, and after reaching a maximum value, it started to decrease beyond 100 μs. The reason behind the decrease in MRR is that at a high value of T_{on} the value of tool wear ratio (TWR) is high, that is, more material melts at cutting tool and workpiece interface, and also it requires proper flushing time. As the pulse off time is too short with respect to pulse on time which leads to improper flushing of debris particles from the gap between the tool and the workpiece, hence arcing occurs which decreases metal removal rate.

3.1.2 Effect of Pulse on Time on Spark Energy

Spark energy is directly proportional to pulse on time (T_{on}), the spark energy increases linearly as the value of T_{on} is increased by keeping the values of voltage and current as constants, as indicated in Fig. 5, which is a straight line.

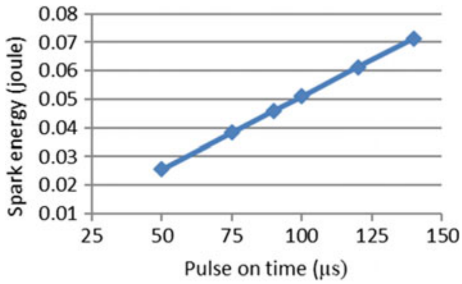


Fig. 5 Spark energy versus pulse on time

3.2 Effect of Current on Metal Removal Rate and Spark Energy

To investigate the effect of current on metal removal rate and spark energy, the voltage was fixed at 60 V and the pulse on time was fixed at 120 μs. The metal removal rate and the spark energy were calculated at different values of currents as 4, 5, 6, 7, 8 and 10 A, respectively, and were noted in Table 4.

3.2.1 Effect of Current on Metal Removal Rate (MRR)

The metal removal rate is mainly affected by current, as indicated in Fig. 6. From 4 to 5 A current MRR increases at a higher rate but the rate of increment keeps on decreasing because of the contamination of plasma column in gap. This is generally caused by higher dislodged material from electrodes.

Table 4 Variation of spark energy and MRR with respect to current

S. no.	Current (A)	Voltage (V)	T_{on} (μs)	Initial weight (g)	Final weight (g)	Weight loss (g)	Spark energy (J)	MRR (mm^3/s)
1	4	60	120	213.7128	213.4539	0.2589	0.0288	0.0369
2	5	60	120	213.4539	213.1313	0.3226	0.0360	0.0460
3	6	60	120	213.1313	212.7404	0.3906	0.0432	0.0550
4	7	60	120	212.7404	212.3401	0.4006	0.0504	0.0570
5	8	60	120	212.3401	211.9175	0.4226	0.0576	0.0602
6	10	60	120	211.9175	211.4240	0.4935	0.0720	0.0703

Fig. 6 MRR versus current

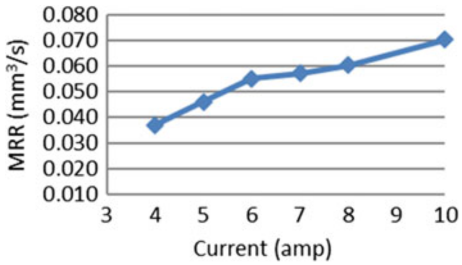
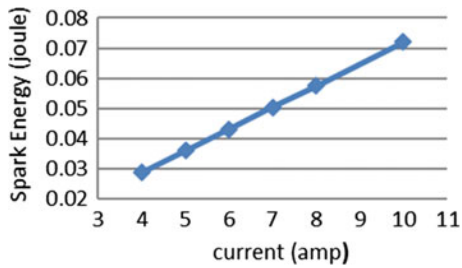


Fig. 7 Spark energy versus current



3.2.2 Effect of Current on Spark Energy

Spark energy is directly proportional to current which is confirmed by the relationship represented in Fig. 7, and it is according to the convention that as the current increases the spark energy increases linearly.

3.3 Effect of Voltage on MRR and Spark Energy

To investigate the effect of current on metal removal rate and spark energy, the current was fixed at 6 A and the pulse on time was fixed at 120 µs. The metal removal rate and the spark energy were calculated at different values of voltages as 20, 30, 40, 60, 80 and 100 V, respectively, and were noted in Table 5.

3.3.1 Effect of Voltage on Metal Removal Rate

Metal removal rate varies with a variation in voltage. Figure 8 depicts that there is a high increase in MRR at the beginning when we start to increase voltage gap and then the increment in metal removal rate with voltage increment slows down and then at higher values of voltage gap, MRR decreases rapidly, as indicated in Fig. 8. The rapid decrease in metal removal rate with increase in voltage can be explained

Table 5 Variation of spark energy and MRR with respect to voltage

S. no.	Current (A)	Voltage (V)	T_{on} (μs)	Initial weight (g)	Final weight (g)	Weight loss (g)	Spark energy (J)	MRR (mm^3/s)
1	6	20	120	211.1578	210.7884	0.3694	0.0144	0.0526
2	6	30	120	210.7884	210.3523	0.4361	0.0216	0.0621
3	6	40	120	210.3523	209.8994	0.4529	0.0288	0.0645
4	6	60	120	209.8994	209.4951	0.4043	0.0432	0.0576
5	6	80	120	209.4951	209.2058	0.2893	0.0576	0.0412
6	6	100	120	209.2058	209.0407	0.1651	0.0720	0.0235

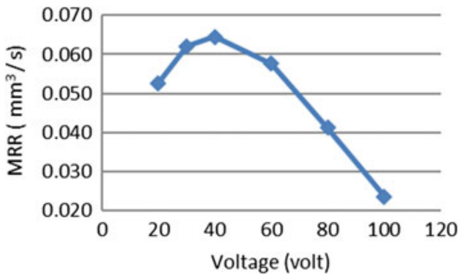


Fig. 8 Metal removal rate versus voltage

as at higher values of voltage the gap between the work and the tool becomes large and chances of contaminations of the plasma columns become high.

3.3.2 Effect of Voltage on Spark Energy

Spark energy is directly proportional to voltage and hence increases linearly with increase in voltage, which is indicated in Fig. 9.

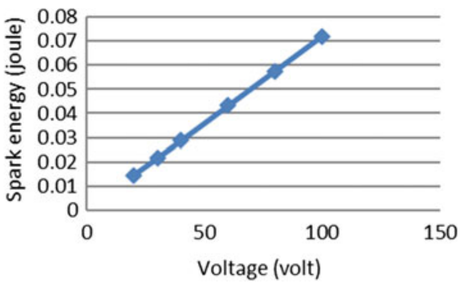


Fig. 9 Spark energy versus voltage

4 Conclusions

In the present work, the effect of some important EDM process parameters, like pulse on time, peak current and voltage on response parameters like metal removal rate and spark energy are investigated. The major conclusions that can be drawn are:

- EDM is an accurate process to machine the selected specimen of Inconel-925 for the complicated work with good metal removal rate.
- The range of current was taken from 4 to 10 A, voltage from 30 to 120 V, pulse on time from 50 to 140 μs.
- The maximum metal removal rate (0.0703 mm^3/s) was obtained at 10 A current, 60 V potential difference and 120 μs pulse on time.
- With increase in pulse on time the MRR first increases and after attaining a maximum value it starts decreasing.
- With increase in current the MRR keeps on increasing.
- With increase in voltage MRR increases initially at very fast rate, then increases slowly and attains a maximum value and afterwards decreases rapidly.
- If spark energy is increased, metal removal rate will increase but TWR will also increase.

5 Future Scope

Though a lot of research have already been done on EDM, still there is much work to be done for the better performance of the process.

- The optimization of the process parameters for each operation of machining needs more work in electro-discharge machining as it is underworked by the researchers.
- Relation among metal removal rate, tool wear ratio and surface roughness ratio should be established applying some mathematical and programming tools.
- Selection of tool for different materials is a very complicated task; it needs more work as little work is found in the literatures over this area.
- In this work only selected parameters are taken for analysis. There are several other parameters like T_{off}, which affect the performance of the process, hence should also be investigated properly.
- Electro-discharge machining process still requires achieving the best MRR, surface finish and low TWR and so on, which indicates research is lacking in this direction and should be worked.
- At present, electro-discharge machining process can be used only to electrically conductive material, and the effort should be applied to work with non-conducting materials.
- At present, the process has low metal removal rate, high tool wear with high additional cost, so effort should be applied to improve these lacking.

References

1. Jain, N.C., Belokar, R.M., Chakaraborti, K.K.: A study and effect of insulated copper electrodes on SAE 7075 aluminium alloys in EDM, emerging trends in manufacturing. In: Proceedings of XVI National Convention of Production Engineers, p. 468. Jan 2002
2. Rajurkar, K.P., Nooka, S.R.: Surface finish of electro-discharge machined components. In: ICAMT-94, pp. 133–143. University of Nebraska, Lincoln, NE, USA, Aug 1994
3. Boujelbene, M., Bayraktar, E., Tebni, W., Ben, S.S.: Influence of machining parameters on the surface integrity in electrical discharge machining. Arch. Mater. Sci. Eng. **37**(2), 110–116 (2009)
4. Puertas, I., Perez, C.J.L.: Modelling the manufacturing parameters in electrical discharge machining of siliconized silicon carbide. Proc. Inst. Mech. Eng. Proquest Sci. J. **6**, 791–803 (2003)
5. Sahani, O.P., Kumar, R., Vashishtha, M.: Effect of electro discharge machining process parameters on material removal rate. J. Basic Appl. Eng. Res. **1**(2), 17–20 (2014)
6. Descoeudres, A.: Characteristics of Electrical Discharge Machining. Ecole Polytechnique Federale De Lausanne (2006)
7. Daneshmand, S. Kahrizi, E.F., Abedi, E., Mir Abdulhosseini, M.: Influence of machining parameters on electro discharge machining of NiTi shape memory alloys. In: IJES 2013, pp. 3095–3104 (2013)
8. Rao, G.K.M., Satyanarayana, S., Praveen, M.: Proceedings of World Congress on Engineering. London (2008)
9. Kataria, R., Singh, R.P., Sharma, P., Phanden, R.K.: Welding of super alloys: a review. Mater. Today Proc. (2020). https://doi.org/10.1016/j.matpr.2020.07.198
10. Kumar, D., Phanden, R.K., Thakur, L.: A review on environment friendly and lightweight magnesium-based metal matrix composites and alloys. Mater. Today Proc. (2020). https://doi.org/10.1016/j.matpr.2020.07.424

Multi-objective Optimization of Aerofoil

Prateet Dosi, Prem Kumar Bharti, Niharika Borah, Anjan Barman, Mriganka Baishnab, and Soumyabrata Bhattacharjee

Abstract NACA 0012 aerofoil has been optimized for maximum lift and minimum drag in different environmental conditions. This redevelopment has been achieved by two modern lift maximization techniques together, vortex generator and morphing. The vortex generator provides a proper path to the air flow that leads to increase in the lift, and morphing enables the structure of aerofoil to change according to the environmental conditions of flight. Keeping all the factors in mind, an aerofoil has been generated and optimized using ANSYS 14.0 software. The result indicates that the coefficient of lift (Cl) has increased in noticeable proportion of 16.67% and the coefficient of drag (Cd) has increased but in small proportion of 6.67%, which suggest that our target has been achieved.

Keywords Vortex generator · Morphing · Optimization · Coefficient of lift · Coefficient of drag

1 Introduction

In broad sense, an aerofoil is a two-dimensional (2D) specimen designed to make the flight fly under variable conditions. In modern days, we mainly focus to reduce the drag faced by the aerofoil as well as to enhance lift. Two modern methods of vortex lift by unsteady excitation and morphing are being used. There might be some changes in lift due to change in camber which also depends upon the angle of attack of the aerofoil [1]. The variation in camber at a given angle of attack limits the capacity to lift generated with aerofoil. The difference in air pressure around the aerofoil can be controlled by vortex generators and discrete control surfaces which help to overcome the limits of flight [2–5].

The relative motions of flight are been opposed by the drag. It has been focused to reduce drag penalty by decreasing the cross section of the aerofoil. Moreover, the sudden change in pressure at the tip of the aerofoil results in separation which

P. Dosi (✉) · P. K. Bharti · N. Borah · A. Barman · M. Baishnab · S. Bhattacharjee
Royal School of Engineering and Technology, Guwahati, Assam 781035, India
e-mail: prateetdosi@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_71

causes increase in drag. The mentioned penalty can be reduced by providing vortex generators. The use of discrete surfaces to control actuators and the structural reinforcement increase the complexity and expense of the design. To get the better off at low cost, camber morphing technique is used as discussed [6–8]. The concept of the two methods that are going to be used is not new, but the methodology on which we are going to carry out our research is new. The diversity of the study represents the absence of an integrated and quantifiable theory. At this stage, our design will contribute toward a new field of development in aerofoil. The two shall contribute toward higher lift and lesser drag penalty of the UAV [9–13]. We will focus our search for super lift by means of unsteady excitation that would emphasize in generating lift and reduce drag by vorticity and vortices evolved by the movement of air over the aerofoil. We would enhance the flow separation and unsteadiness in a controlled manner that would contribute to our serve. Morphing aircraft design requires tighter integration of the aerodynamic and structural design to ensure that the aerodynamic design produced can be achieved by the morphing systems and structures available.

Our task concerns only 2D optimization, but the optimization groundwork could be triflingly extended to 3D with a suitable aerodynamic analysis tool. An eminently simple mechanism may only meet the target shapes to a certain state. A more complex system will match the shapes more precisely but come at the cost of increased weight and complexity. So, the mechanism which would meet our target would be simple.

2 Purpose of Work

Upon investigation the following problems were found in the present design.

- Low coefficient of lift and higher viscosity experienced.
- Flow separation contributing to increased drag.
- The variation in air pressure around the surface of the aerofoil limits the controlling capacity of the flight.
- The analysis reveals the difficulty of the aerofoil to adjust under variable flight condition and the control of air flow over the surface.
- Moreover, the present conditions reveal the ability of adjustment at high cost and at the expense of increased weight by the use of sophisticated mechanism.
- Finally, an unoptimized aerofoil design that results in the ability of maneuverability of flight.

To overcome these problems faced by the present design, we are carrying out our task to improve the ability of the aerofoil.

3 Theoretical Modeling

Modeling involves analysis of the available designs for purpose of researching its pros and cons. The analysis reveals the difficulty of the aerofoil to adjust under variable flight condition and the control of air flow over the surface. Moreover, the present conditions reveal the ability of adjustment at high cost and at the expense of increased weight by the use of sophisticated mechanism. The study also involves the determination of type of flow (laminar and turbulent) over the surface of aerofoil. The task also determines the region of flow separation, the governing equation of flow and analysis.

Depending on the analysis, the parameters on which we need to work to achieve our tasks are:

- Coefficient of lift
- Coefficient of drag
- Angle of attack.

The governing equations are:

Reynolds-Averages Navier–Stokes equation [3]

$$\rho\left[\frac{\partial u}{\partial t}\right]+\left[u\frac{\partial u}{\partial x}\right]+\left[v\frac{\partial u}{\partial y}\right]=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+\rho g_x$$

$$\rho\left[\frac{\partial v}{\partial t}\right]+\left[u\frac{\partial v}{\partial x}\right]+\left[v\frac{\partial v}{\partial y}\right]=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\rho g_y$$

Or in vectorial form

$$\rho\left[\frac{\partial \vec{V}}{\partial x}\right]+\left(\vec{V}.\vec{\nabla}\right)\vec{V}=-\vec{\nabla}p+\mu\nabla^2\vec{V}+\rho g$$

Using vector identities

$$\rho\left[\frac{\partial \vec{V}}{\partial t}+\vec{\nabla}\left(\vec{V}.\vec{V}\right)-\vec{V}\times\vec{\omega}\right]=-\vec{\nabla}p+\mu\left[\vec{\nabla}\left(\vec{\nabla}.\vec{V}\right)-\vec{\nabla}\times\vec{\omega}\right]+\rho g$$

- *K*-omega model [4]

The standard $K-\omega$ miniature is based on the Wilcox [14] model, which blends modifications for low Reynolds number effects, compressibility and shear flow spreading.

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial y}{\partial x_j}=P-\beta^*\rho\omega k+\frac{\partial}{\partial x_j}\left[\left(\mu+\sigma_k\frac{\rho k}{\omega}\right)\frac{\partial k}{\partial x_j}\right]$$

$$\frac{\partial(\rho\omega)}{\partial t}+\frac{\partial\left(\rho u_j\omega\right)}{\partial x_j}=\frac{\gamma\omega}{k}P-\beta\rho\omega^2+\frac{\partial}{\partial x_j}\left[\left(\mu+\sigma_\omega\frac{\rho k}{\omega}\right)\frac{\partial\omega}{\partial x_j}\right]+\frac{\rho\sigma_d}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial\omega}{\partial x_j}$$

where

$$P=\tau_{ij}\frac{\partial u_i}{\partial x_j}$$

$$\tau_{ij}=\mu\left(2S_{ij}-\frac{2}{3}\frac{\partial u_k}{\partial x_k}\delta_{ij}\right)-\frac{2}{3}\rho k\delta_{ij}$$

$$S_{ij}=\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)$$

Radial basis functions [1]

$Xa = H_{sa}\, x_s$.
The coupling matrix, H_{sa}, is the multiplication of two matrices:
$H_{sa} = C^{-1}{}_{SS} \times A_{sa}$.
C_{SS} and A_{sa} are calculated as:

$$C_{SS}=\begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 1 & \ldots & 1 \\ 0 & 0 & 0 & 0 & X_{S1} & X_{S2} & \ldots & X_{SN} \\ 0 & 0 & 0 & 0 & Y_{S1} & Y_{S2} & \ldots & Y_{SN} \\ 0 & 0 & 0 & 0 & Z_{S1} & Z_{S2} & \ldots & Z_{SN} \\ 1 & X_{S1} & Y_{S1} & Z_{S1} & \emptyset_{S1S1} & \emptyset_{S1S2} & \ldots & \emptyset_{S1SN} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & X_{SN} & Y_{SN} & Z_{SN} & \emptyset_{SNS1} & \emptyset_{SNS2} & \ldots & \emptyset_{SNSN} \end{bmatrix}$$

$$A_{sa}=\begin{bmatrix} 1 & X_{a1} & Y_{a1} & Z_{a1} & \emptyset_{a1s1} & \emptyset_{a1s1} & \cdots & \emptyset_{a1sN} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & X_{aN} & Y_{aN} & Z_{aN} & \emptyset_{aNs1} & \emptyset_{aNs2} & \cdots & \emptyset_{aNsN} \end{bmatrix}$$

The surface miniature blueprints define a design entity by a number of design parameters. A splitted problem to this is often considered parallelly, the distortion of the consequent surface during the enhancing task, which is needed at low deformation of a body fitted CFD mesh. The efficacy of a parametrium method is.

(i) Being capable of changing shape and rugged enough to cover the design space, and
(ii) Ability to adapt shapes for different design parametrium. Procedure is divided as either constructive, deformative or unified.

Our final tasks involve designing a 2D structure using the above parametrium and equations, which would serve our cause at low expense and decreased weight.

4 Optimization Frameworks

Optimization framework involves the designing of the aerofoil structure. The following structure was developed as shown in Fig. 1 and its CFD analysis was performed on ANSYS 14.0.

The CFD analysis briefly shows the variation of flow regimes of the aerofoil. A comparable variation of flow regimes has been shown for the aerofoil. The flow regime shows the variation of flow over the aerofoil due to structural variation, variation in separation and pressure across the aerofoil (Figs. 2, 3, 4, 5, 6, 7, 8 and 9).

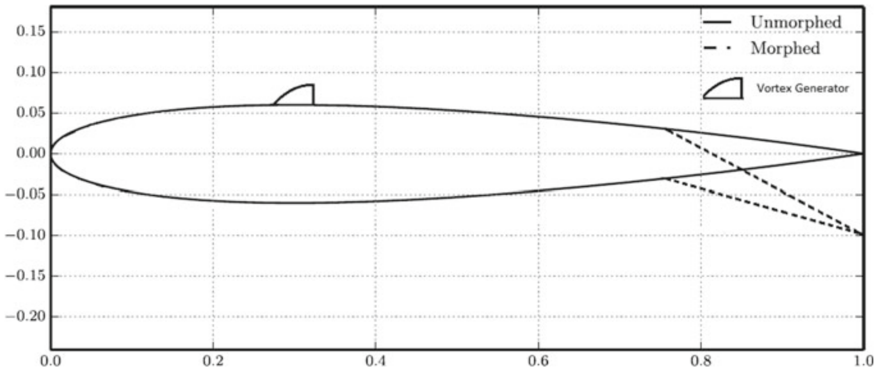


Fig. 1 NACA 0012 aerofoil morphed with vortex generators

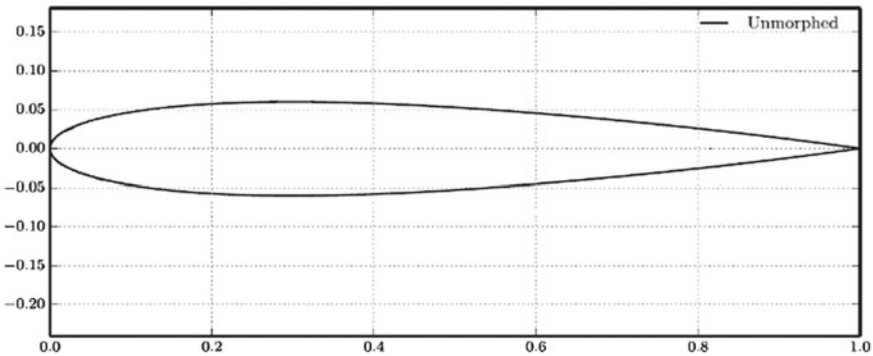


Fig. 2 NACA 0012 unmorphed structure

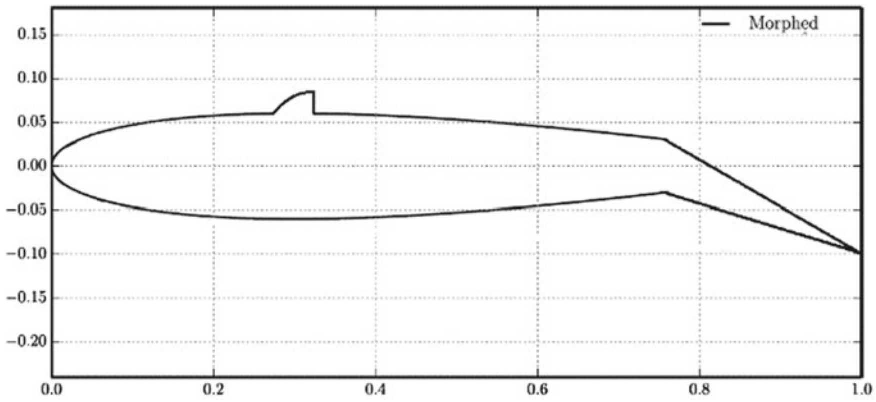


Fig. 3 NACA 0012 morphed structure with vortex generator

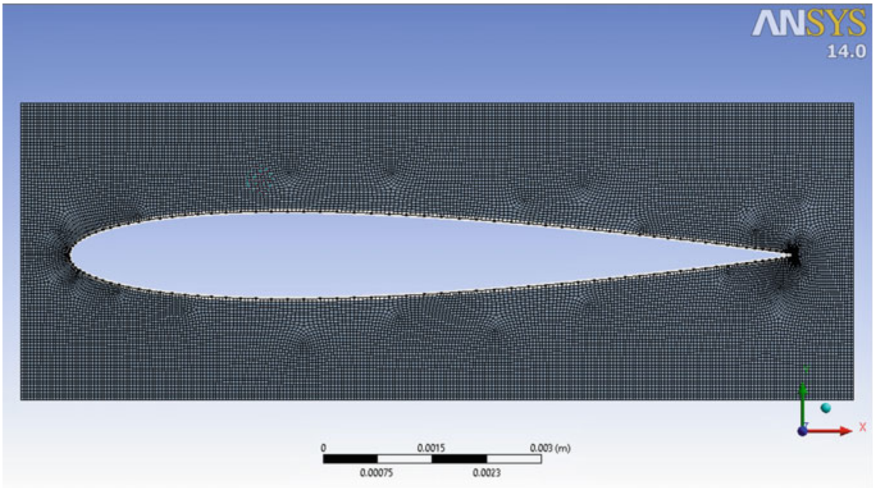


Fig. 4 Mesh generation of original NACA 0012

5 Results

A multi-octave optimization method for aerofoil has been designed with the motive to integrate the vortex generators and morphing systems into the optimization procedure. In order to perform this optimization, the techniques were combined and the CFD analysis was performed with ANSYS 14.0. The analysis results graph has been presented showing the variation of lift and drag over the entire surface of the aerofoil. The curve showing the variation of Cl / Cd versus angle of attack for aerofoil has been presented aerofoil (refer Figs. 10, 11, 12 and 13). Results indicate that this is a method that can produce better lift than the available present methods. The data

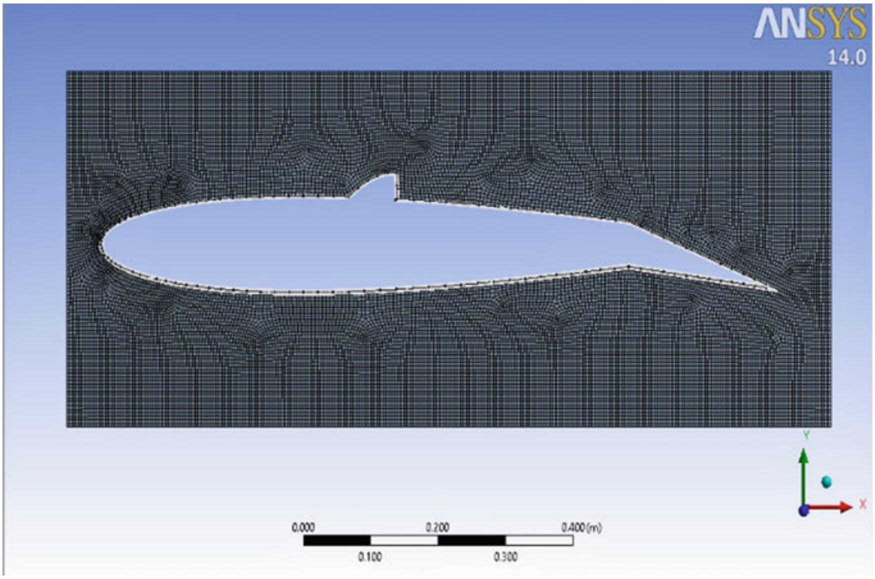


Fig. 5 Mesh generation of structural modified NACA 0012

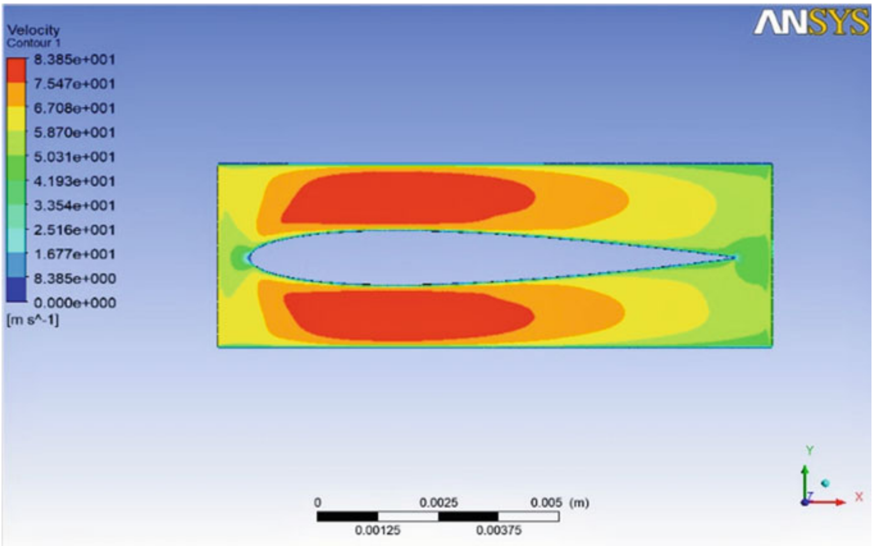


Fig. 6 Velocity distribution of original NACA 0012

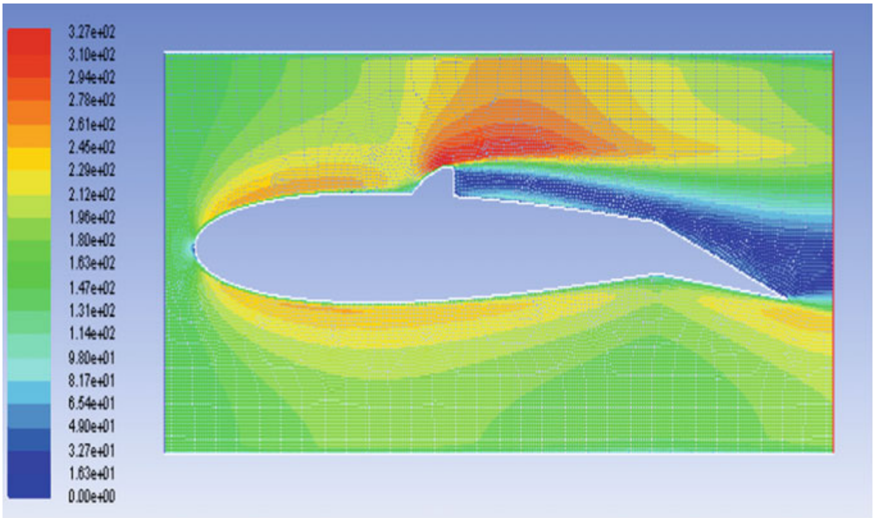


Fig. 7 Velocity distribution of structural modified NACA 0012

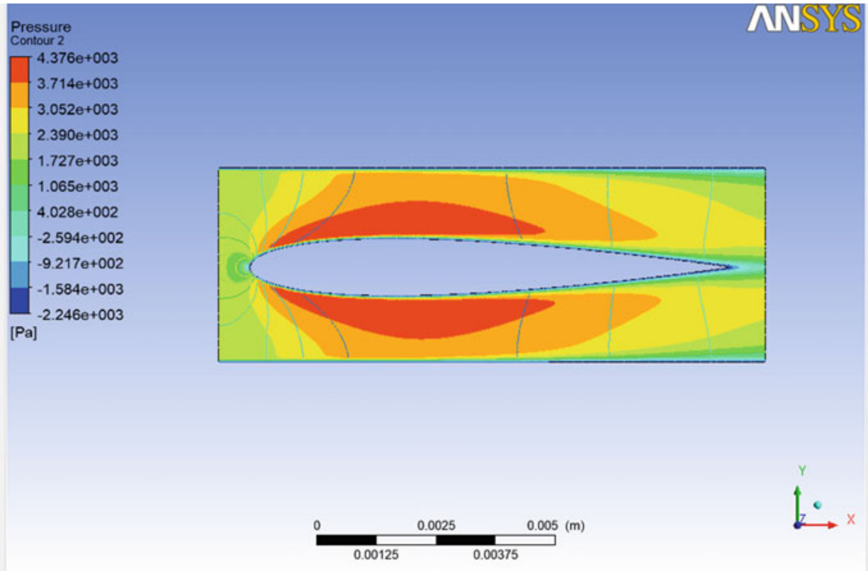


Fig. 8 Pressure distribution of original NACA 0012

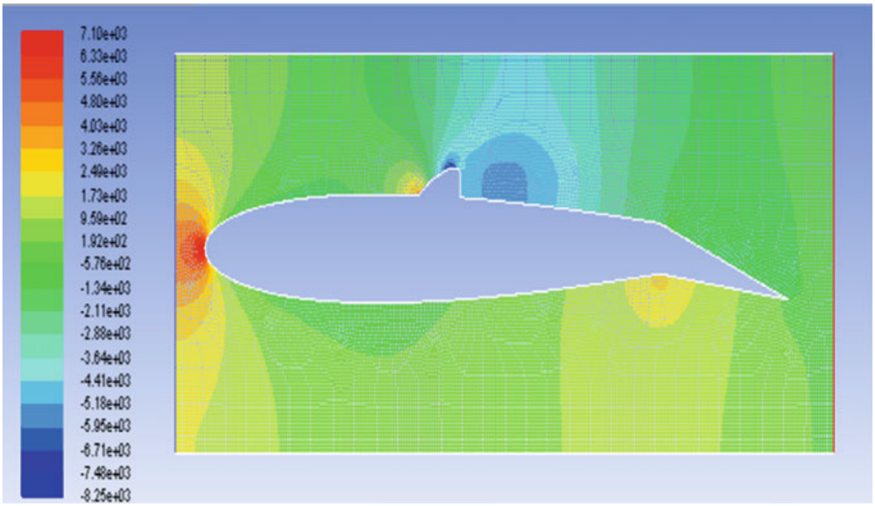


Fig. 9 Pressure distribution of structural modified NACA 0012

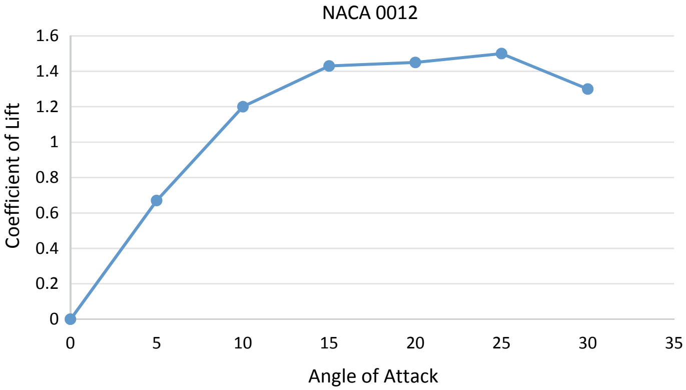


Fig. 10 Coefficient of lift versus angle of attach (NACA 0012)

also predict that the drag penalty is also greatly reduced. The final results show a satisfactory improvement of the aerofoil performance.

6 Conclusion

- The paper is carrying a totally new concept of mechanism of raising lift and reducing drag of NACA four-digit aerofoil.

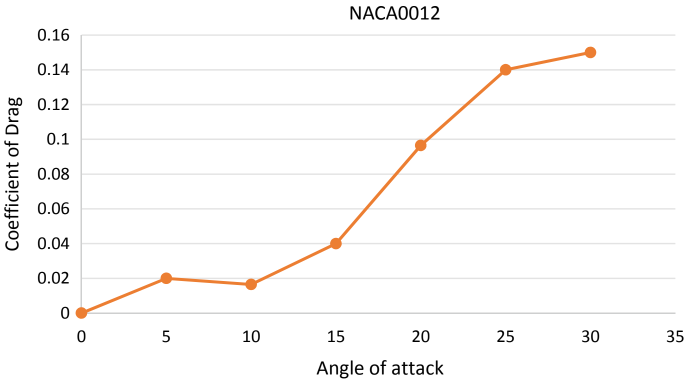


Fig. 11 Coefficient of drag versus angle of attach (NACA 0012)

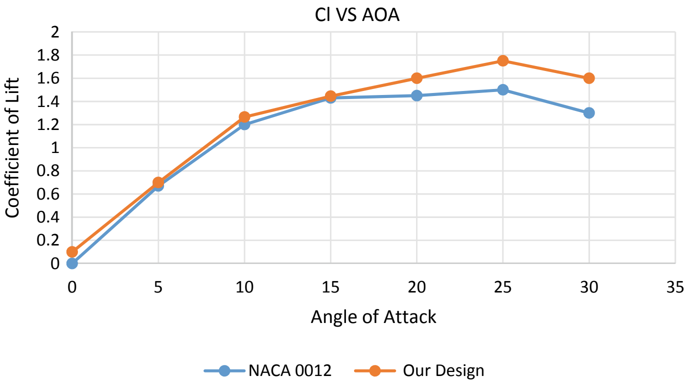


Fig. 12 Coefficient of lift versus angle of attach (NACA 0012 vs. our design)

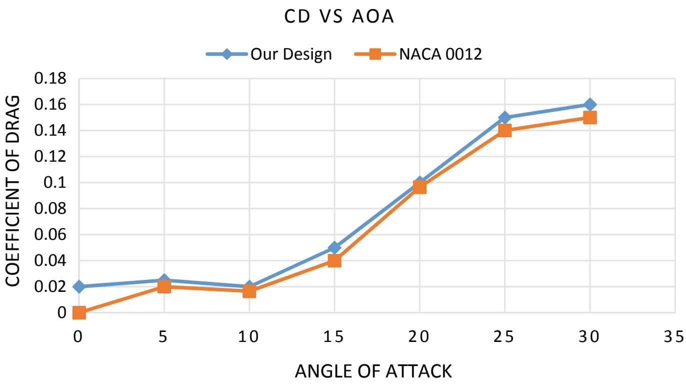


Fig. 13 Coefficient of drag versus angle of attach (NACA 0012 vs. our design)

- We are dealing with a design that has both vortex generator and morphing combined.
- The above result carried out in ANSYS 14.0 shows that lift and drag have increased but lift has increased considerably by large factor, concluding that if both techniques combined, they can produce satisfactory improvement in flight lift.

References

1. Fincham, J.H.S., Friswell, M.I.: Aerodynamic optimisation of a camber morphing aerofoil. Aerosp. Sci. Technol. **43**, 245–255 (2015). https://doi.org/10.1016/j.ast.2015.02.023
2. Wu, J.Z., Vakili, A.D., Wu, J.M.: Review of the physics of enhancing vortex lift by unsteady excitation. Prog. Aerosp. Sci. **28**(2), 73–131 (1991). https://doi.org/10.1016/0376-0421(91)90001-K
3. Eyi, S., Hager, J.O., Lee, K.D.: Airfoil design optimization using the Navier-Stokes equations. J. Optim. Theory Appl. **83**(3), 447–461 (1994). https://doi.org/10.1007/BF02207637
4. Menter, F.R.: AIAA-93-2906 Zonal two equation $k{-}\omega$ turbulence models for aerodynamic flows. In: 24th Fluid Dynamics Conference for Aerodynamic Flows. Fluid Dynamics (1993)
5. Poole, D.J., Allen, C.B., Rendall, T.C.S.: High-fidelity aerodynamic shape optimization using efficient orthogonal modal design variables with a constrained global optimizer. Comput. Fluids **143**, 1–15 (2017). https://doi.org/10.1016/j.compfluid.2016.11.002
6. Wendt, B.J., Reichert, B.A.: The modelling of symmetric airfoil vortex generators. In: 34th Aerospace Sciences Meeting and Exhibit (1996). https://doi.org/10.2514/6.1996-807
7. Bazilevs, Y., Hsu, M., Kiendl, J., Wüchner, R., Bletzinger, K.: 3D simulation of wind turbine rotors at full scale. Part II: fluid–structure interaction modeling with composite blades. Int. J. Numer. Methods Fluids **65**(Oct 2010), 236–253 (2011). https://doi.org/10.1002/fld
8. Phanden, R.K.: Multi agents approach for job shop scheduling problem using genetic algorithm and variable neighborhood search method. In: Proceedings of the 20th World Multi-conference on Systemics, Cybernetics, and Informatics, July 2016, pp. 275–278
9. Eleni, D.C.: Evaluation of the turbulence models for the simulation of the flow over a national advisory committee for aeronautics (NACA) 0012 airfoil. J. Mech. Eng. Res. **4**(3), 100–111 (2012). https://doi.org/10.5897/jmer11.074
10. Sørensen, N.N., Zahle, F., Bak, C., Vronsky, T.: Prediction of the effect of vortex generators on airfoil performance. J. Phys. Conf. Ser. **524**(1), 1–11 (2014). https://doi.org/10.1088/1742-6596/524/1/012019
11. Alawadhi, H.A., Alex, A.G., Kim, Y.H.: CFD analysis of wing trailing edge vortex generator using serrations. EPJ Web Conf. **67**, 1–8 (2014). https://doi.org/10.1051/epjconf/20146702002
12. Ahmad, K.A., Watterson, J.K., Cole, J.S., Briggs, I.: Sub-boundary layer vortex generator control of a separated diffuser flow. In: 35th AIAA Fluid Dynamics Conference and Exhibit, June 2005, pp. 1–8. https://doi.org/10.2514/6.2005-4650
13. Sahu, N.K., Imam, M.S.: Analysis of transonic flow over an airfoil NACA0012 using CFD. IJISET-Int. J. Innov. Sci. Eng. Technol. **2**(4), 379–388 (2015)
14. Wilcox, D.C.: Reassessment of the scale-determining equation for advanced turbulence models, AIAA J. **26**(11), 1299–1310. https://doi.org/10.2514/3.10041 (1988)

Preliminary Investigation of Wire Cut EDM on Polycrystalline Silicon Ingot

Raminder Singh, Anish Kumar, and Renu Sharma

Abstract The semiconductor and solar industry face the great difficulty in cutting of silicon ingots in conventional machining to facilitate the manufacturing of solar cells. In this research work the wire cut EDM non-conventional tool was selected for cutting of polycrystalline silicon. The individual influence of various input parameters such as T_{on}, T_{off}, I_{P}, SG_{v}, W_{F}, W_{T} and W_{P} on cutting speed and kerf width was investigated. The influences of all the parameters were examined through one factor at a time approach. The results obtained through this preliminary investigation due to increase of T_{on}, I_{P} and decrease of T_{off}, SG_{v} have significant influence on cutting speed and kerf width. The W_{F}, W_{T} and W_{P} have less influence observed on performance measures. The machined surfaces were examined through scanning electron microscope and also the element migration through energy-dispersive X-ray analysis was examined. Further, this preliminary investigation has been employed to fix the level of parameters for the main study and the results find the application in photovoltaic and semiconductor industries.

Keywords Wire cut EDM · Polycrystalline silicon ingot · Cutting speed · Kerf width · One factor at a time approach

Abbreviations

WEDM	Wire electric discharge machining
T_{on}	Pulse on time
T_{off}	Pulse off time
I_{p}	Peak current
SG_{V}	Spark gap voltage

R. Singh · A. Kumar (✉)
Mechanical Engineering Department, M. M. Deemed To Be University Mullana, Ambala, Haryana 133207, India
e-mail: anish_kaushik@rediffmail.com

R. Sharma
Physics Department, M. M. Deemed To Be University Mullana, Ambala, Haryana 133207, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_72

W_F	Wire feed
W_T	Wire tension
W_P	Water pressure

1 Introduction

Today, the world is encountering problems for energy disaster and global warming. The efforts have been done by the researchers in the field of renewable energy resources. Among them, the great demand of photovoltaic applications is in the field of solar energy and semiconductor materials. Owing to high costs as compared to conventional sources, it is widely used for two reasons: environmental and practical. The solar energy is available widely in everywhere. Therefore, solar energy was engaged in the generation of electricity and it appears that in the near future the common use of it will increase. Conventional methods face great difficulty in slicing the silicon ingot due to unique physical properties, like saws of inner diameter and wire saw [1–4]. To overcome this problem, in the recent years wire cut EDM is a well-developed method to slice polycrystalline silicon semiconductor materials. The mechanism involves non-contact machining to remove the material by spark erosion of wire electrode. Normally the wire electrode used in this process is brass wire. During the cutting process the debris is flushed by dielectric medium [5]. The studies relating to slicing of wire cut EDM for polycrystalline silicon material are limited. Yu et al. [6–8] achieved high efficiency of wire cut EDM in machining of polycrystalline silicon using auxiliary-pulse voltage supply to produce good machining characteristics. Dongre et al. [9, 10] observed that 30–40% higher metal removal rate was achieved in wire EDM slicing of silicon ingots as compared to conventional method such as inner diameter and single-wire abrasive saw. Slicing and kerf loss was mainly influenced by current, voltage and Ton. Yeh et al. [11] proved that by using phosphorous and sodium pyrophosphate powders mixed in dielectric increases the working efficiency of wire cut EDM of polycrystalline silicon. Punturat et al. [12] observed the craters, micro-cracks and other irregularities on WEDM surface with influence of parameters on n-type mono-crystalline material. Ding et al. [13] studied the multi-cutting by wire cut EDM when metal material processing was applied to cut semiconductor mono-crystalline silicon with specific crystallographic orientation. Luo et al. [14] investigated the silicon wafering of wire cut EDM and observed the machined surfaces with drops, islands, cavities, cracks, craters and so on.

It is presumed from the above-mentioned aspects that most of the studies have been reported on cutting mechanism and other non-conventional machining capabilities. The present work to investigate the influence of seven parameters of wire cut EDM on polycrystalline material through one factor at a time approach. Very few research works are available for wire cut EDM of polycrystalline material. This approach has been used to fix the levels and their range of parameters for future empirical modeling and also to obtain the optimal results for output responses.

2 Materials and Methods

A polycrystalline silicon ingot of dimension 125 × 125 × 10 mm as shown in Fig. 1a, b was cut through thin single-strand zinc-coated 0.25Ø wire. The cutting was performed on wire cut EDM model-Sprintcut and Make Electronic Machine Tools Ltd. Pune as shown in Fig. 1c, d. Seven parameters were considered for this experimental work with five levels for T_{on}, T_{off}, I_{P}, SG_{v}, W_{F}, W_{T} and W_{P}. The experimentation was done using one factor at a time approach, and the one factor of machine varies by keeping other factors constant at mid-level. The levels of fixed and varied machining parameters are shown in Table 1. Therefore, in this investigation

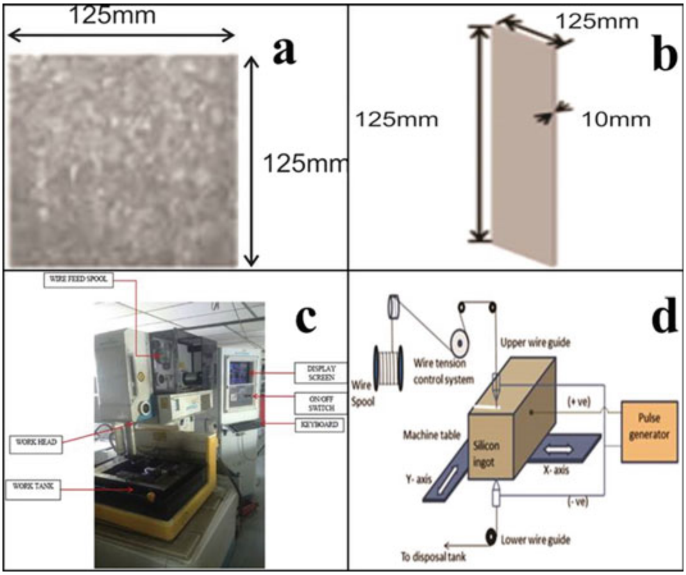


Fig. 1 **a**, **b** Schematic of cut piece of silicon ingot. **c**, **d** Schematic of experimental setup

Table 1 Input machining parameters and their levels

S. no.	Machining parameters	Units	Range and their levels				
			1	2	3	4	5
1	T_{on}	µs	114	117	120	123	126
2	T_{off}	µs	47	50	53	56	59
3	I_{P}	A	20	30	40	45	49
4	SGv	V	25	35	45	55	65
5	W_{F}	m/min	2	5	8	11	14
6	W_{T}	g	450	600	850	1400	2200
7	W_{P}	kg/mm^2	4	6	8	10	15

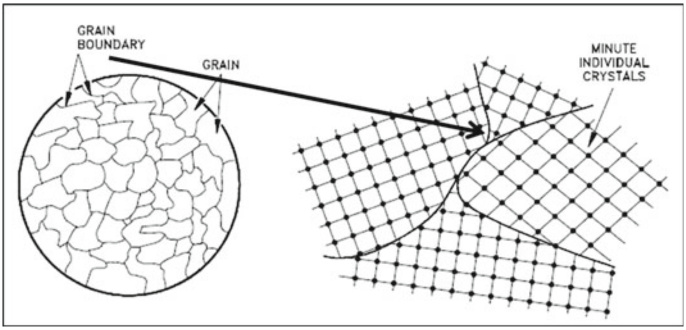


Fig. 2 Schematic of polycrystalline grain structure [2]

cutting speed and kerf width were considered as performance measures. The cutting speed was directly noted through machine display panel and kerf width was measured by Mitutoyo profilometer. The grain structure of polycrystalline silicon material is as shown in Fig. 2. Every grain separates with grain boundary at a different orientation from its neighbor.

3 Results and Discussion

Experimental design according to one factor at a time approach for different machining parameters setting along with results is shown in Table 2.

3.1 *Influence of T_{on} on Cutting Speed and Kerf Width*

Figure 3a depicts the effect of T_{on} for cutting speed and kerf width. It was observed that as T_{on} increases from 114 to 126 μs, the cutting speed increases by 0.53 to 0.78 mm/min (47%) and simultaneously kerf width also increased from 0.379 to 0.413 mm (9%). This is due to the fact that high T_{on} means more discharge energy between wire and workpiece which will expedite the melting and evaporating. The surface morphology has been observed with large size craters, debris and lumps deposited on the machined surface as shown in Fig. 3b. There is less effect on kerf width. The machined surface composition was altered due to migration of material, dielectric and tool elements which was observed through energy-dispersive X-ray analysis as shown in Fig. 3c.

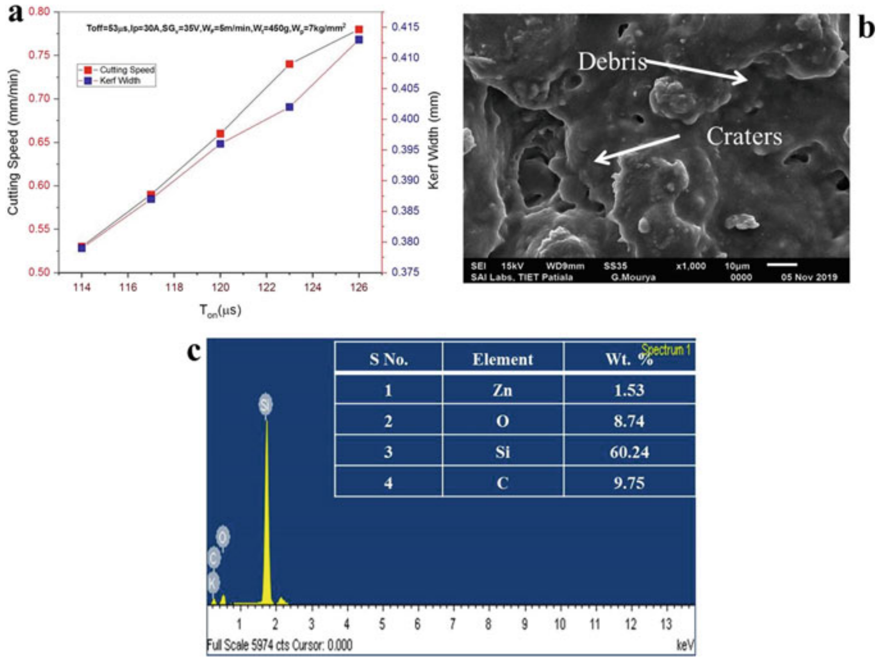
Table 2 Experimental result of performance characteristics

S. no.	Machining parameters							Performance characteristics	
	T_{on}	T_{off}	I_p	SG_V	W_F	W_t	W_P	Cutting speed (mm/min)	Kerf width (mm)
1	114	53	30	35	5	450	7	0.53	0.379
2	117	53	30	35	5	450	7	0.59	0.387
3	120	53	30	35	5	450	7	0.66	0.396
4	123	53	30	35	5	450	7	0.74	0.402
5	126	53	30	35	5	450	7	0.78	0.413
6	120	59	30	35	5	450	7	0.39	0.358
7	120	56	30	35	5	450	7	0.48	0.367
8	120	53	30	35	5	450	7	0.56	0.379
9	120	50	30	35	5	450	7	0.68	0.388
10	120	47	30	35	5	450	7	0.78	0.395
11	120	53	20	35	5	450	7	0.44	0.338
12	120	53	30	35	5	450	7	0.54	0.347
13	120	53	40	35	5	450	7	0.62	0.352
14	120	53	45	35	5	450	7	0.69	0.357
15	120	53	49	35	5	450	7	0.72	0.363
16	120	53	30	25	5	450	7	0.53	0.492
17	120	53	30	35	5	450	7	0.47	0.483
18	120	53	30	45	5	450	7	0.41	0.471
19	120	53	30	55	5	450	7	0.35	0.464
20	120	53	30	65	5	450	7	0.28	0.452

(continued)

Table 2 (continued)

S. no.	Machining parameters							Performance characteristics	
	T_{on}	T_{off}	I_p	SG_V	W_F	W_t	W_P	Cutting speed (mm/min)	Kerf width (mm)
21	120	53	30	35	2	450	7	0.37	0.363
22	120	53	30	35	5	450	7	0.42	0.370
23	120	53	30	35	8	450	7	0.47	0.375
24	120	53	30	35	11	450	7	0.54	0.381
25	120	53	30	35	14	450	7	0.64	0.385
26	120	53	30	35	5	450	7	0.55	0.431
27	120	53	30	35	5	600	7	0.51	0.424
28	120	53	30	35	5	850	7	0.48	0.419
29	120	53	30	35	5	1400	7	0.42	0.411
30	120	53	30	35	5	2200	7	0.35	0.403
31	120	53	30	35	5	450	4	0.37	0.332
32	120	53	30	35	5	450	6	0.41	0.338
33	120	53	30	35	5	450	8	0.46	0.345
34	120	53	30	35	5	450	10	0.54	0.357
35	120	53	30	35	5	450	15	0.59	0.361



S No.	Element	Wt. %
1	Zn	1.53
2	O	8.74
3	Si	60.24
4	C	9.75

Fig. 3 **a** Influence of T_{on} on cutting speed and kerf width. **b** SEM image at T_{on} = 120 µs. **c** Energy-dispersive X-ray analysis at T_{on} = 120 µs

3.2 Influence of T_{off} on Cutting Speed and Kerf Width

Figure 4 illustrates the influence of T_{off} on cutting speed and kerf. It was observed that as the T_{off} decreases from 59 to 47 µs cutting speed increases from 0.39 to 0.78 mm/min (100% rises) while on the contrary an increase of T_{off} results in decrease of the cutting speed. The kerf width also observed the same effect on increasing and decreasing of T_{off}, as it resulted in 0.358–0.395 mm (10%). T_{off} is the duration of discharge time between two sequential sparks. When the spark turned off time is high then it will allow the dielectric to flow and remove the debris between the spark gaps. Thus, less cutting speed and kerf width is observed. At shorter T_{off} the frequency of sparks increases within a given period of time and the dielectric takes less time to flush away the debris and ionization becomes higher with cutting speed and kerf width.

3.3 Influence of I_P on Cutting Speed and Kerf Width

Figure 5 describes the influence of I_P on cutting speed and kerf width. It was observed that with an increase of I_p from 20 to 49 A, the cutting speed increases from 0.44 to

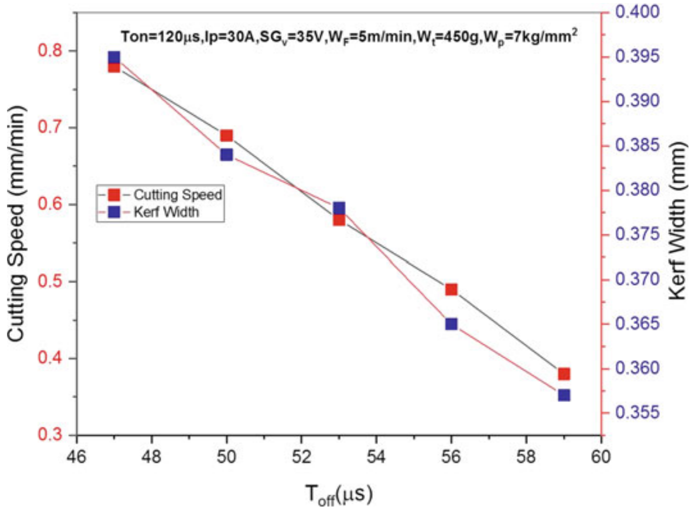


Fig. 4 Influence of T_{off} on cutting speed and kerf width

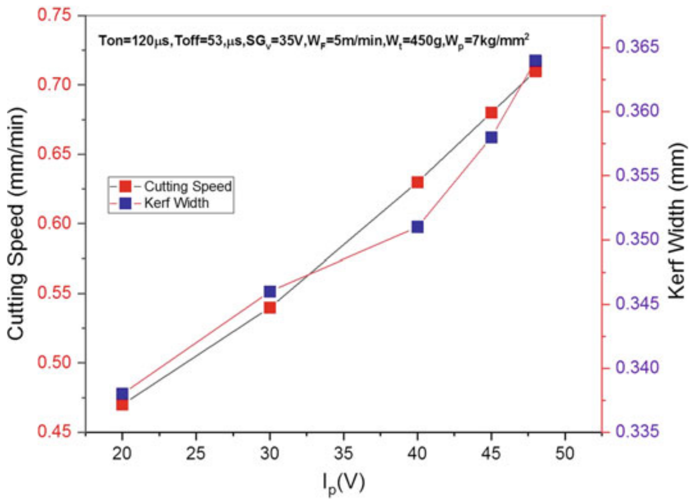


Fig. 5 Influence of I_P on cutting speed and kerf width

0.72 mm/min (64%). This is due to the fact that higher values of I_P leads to increase in width of discharge energy across the wire resulting in melting and evaporation that leads to higher cutting speed. Moreover, it was also observed that when the value of I_P is more than 49 A the wire breaks, which will halt the machining process. The kerf width was also increased from 0.338 to 0.363 mm (7.4%). The more amount of material melted to inter-electrode gap between the wire and cutting path of silicon

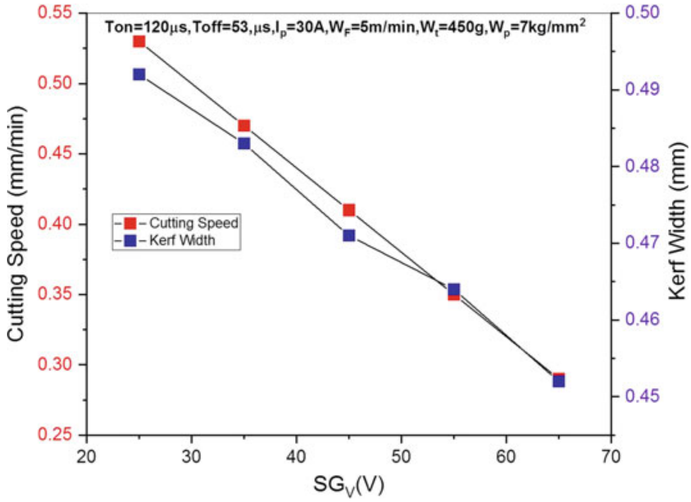


Fig. 6 Influence of SG_v on cutting speed and kerf width

ingot will increase the cut that varied along with increase of I_P and at the exit of kerf higher width will be obtained.

3.4 *Influence of SG_v on Cutting Speed and Kerf Width*

The influence of SG_v on cutting speed and kerf width was shown in Fig. 6. When SG_v increases from 25 to 65 V the cutting speed decreases by 0.5 to 0.28 mm/min (78%) and kerf width also decreases by 0.492 to 0.452 mm (8%) simultaneously. This may happen due to the width of spark decreases and electric field strength also decreases. The higher width of spark means longer waiting time for another spark so that it improves the flushing and obtains the stable cut. On the other hand, decrease of SG_v the spark waiting time is lesser, and hence more number of sparks per unit time that leads to higher cutting speed and kerf width.

3.5 *Influence of W_F on Cutting Speed and Kerf Width*

The influence of W_F on cutting speed and kerf width was illustrated in Fig. 7. It was observed that W_F rate at which the wire movements along the wire guide path, it is always necessary to set the W_F to maximum. This will result in less wire breakage; better machining stability improves the cutting speed and kerf width. On high values of W_F rate (2–14 mm/min) cutting speed increases from 0.37 to 0.64 mm/min (72%), whereas kerf width was also affected from 0.363 to 0.385 mm (7%).

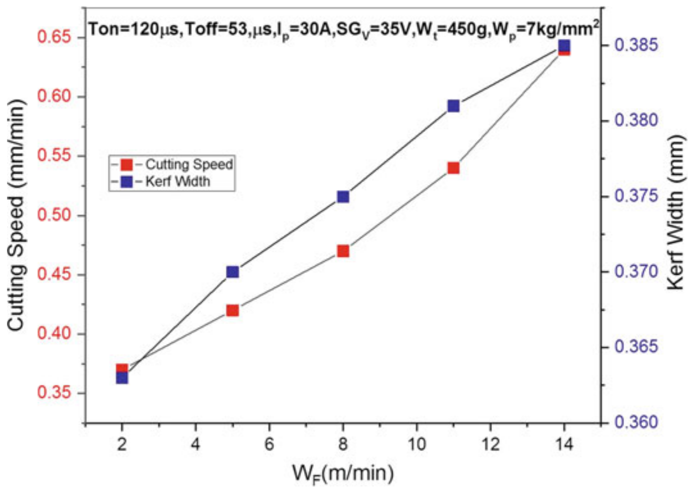


Fig. 7 Influence of W_F on cutting speed and kerf width

3.6 Influence of W_T on Cutting Speed and Kerf Width

As shown in Fig. 8, when W_T varies from 450 to 2200 g the cutting speed increases from 0.35 to 0.55 mm/min (57%) and kerf width (0.431–0.403 mm) also shows the increasing and decreasing trend. The cutting of silicon ingot mainly depends upon the low and high W_T. If it is high the wire moves continuously on the wire guide rollers which will increase the cutting speed and kerf width. But if it is low it produces

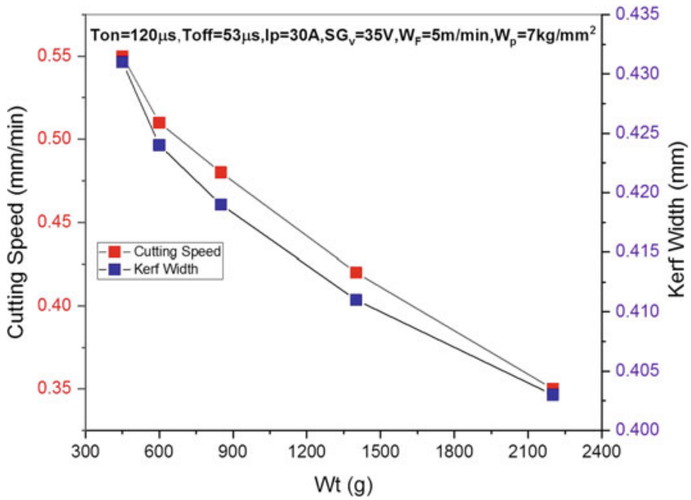


Fig. 8 Influence of W_T on cutting speed and kerf width

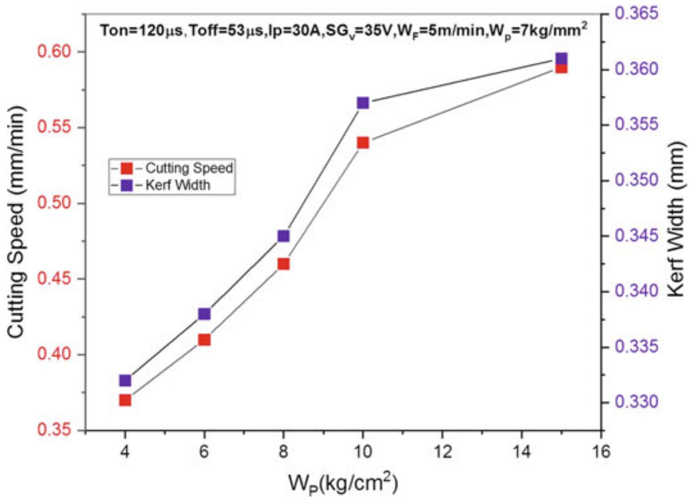


Fig. 9 Influence of W_P on cutting speed and kerf width

the wire lag or deflection that will result in low cutting speed and kerf width. The debris remains clogged in the machining gap that hinders the productivity. Smaller W_t produces inaccurate job profile. The higher value of W_t tends to frequent wire breakage. The larger W_T was recommended for cutting of thick jobs. For present work the medium W_T was considered so that maximum cutting speed and minimum kerf width is achieved.

3.7 *Influence of W_P on Cutting Speed and Kerf Width*

Figure 9 displays the influence of W_P on cutting speed and kerf width. It was observed that the cutting speed increases from 0.37 to 0.59 (59%) with increase of W_P from 4 to 15 kg/cm^2. At higher W_P the wire and the workpiece cools down rapidly, which removes the debris between them. The kerf width was (0.332–0.361 mm) also affected with increase of W_P. This will also happen due to faster removal of debris between gaps which increased the kerf width with stable machining.

4 Conclusions

The present work is a preliminary study of wire cut EDM of polycrystalline silicon ingot material, and the following conclusions are drawn for cutting speed and kerf width:

1. There are seven parameters investigated that show the significant influence on cutting speed and kerf width. The cutting speed was significantly affected 47% by T_{on}, 64% by I_{P}, 78% by SG_{V}, 72% by W_{F} and 100% by T_{off}. The kerf width was observed with less effect (6–10%) and it varies from 0.332 to 0.492 mm.
2. Highest kerf width (0.492 mm) was obtained with 25 V SG_{v}. Lowest cutting speed (0.28 mm/min) was obtained with 65 V SG_{v} and lowest kerf width (0.332 mm) was obtained at W_{P} (4 kg/mm^2). W_{T} (57%) and W_{P} (59%) have less significant parameters on cutting speed and kerf width.

References

1. Huijun, P., Zhidong, L., Lian, G., Mingbo, Q., Zongjun, T.: Study of small holes on monocrystalline silicon cut by WEDM. Mater. Sci. Semicond. Process. **16**, 385–389 (2013)
2. Sreejith, P.S., Udupa, G., Noor, Y.B.M., Ngoi, B.K.A.: Recent advances in machining of silicon wafers for semiconductor applications. Int. J. Adv. Manuf. Technol. **17**, 157–162 (2001)
3. Dobrazanski, L.A., Szczesna, M., Szindler, M., Drygala, A.: Electrical properties mono- and polycrystalline silicon solar cells. J. Achiev. Mater. Manuf. Eng. **59**(2), 67–74 (2013)
4. Bose, D.N.: Polycrystalline production in India. Curr. Sci. **17**(1), 20–21 (2014)
5. Kumar, A., Kumar, V., Kumar, J.: Investigation of micro-cracks susceptibility on machined pure titanium surface in WEDM process. J. Manuf. Sci. Prod. **16**(2), 123–139 (2016)
6. Yu, B.-H., Lee, H.K., Lin, Y.-X., Qin, S.-J., Hunag, F.-Y., Yan, B.-H.: Study of wire electric discharge machining for poly-silicon. In: Asian Symposium for Precision Engineering and Nanotechnology (2009)
7. Yu, B.-H., Lin, Y.-X., Lee, H.-K., Mai, C.-C., Yan, B.-H.: Improvement of wire electrical discharge machining efficiency in machining polycrystalline silicon with auxiliary-pulse voltage supply. Int. J. Adv. Manuf. Technol. **57**, 991–1001 (2011)
8. Yu, B.-H., Lee, H.K., Lin, Y.-X., Qin, S.-J., Yan, B.-H., Hunag, F.-Y.: Machining characteristics of polycrystalline silicon by wire electrical discharge machining. Mater. Manuf. Process. **26**, 1443–1450 (2011)
9. Dongre, G., Singh, R., Joshi, S.S.: Response surface analysis of slicing of silicon ingots with focus on photovoltaic application. Mach. Sci. Technol. Int. **16**, 624–652 (2012)
10. Dongre, G., Vesvivkar, C., Singh, R., Joshi, S.S.: Modeling of silicon ingot slicing process by wire electrical discharge machining. Proc. Inst. Mech. Eng. Part B J. Eng. Manuf. **227**(11), 1664–1678 (2013)
11. Yeh, C.C., Wu, K.L., Lee, J.W., Yan, B.H.: Study on surface characteristics using phosphorous dielectric on wire electrical discharge machining of polycrystalline silicon. Int. J. Adv. Manuf. Technol. **69**(1–4), 71–80 (2013)
12. Punturat, J., Viboon, T., Dumkum, C.: Surface characteristics and damage of monocrystalline silicon induced by wire-EDM. Appl. Surf. Sci. **320**, 83–92 (2014)
13. Ding, H., Liu, Z., Qiu, M., Chen, H., Tian, Z., Shen, L.: Study of multi-cutting by WEDM for specific crystallographic planes of monocrystalline silicon. Int. J. Adv. Manuf. Technol. **84**(5–8), 1201–1208 (2016)
14. Luo, Y.F., Chen, C.G., Tong, Z.F.: Investigation of silicon wafering by wire EDM. J. Mater. Sci. **27**, 5805–5810 (1992)

Taguchi-Based Hardness Optimization of Friction Stir Welding Process

Shwetank Avikal, Jasmeet S. Kalra, Rohit Singh, and K. C. Nithin Kumar

Abstract Friction stir welding (FSW) has been widely acceptable in various welding applications nowadays due to its versatility like the ease in use and eco-friendly. FSW is a solid-phase joining process. It has the inherent property to weld aluminum and other such metals over conventional or solid/liquid phase joining process. FSW seems to be an efficient and one of the new developments in the field of joining process. In the present study, the Taguchi optimization technique is used to improve the hardness and other operational parameters on AA4015. Results show that for maximizing the hardness and optimizing operational parameters of the welded joint, the feed rate is the most influential factor.

Keywords Taguchi · Optimization · Aluminum · FSW · Hardness · Welding

1 Introduction

Aluminum is widely used in the aero and defense sector due to inherent advantages like low weight density and properties like high thermal conductivity and so on. Aluminum and its alloys are not easy to weld due to its porousness and thermal conductivity issue in the weld zone. Also, there is a loss in the mechanical and thermal properties of the noticeable material. Owing to these factors, the material is not easy to weld properly. FSW is a solid phase as well as non-consumable rotating tool welding process. The arrangement of the friction stirs welding inserted the probe in the rotating tool [1–4]. Many researchers optimize the parameter of friction stir welding (FSW) using the Taguchi optimization technique. Kesharwania et al. [5] have applied the Taguchi-gray method to optimize the parameter of FSW to join two dissimilar thin aluminum sheets [5]. Tutar et al. [6] used Taguchi orthogonal array technique to optimize the parameter of FSW like a tensile shear load of the joint on

S. Avikal · J. S. Kalra · R. Singh (✉)
Department of Mechanical Engineering, Graphic Era Hill University, Dehradun, India
e-mail: rohitmajila@gmail.com

K. C. Nithin Kumar
Department of Mechanical Engineering, Graphic Era Deemed To Be University, Dehradun, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_73

AA3003-H12 aluminum alloy [6]. Sahu et al. [7] used the gray-Taguchi technique on AM20 magnesium alloy for optimizing operational parameters [7]. Singh et al. [8] have applied gray-based Taguchi optimization for heat-treated welded joint [8]. Avikal et al. [9] applied gray-based Taguchi optimization for multi-lobe bearing [9].

2 Taguchi Approach

Taguchi method was given by Genichi Taguchi which statistically improves quality of manufactured goods; also, it can be applied to various other fields. In Taguchi, optimization process is based on three-step approach that is system, parameter and tolerance design [1]. The Taguchi method uses orthogonal array to study a large number of variables with a small number of experiments, and orthogonal array significantly reduces number of experiments which help further in reduction of research and development cost [10, 11]. For analyzing the results the Taguchi method uses signal-to-noise (S/N) ratio. This ratio includes mean and the variability factors [12].

The S/N ratio is calculated using the following formulae:

$$\mathrm{S/N} = -10 \log\left[\left(\sum_{1}^{n} \frac{1}{Y_i^2}\right)/n\right]$$

3 Experimental Technique

3.1 Material Selection

The material selected for the study is aluminum (Grade 1050A) sheet of thickness 3 mm and the tool material selected is mild steel. The aluminum is considered as a soft metal which cannot be welded with fusion welding. The properties of material have been given in Table 1.

Table 1 Composition and mechanical properties of aluminum

Composition	Density	Modulus of elasticity	Tensile strength	Hardness
Fe: 0.0–0.7% Mg: 0.1–0.5% Si: 1.40–2.20% Mn: 0.6–1.20% Others: 0.2–0.4% Al: 97.7–95.0%	2.70 g/cm^3	70 GPa	150–200 MPa	50 HB

Table 2 Orthogonal array

	Feed rate	Shoulder diameter	Tip diameter
1	1.5	15	4
2	1.5	15	5
3	1.5	20	4
4	1.5	20	5
5	2.0	15	4
6	2.0	15	5
7	2.0	20	4
8	2.0	20	5

3.2 Orthogonal Array Selection

Orthogonal array has been selected for design of experiments (DOE). Parameters which are incorporated in the present study are as follows:

Feed rate (mm/min) = 1.5, 2.0
Shoulder diameter (mm) = 15, 20.
Tip diameter (mm) = 4, 5

For this work an L8 orthogonal array has been selected with three factors and two levels. MINITAB software has been used in the present study for designing the Taguchi orthogonal array. It is shown in Table 2.

3.3 Preparation of the Fixture

A fixture is a work-holding device used while performing task in the job. The main purpose of the fixture is to securely support and locate the job, ensuring conformity and interchangeability. The fixture designed is of mild steel. The dimension of fixture is 40 × 40 mm.

3.4 Preparation of Specimen and Tool

Totally eight experiments have been performed with varying parameter. Therefore, eight specimens have been prepared according to fixture to conduct the experiment upon it. The dimension of the specimen is 20 × 40 mm per side.

For preparation of tool two different parameters has been considered: shoulder diameter and shoulder tip. Therefore, according to orthogonal array four different tools having shoulder diameter of 15 and 20 mm and pin diameter of 4 and 5 mm have been prepared.

3.5 Welding Operation

After the designing of array, tool, specimen and fixture, welding has been performed on the specimen. The fixture was fixed on the table of horizontal milling machine and the tool was fixed in collet. Then the required rpm has been given to the rotating tool and the required feed has been given to the workpiece fixed in fixture. This rotational motion of tool along with the transverse motion of fixture gives us the required welding on the workpiece.

3.6 Mechanical Test

After welding, hardness tests have been performed upon welded area. The hardness tests have been performed in Rockwell hardness machine with ball indenters of diameter 1/16″, as first minor load of 10 kgf is applied following with major load of 150 kgf which gives us the hardness of the welded area. The scale which is used here is B scale.

4 Test Results and Calculation

After performing the hardness test on our specimen, the results have been shown in Table 3. Table 4 presents the response table for S/N ratio and Table 5 presents the response table for mean.

Figure 1 shows the mean of the response of Table 4, which clearly indicates that the feed rate is the most influential parameter among all the parameters taken for study.

Table 3 Mean and S/N ratio

S. no	Feed rate	Shoulder diameter	Tool diameter	Hardness			Mean	S/N ratio
				Trial 1	Trial 2	Trial 3		
1	1.5	15	4	30	38	35	34.33	30.7
2	1.5	15	5	35	31	31	32.33	30.19
3	1.5	20	4	44	51	46	47	33.44
4	1.5	20	5	50	42	45	45.66	33.19
5	2.0	15	4	48	51	51	50	33.97
6	2.0	15	5	44	51	48	47.66	33.56
7	2.0	20	4	35	31	31	32.33	30.19
8	2.0	20	5	37	39	39	38.33	31.67

Table 4 Response table for S/N ratio (larger is better)

Level	Feed rate (A)	Shoulder diameter (B)	Tool diameter (C)
1	31.88	32.11	32.08
2	32.35	32.12	32.15
Delta	0.47	0.01	0.07
Rank	1	3	2

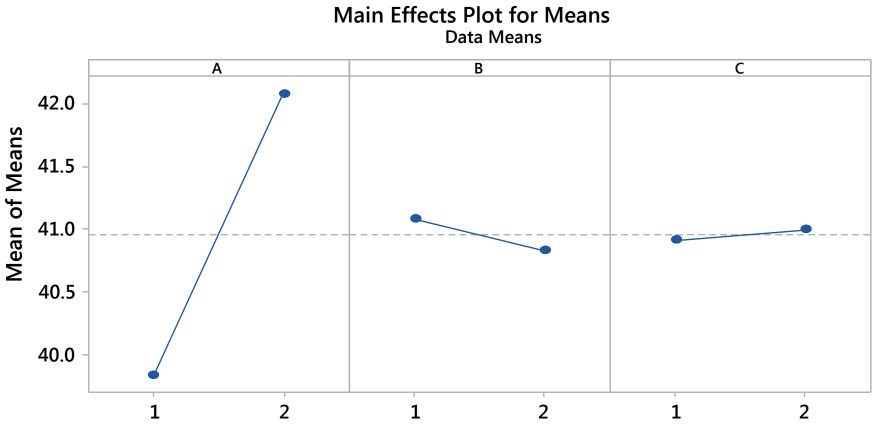


Fig. 1 Main effect plot of means

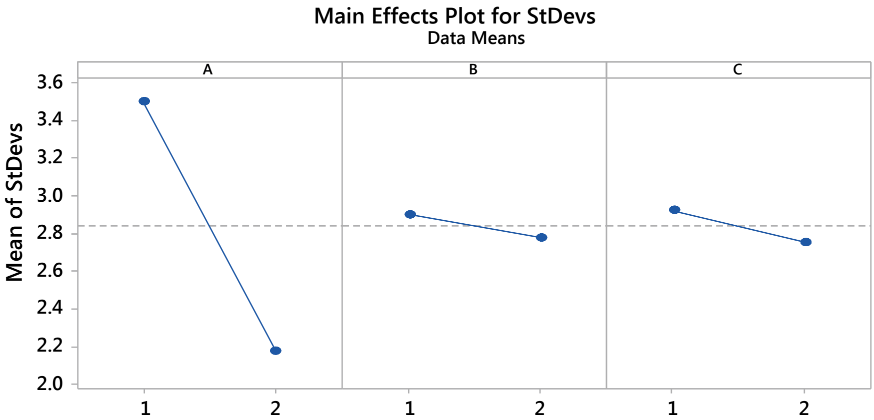


Fig. 2 Main effect plot for S/N ratio

Figure 2 shows the standard deviation of the means which clearly indicates that to optimize the hardness of the material feed rate is the most influential parameter.

5 Conclusions

Taguchi S/N ratios were applied in the present work to improve the hardness of the welded joint. Results of this study are summarized as follows:

- By using Taguchi orthogonal array the number of experiments is reduced to eight.
- Feed rate is the most influential parameter for maximizing the hardness.
- Results shows that the feed rate is the most influential parameter to get the maximum hardness as compared to shoulder diameter and tool tip diameter. Shoulder diameter is the second most influential parameter and tool tip diameter is the least important parameter.
- For maximizing the hardness of the weld joint the optimum condition is feed rate of 2.5 mm/min, shoulder diameter of 20 mm and a tip diameter of 5 mm.
- The confirmation experiment with suggested parameter has been performed and optimum results have been obtained.
- The limitation of the present approach is that it cannot be applied in a multi-objective problem. Another disadvantage is that in Taguchi method there is difficulty in accounting for interactions between parameters.
- In the future work, more parameter can be taken like tensile strength, bending strength, and so on with more advance approaches like gray-Taguchi and ANOVA.

References

1. Thomas W.M., Nicholas E.D., Needham J.C., Murch, M.G., Temple, P.T., Dawes, C.J.: Friction stir butt welding, International patent no. PCT/GB92/02203 (1991)
2. Su, J.Q., Nelson, T.W., Mishra, R., Mahoney, M.: Microstructural investigation of frication stir welded 7050–T651 aluminum. Acta Mater. **51**(3), 713–729 (2003)
3. Rhodes, C.G., Mahoney, M.W., Bingel, W.H.: Effects of friction stir welding on microstructure of 7075 aluminum. Scr. Mater. **36**(1), 69–75 (1997)
4. Kadaganchi, R., Gankidi, M.R., Gokhale, H.: Optimization of process parameters of aluminum alloy AA 2014–T6 friction stir welds by response surface methodology. Def. Technol. **11**(3), 209–219 (2015)
5. Kesharwani, R.K., Panda, S.K., Pal, S.K.: Multi objective optimization of friction stir welding parameters for joining of two dissimilar thin aluminum sheets. Proc. Mater. Sci. **6**, 178–187 (2014)
6. Tutar, M., Aydin, H., Yuce, C., Yavuz, N., Bayram, A.: The optimization of process parameters for friction stir spot-welded AA3003-H12 aluminum alloy using a Taguchi orthogonal array. Mater. Des. **63**, 789–797 (2014)
7. Sahu, P.K., Pal, S.: Multi-response optimization of process parameters in friction stir welded AM20 magnesium alloy by Taguchi grey relational analysis. J. Magn. Alloys **3**(1), 36–46 (2015). https://www.sciencedirect.com/science/article/pii/S2213956714000863

8. Singh, R., Rashmi, N., Bhingole, P., Avikal, A.: Gray based Taguchi optimization for heat treated welded joint. Mater. Today Proc. **5**, 19156–19165 (2018)
9. Avikal, S., Kumar, N.K.C., Singh, A.R., Jain, R.: Gray based Taguchi optimization for multi-lobe bearing. Mater. Today Proc. **5** (2020)
10. Khoei, A.R., Masters, I., Gethin, D.T.: Design optimization of aluminum recycling processes using Taguchi technique. J. Mater. Process. Technol. **127**, 96–106 (2002)
11. Yadav, H.C., Jain, R., Singh, A.R., Mishra, P.K.: Kano integrated robust design approach for aesthetical product design: a case study of a car profile. J. Intell. Manuf. **28**, 1709–1727 (2016)
12. Shanmugarajan, B., Shrivastava, R., Sathiya, P.: Optimization of laser welding parameters for welding of P92 material using Taguchi based grey relational analysis. Def. Technol. **12**(4), 343–350 (2016)

A Fundamental Introduction and Recent Developments of Magnetic Abrasive Finishing: A Review

Ashutosh Pandey and Swati Gangwar

Abstract Recent industrial progress demands various advance machining operations for achieving the superfinishing surfaces. These types of surface cannot be achieved by conventional finishing processes such as grinding, burnishing, honing and lapping. In many cases, some parts of machine do not have requisite surface finish and properties of surface. Firstly, honing superfinishing and other finishing operations are used to finish the small part of a machine. Medical instruments, components of aerospace and other atomic energy parts demand accuracy in surface finish. For finding this type of finishing, a recent or novel finishing operation is denominated, which is known as magnetic abrasive finishing process. The magnetic abrasive finishing is a non-traditional finishing process. This process is applicable to achieve good surface finish and enhance mechanical properties. In magnetic abrasive finishing, the workpiece is put between the magnetic North and South Poles and the gap between the poles and the workpiece is filled with magnetic abrasive particles. The magnetic abrasive flexible brush is made when abrasive particles interact with each other and magnetic field is created in the finishing zone for removing materials to achieve good surface quality of the workpiece material. In this paper, we discuss the different parameters of MAF which have a huge impact on the achievement of surface finish as well as on surface quality of various alloys.

Keywords Magnetic abrasive finishing · Lapping · Grinding · Surface finish

1 Introduction

For attaining good finishing of different workpieces, various surface finishing operations have been employed, but according to the latest demands, the traditional finishing process cannot conform for high precision and surface quality. For the present necessities in the industries, a combination of the machining processes may be offered. In the traditional lapping process, slack abrasive particles have been used.

A. Pandey · S. Gangwar (✉)
Mechanical Engineering, Madan Mohan Malaviya University of Technology, Gorakhpur, India
e-mail: sgme@mmmut.ac.in

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_74

This is in the form of a concentrated paste. Then the actions between lapping plate, workpiece and abrasives are the finishing mechanism. Abrasive particles move independently and they create the indentation cracks along the workpiece. Some materials are removed to obtain a smooth surface [1, 2]. Polishing is a method of finishing. This is used for sleeking the workpiece surface [3]. Honing process is used for improving the geometrical form of the surface. Abrasive grains have been used in the form of powder. It may also improve the surface texture. This process is applied for internal finishing [4]. So, there is a broad application of traditional finishing process. It has many limitations on surface dimensional accuracy and surface finish. These problems include higher cost required to finish material, lower environmental safety, and so on. When pressure is high on the surface of workpiece, it may be spoiling the finished surface [5].

Yin and Shinmura [6] indicated that curved surfaces are typical to finish. So various conventional finishing processes are not successful. Micro-curved surfaces of cast parts of magnesium alloys are complicated to finish because solid tool cannot be able to enter areas. Magnetic abrasive finishing process is the best non-traditional finishing process. This is used in micro-level finishing of material. This technique was first prolongated as finishing process in the United States in 1930s. In 1960s, university research started in Germany, USA, Poland and so on with practical usage taking a form from 1980 to 1990s. Industries and people demand for high surface quality and superior precision. So different industries like semiconductor, optics, aerospace and so on are continuing the development of using better method [7]. MAF process is a modern technique. In this technique, magnetic power is used as a machining force. This force is applied on abrasive particles. Abrasive particles play an important role in finishing process. These particles are magnetic in nature. These abrasives are produced by intermixing of abrasive and ferrous particles in well-controlled manner by magnetic field [8–11]. Force acts toward the workpiece surface. Electric current is applied to manage the process efficiency. Over finishing is prevented by the monitoring of automation [12]. In the magnetic abrasive finishing process, the workpiece is put between the magnetic poles (North and South). Abrasive particles are magnetic in nature. This particle is filled between the gap of a workpiece and magnetic poles. These particles combine with each other. This constructs a flexible magnetic abrasive brush. It acts as a multi-point cutting tool. The workpiece is kept into magnetic field. Finishing edge surface, rotational speed, vibration along the axis and so on are carried out [13] (Fig. 1).

2 Classification of Magnetic Abrasive Finishing

Magnetic abrasive finishing (MAF) can be classified on the basis of magnetic field.

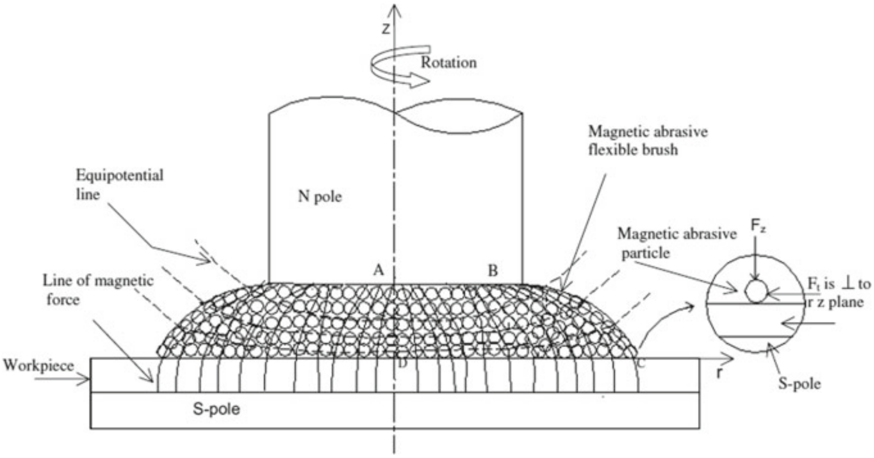


Fig. 1 Diagram of plane magnetic abrasive finishing [9]

2.1 *Magnetic Abrasive Finishing with DC*

Kurobe [14] evolved a polishing setup for executing the finishing process. Setup consists of fluid that is magnetic in nature. Grooves are filled by the fluid in the disk. Magnets are set in the disk in the manner of up and down. Abrasive particles are mixed with water. Magnetic field is created due to supply of DC voltage. That induces the pressure of polishing to execute the operation. Jain et al. [15] described that effect of circumferential speed and the gap between the workpiece and the tool on magnetic abrasive finishing performance. Cylindrical workpiece of stainless steel is used in this experiment. The input current is 2.5 A. The homogeneous abrasive powder is used. This is loosely bonded. Wang and Hu [16] described the internal MAF. This finishing process is used in the application of finishing of inner surface of tubes. Magnetic force and abrasives are defined by the magnetic field.

Yan et al. [17] calculated about electrolytic MAF process. In this finishing process, electrolyte is used to produce the passive film. Different parameters like electrode gap, current, magnetic flux, and so on have been studied. Surface roughness improves due to increasing of feeding rate and electrolytic current. High electrolytic current disturbs the magnetic field and steel grit. Singh [18] used the Taguchi optimization technique to find the influencing parameter of surface quality. Working gap as well as voltage are the most effective parameters. The effect of rotational speed and grain mess number appear to be small. It is investigated that it is necessary for improving the roughness. High-level voltage (11.5 V), small working gap, and large grain mess numbers are evaluated. Change in roughness is indicated by tangential cutting force and magnetic force. This also decreases in working and increase in magnetic force with increasing of the voltage.

2.2 Magnetic Abrasive Finishing with Permanent Magnet

Lin et al. [19] used a permanent magnetic abrasive finishing mechanism. Taguchi technique was used for gathering the experimental data. This is taken from the experimental result. It was obtained that SUS 304 material could improve the roughness from 2.670 to 0.158 μm using permanent magnet abrasive finishing. Singh and Singh [20] investigated that the inner finishing of brass tubes is affected when the MAF process was used. Poles are a permanent magnet. This rotates around the workpiece due to the magnetic field. Due to the pole's rotation, workpiece was finished. Kwak [21] investigated that the density of magnetic flux is improved in the MAF process. MAF employed with permanent magnet has magnificently improved the roughness of surfaces of different type of workpiece shapes, including cylindrical workpiece, plate type workpiece capillary tube and so on. This magnetic abrasive finishing process is mostly used for the workpieces having cylindrical shapes.

2.3 Magnetic Abrasive Finishing with Alternating Current

Sinmura et al. [22] studied the new finishing process. In this finishing process, three-phase alternating current is used which supports the rotation of magnetic tools and finish the workpiece material of SUS 304. The loose abrasive slurry is used. This type of the finishing process is used in the application of internal surface finishing of tubes. Yamaguchi et al. [23] investigated a new internal finishing process which is more in precision. They found that it is used to control surface integrity of the interior surface of component. A magnetic field controls the dynamic motion as well as force of tool. This is required in finishing of tube-type workpiece and cylindrical workpiece with alternating current. Alternating magnetic field is varying and it is difficult to control, but still it has been used for modification of the surface.

3 Principle of Magnetic Abrasive Finishing

3.1 Process Set of Plane Magnetic Abrasive Finishing

Diagram of MAF for plane surface is shown in Fig. 2. The finishing procedure is performed by the magnetic field. Magnetic field exists across the distance between the workpiece and magnetic poles. Magnetic poles form the magnetic field and this field forms a magnetic abrasive brush. Normal force acting on workpiece causes the deletion of material. Gradually it improves the roughness via poles feeding. Plane magnetic abrasive finishing diagram is shown in Fig. 3. Finishing is done by the use of magnetic field across the space between poles and workpiece. Magnetic force, which is generated by the magnetic field, is liable for the normal force that causes the

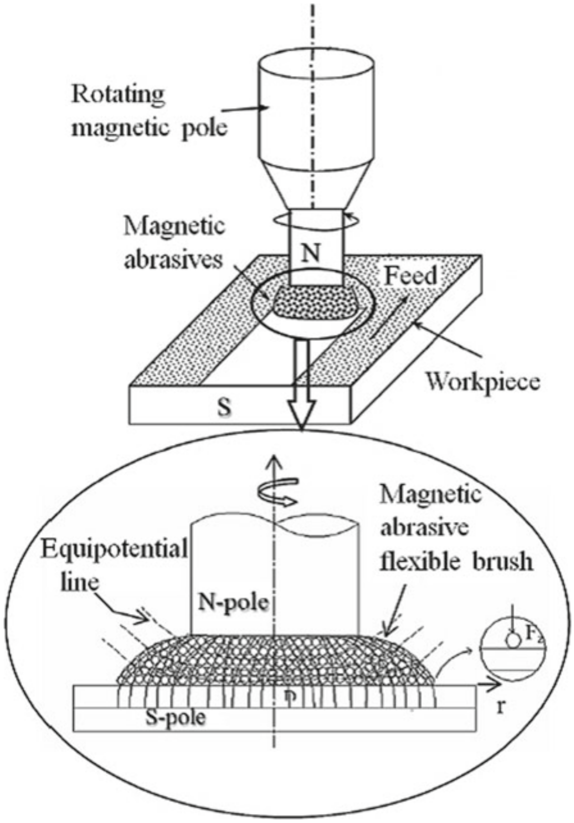


Fig. 2 Mechanism of plane MAF [24]

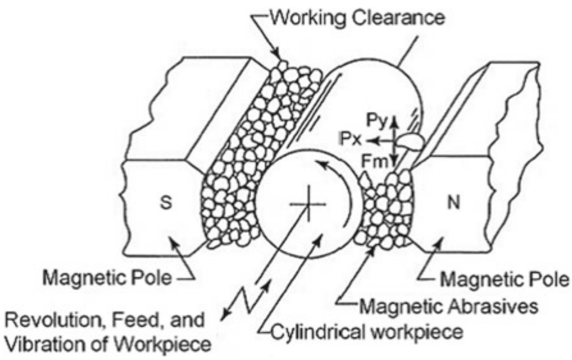


Fig. 3 Figure of cylindrical MAF [25]

penetration in the workpiece. Magnetic abrasive gives the result of material removal in the form of microchip [24].

3.2 Process Setup of Cylindrical Magnetic Abrasive Finishing

Cylindrical magnetic abrasive finishing is shown in Fig. 3. In this finishing process, workpiece is put between the magnetic poles (North and South). Abrasive particles are filled between the workpiece material and magnetic poles. Particles are made of ferromagnetic materials. These particles are magnetic in nature. Abrasives particles are magnetically attached with magnetic poles [25]. This is in the direction of magnetic force. Due to this, a flexible brush is built which is known as magnetic abrasive flexible brush. A simple view of cylindrical MAF is seen in Fig. 3.

3.3 Process Setup of Internal Magnetic Abrasive Finishing

The MAF process is also used for interior surface finishing. This type of finishing was developed in Japan in the belatedly 1980s and 1990s. This finishing process consists of two subsystems:

1. Workpiece rotating [26]
2. Rotating system of magnetic poles [27].

In this finishing process, abrasive particles are kept into the workpiece. These particles are attached through the magnetic fields. The magnetic field is created by dipole–dipole attraction. This makes flexible abrasive brush [28]. Finishing process generates the micro-indentation of workpiece. Tangential force is created by FAMB. This force is the primary cutting force. This force is responsible for micro-chipping. A diagram of internal magnetic MAF is shown in Fig. 4, and its two-dimensional nature in Fig. 5.

4 Recent Growth of Magnetic Abrasives Finishing

Judal et al. [30] have taken the stainless steel AlSI304 (non-magnetic) as workpiece materials having inner diameter = 17 mm, outer diameter = 19 mm and length = 40 mm. They also developed a cylindrical MAF setup and found that the average material removal as 19.79 mg, and average surface roughness as 1.1 μm. They also concluded that frequency of vibration as well as abrasive particles size considerably make an impression on the surface roughness and material removal. Heng et al. [31]

Fig. 4 Internal magnetic abrasive finishing process diagram [29]

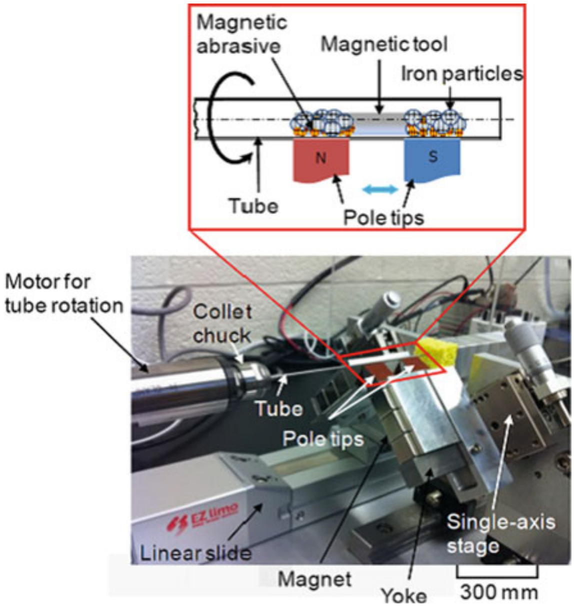
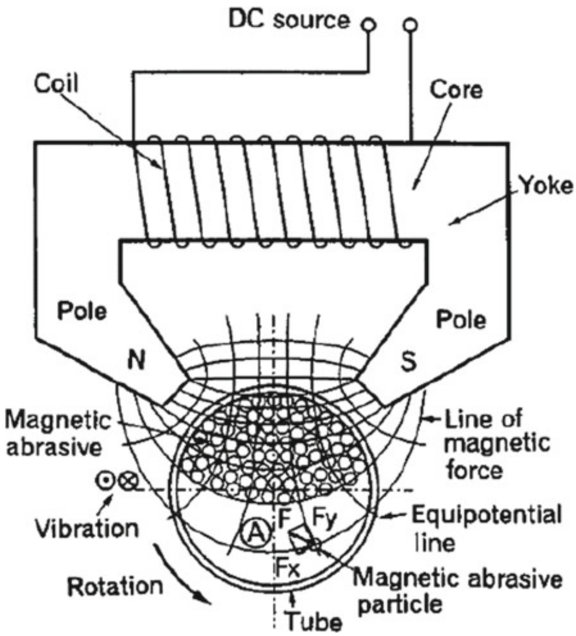


Fig. 5 Two-dimensional abrasive nature of the process [29]



investigated the effect of carbon nanotubes during the finishing of circular magnesium alloy with the use of magnetic abrasive finishing. In this experiment comparison between carbon nanotubes mixed with magnetic abrasive particles. Non-carbon nanotubes mixed with magnetic abrasive particles were done. They concluded that CNT mixed with magnetic abrasive particles offer good surface finish in contrast to non-CNT mixed with magnetic abrasive particles. The reason behind it is carbon nanotubes have good mechanical properties like elasticity. Singh et al. [32] did the investigation of the forces occurring during a MAF process. In this experimental investigation, workpiece and its fixture are prepared. These are of the same ferromagnetic alloy steel. Flux density (magnetic) varies between 0 and 0.44 T in the working gap of 1.00–2.00 mm. Abrasives (SiC) are used for mesh number 600 while iron particles for mesh number 300. They concluded that flux density increases due to decrease in the area of domain. The magnetic field is affected in the lower gap. Gap decreases with increasing magnetic force. This indicates the enhancement of surface roughness as well as forces. Tian et al. [33] evaluated the magnetic abrasive finishing in obtaining the micro-finishing on workpiece of Ti-6Al-4V. In this experiment multiple tip pole finishing is fabricated. It makes the finishing. They concluded that surface roughness 0.073 μm was obtained from the initial 1.195 μm based on the 400 rpm rotational speed of spindle. Rotary table speed is 160 rpm and working gap is 0.7 mm. These enhanced by over 94%. After finishing a smooth surface was obtained without scratches. Jaiswal et al. [34] investigated the magnetic force apportion on workpiece surface by using Galerkin's finite element method (FEM) model. Further, Fortran 90 programming language was used for coding and modeling of magnetic force, surface irregularities and removal of material. Small amount of material erased from surface during indentation was analyzed in their model.

5 Conclusion

Magnetic abrasive finishing is a process that is used for improving the surface finish. This finishing operation provides dimensional accuracy of diverse workpiece shapes such as cylindrical as well as surface accuracy. This paper describes the working principles, types of MAF and recent advances of MAF and explains the results of various researchers in the field of magnetic abrasive finishing.

Conclusion of this study is summarized as follows:

- MAF can be used for external as well as internal surface finishing. This is used in the application of industrial and medical sectors that required micro-level finishing.
- Shapes and size of magnetic poles, working gap, abrasives, and material shape affect the magnetic force. These are very effective parameters.
- Magnetic abrasive finishing is rarely used with alternating current because of difficulty in maintaining and controlling of variable magnetic field.

- Magnetic abrasive finishing has been used with permanent magnet as good finishing of materials for various applications by surface roughness reducing to a satisfactory extent.
- Magnetic abrasive finishing has been successfully applied with direct current for external and internal surface modification of material and has given the nice outcome.

References

1. Cho, B.J., Kim, H.M., Moon, D.J., Park, J.G.: On the mechanism of material removal by fixed abrasive lapping of various glass substrates. Wear **302**, 1334–1339 (2013)
2. Kumar, H., Singh, S., Kumar, P.: Magnetic abrasive finishing—a review. Int. J. Eng. Res. Technol. (IJERT) **2**(3) (2013). ISSN: 2278-0181
3. Ong, N.S., Venkatesh, V.C.: Semi-ductile grinding and polishing of pyrex glass. J. Mater. Process. Technol. **83**, 261–266 (1998)
4. Rajkumar, S., Sasikkumar, M., Ramachandran, R.V., Sabariguru, T., Vinothkumar, M.: Design and implementation of reducing stick mark in honing machining process by using universal joint. Int. J. Mod. Trends Eng. Sci. **2**, 1–4 (2015)
5. Deepak, B., Walia, R.S., Suri, N.M.: Effect of rotational motion on the flat work piece magnetic abrasive finishing. Int. J. Surf. Eng. Mater. Technol. **2**(1), 50–54 (2012)
6. Yamaguchi, H., Shinmura, T., Kaneko, T.: Development of a new internal finishing process applying magnetic abrasive finishing by use of pole rotation system. Int. J. Jpn Soc. Precis. Eng. **30**(4), 317–322 (1996)
7. Shinmura, T., Takazawa, K., Hatano, E., Matsunaga, M.: Study on magnetic abrasive finishing. Appals CIBP **39**(1), 325–332 (1990)
8. Mulik, R.S., Pandey, P.M.: Mechanism of surface finishing in ultrasonic-assisted magnetic abrasive finishing process. Mater. Manuf. Process. **25**, 1418–1427 (2010). https://doi.org/10.1080/10426914.2010.499580
9. Judal, K.B., Yadava, V., Pathak, D.: Experimental investigation of vibration assisted cylindrical-magnetic abrasive finishing of aluminium workpiece. Mater. Manuf. Process. **28**(11), 1196–1202 (2013). https://doi.org/10.1080/10426914.2013.811725
10. Judal, K.B., Yadava, V.: Experimental investigations into electrochemical magnetic abrasive machining of cylindrical shaped nonmagnetic stainless-steel workpiece. Mater. Manuf. Process. **28**(10), 1095–1101 (2013). https://doi.org/10.1080/10426914.2013.792427
11. Amineh, S.J., Tehrani, A.F., Mosaddegh, P., Mohammadi, A.: A comprehensive experimental study on finishing aluminum tube by proposed UAMAF process. Mater. Manuf. Process. **30**(1), 93–98 (2015). https://doi.org/10.1080/10426914.2014.965319
12. Shinmura, T., Takazawa, K., Hatano, E., Aizawa, T.: Study on magnetic abrasive process—process principle and finishing possibility. Bull. Jpn. Soc. Precis. Eng. **19**(1), 54–55 (1985)
13. Kurobe, T.: Magnetic field assisted fine finishing. Bull. Jpn. Soc. Precis. Eng. **17**(1), 49–53 (1983)
14. Jain, V.K.: Magnetic field assisted abrasive based micro-/nanofinishing. J. Mater. Process. Technol. **209**, 6022–6038 (2009)
15. Wang, Y., Hu, D.: Study on the inner surface finishing of tubing by magnetic abrasive finishing. Int. J. Mach. Tools Manuf. **45**, 43–49 (2005)
16. Yan, B., Chang, G., Cheng, T., Hsu, R.: Electrolytic magnetic abrasive finishing. Int. J. Mach. Tools Manuf. **43**, 1355–1366 (2003)
17. Singh, D.K., Jain, V.K., Raghuram, V.: Parametric study of magnetic abrasive finishing process. J. Mater. Process. Technol. **149**(1–3), 22–29 (2004)

18. Lin, C.T., Yang, L.D., Chow, H.M.: Study of magnetic abrasive finishing in free-form surface operations using the Taguchi method. Int. Adv. Manuf. Technol. **34**(122–130), 114 (2007)
19. Singh, S., Singh, L.: Effect of magnetic abrasives in internal finishing of brass tubes using MAF method. J. Acad. Ind. Res. (JAIR) **23**, 689–692 (2014)
20. Kwak, J.S.: Enhanced magnetic abrasive polishing of non-ferrous metals utilizing a permanent magnet. Int. J. Mach. Tools Manuf. **49**, 613–618 (2009)
21. Shinmura, T., Yamaguchi, H., Shinbo, Y.: A new internal finishing process of a non-ferromagnetic tubing by applying a rotating magnetic field. Precis. Eng. **26**(4), 302–304 (1992)
22. Yamaguchi, H., Shinmura, T., Takenaga, M.: Development of a new precision internal machining process using an alternating magnetic field. Precis. Eng. **27**, 51–58 (2003)
23. Patel, K.B., Patel, K.M.: Magnetic abrasive finishing of AISI52100. Int. J. Trend Res. Dev. **1**(1), 1–8 (2014)
24. Laroux, K.G.: Using magnetic abrasive finishing for deburring produces parts that perform well and look great. In: Alluring and Deburring, vol. 60 (2008)
25. Verma, G.C., Kala, P., Pandey, P.M.: Experimental investigations into internal magnetic abrasive finishing of pipes. Int. J. Adv. Manuf. Technol. **88**, 1657–1658 (2017)
26. Yamaguchi, H., Kang, J.: Study of ferrous tools in internal surface and edge finishing of flexible capillary tubes by magnetic abrasive finishing. Trans. NAMRI/SME **38**, 177–184 (2010)
27. Singh, P.; Singh, L.: Optimization of magnetic abrasive finishing parameters with response surface methodology. In: Proceedings of the International Conference on Research and Innovations in Mechanical Engineering. Lecture Notes in Mechanical Engineering, vol. 30, pp. 273–286 (2014)
28. Kang, J., Andrew, G., Yamaguchi, H.: High-speed internal finishing of capillary tubes by magnetic abrasive finishing. In: 5th CIRP Conference on High Performance Cutting, Procedia CIRP, vol. 1 (2012)
29. Shinmura, T., Yamaguchi, H.: Study on a new internal finishing process by the application of magnetic abrasive machining (intern finishing of stainless steel tube and clean gas bomb). Jpn. Soc. Mech. Eng. **38**(4), 798–804 (1995)
30. Judal, K.B., Yadava, V.: Cylindrical electrochemical magnetic abrasive machining of AISI-304 stainless steel. J. Mater. Manuf. Process. **28**(4), 449–456 (2013)
31. Heng, L., Yang, G.E., Wang, R., Kim, M.S., Mun, S.D.: Effect of carbon nano-tube (CNT) particles in magnetic abrasive finishing of Mg alloy bars. J. Mech. Sci. Technol. **29**, 5325–5333 (2015)
32. Singh, D.K., Jain, V.K., Raghuran, V.: Experimental investigation into forces acting during a magnetic abrasive finishing process. Int. J. Adv. Manuf. Technol. **30**, 652–662 (2006)
33. Tian, Y., Shi, C., Fan, Z., Zhou, Q.: Experimental investigations of magnetic abrasive finishing of Ti-6Al-4V using multiple pole-tip finishing tool. Int. J. Adv. Manuf. Technol. **106**(7–8), 3071–3080 (2020)
34. Jaiswal, S.C., Jain, V.K., Dixit, P.M.: Modelling and simulation of magnetic abrasive finishing. Int. J. Adv. Manuf. Technol. **26**, 477–490 (2005)

Study of the Effect of Dielectric on Performance Measure in EDM

Md. Ehsan Asgar and Ajay Kumar Singh Singholi

Abstract Electrical discharge machining (EDM) is an electro-thermal machining process, which is basically a nonconventional method and is broadly used for machining of intricate cut of the hard materials like super alloys or composites with high precision and accuracy. In this process, a pulse discharge is generated between the workpiece and the tool, and also the removal of material from the workpiece takes place. This removal occurs in the presence of dielectric fluid, due to melting and vaporization. In machining process, the dielectric fluid plays a significant role, affecting the different response variables such as material removal rate (MRR), kerf width, surface roughness (SR), tool wear rate (TWR), and so on. So many important factors are considered when we use dielectric fluid in EDM machining such as health, safety and environment, especially when hydrocarbon-based dielectric fluids are used. Toxic emission in this machining process leads to various environmental problem, several health issues due to release of toxic fumes, vapors and aerosols during the machining process. This paper presents the study of different dielectric fluids used in electro-discharge machining and suggests the alternate green dielectric to minimize the environmental impact, leading toward the sustainability.

Keywords EDM · Distilled water · SR · Dielectric fluid · Vegetable oil

1 Introduction

Electro-discharge machining is among the nontraditional method of machining processes, in which thermal energy is used for removal of material. The basic principle is to change electrical discharge into thermal energy through a series of individually separated dielectric fluid [1]. The role of dielectric fluid is important as material removal occurs due to repetitive discharge between the electrode and the

Md. E. Asgar (✉)
GGS Indraprastha University, New Delhi, India
e-mail: asgarehsan@gmail.com

A. K. S. Singholi
GB Pant Government Engineering College, New Delhi, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_75

Table 1 Desired characteristics of different dielectric used in EDM [7–9]

Characteristics	Desired	Vegetable oil	Kerosene	Hydrocarbon oil	Water
Specific gravity	Low	Low	Moderate	High	Low
Flash point	High	High	Low	Low	Low
Toxicity	Low	Low	High	High	Low
Breakdown voltage	High	High	Low	Low	Moderate
Viscosity	Low	Low	Low	High	Low
Carbon content	Low	Negligible	High	High	Negligible
Biodegradability	More	More	Low	Low	More

workpiece. Dielectric fluid removes debris waste throughout the machining and acts as a coolant to maintain temperature. Dielectric fluid insulating is important to avoid electrolysis during EDM machining [2, 3]. The most commonly used dielectric fluids are kerosene, distilled water and hydrocarbon-based dielectric, and decomposition of this dielectric leads to some environmental impact and reduces the performance of machining [4], especially in the hydrocarbon-based dielectric which produces harmful elements that affect the operator health and environment. To overcome this problem, green process is adapted in the EDM by many researchers that includes dry EDM, gaseous dielectric fluid. Currently vegetable oil-based dielectric is attempted to attain sustainable idea in the EDM process [5, 6]. The characteristics of different dielectric fluid used in the EDM process are tabulated in Table 1.

2 EDM Process

In electrical discharge machining, the material erosion from the workpiece surface can be described as follows. Due to growth of strong electrostatic field, breakdown of dielectric medium between the tool (cathode) and the workpiece (anode) happens if the voltage is developed across them. On electrode surface, electrons are discharged from cathode to the anode due to electric fields and they are having minimum distance between them. As a result, dielectric molecules of a medium are affected by electrons and break into +ve ions and electrons, which move along the same ionization path. Therefore, it enhances the field strength. They discharge a large quantity of electrons from the surface, and results in the formation of an ionized column in the spark gap between the electrode and the workpiece. There is a release of huge amount of thermal energy that melts the material from workpiece, and also develops a very small cavity on work surface [10]. Creation of ionized column using EDM process in the shortest distance of work surfaces is shown in Fig. 1.

DC source is used to recharge the capacitor through a resistor after each discharge, as shown in Fig. 2.

Discharge energy is concentrated into a channel of very small cross-sectional area with the help of dielectric fluid. The dielectric fluid also behaves as a coolant and also

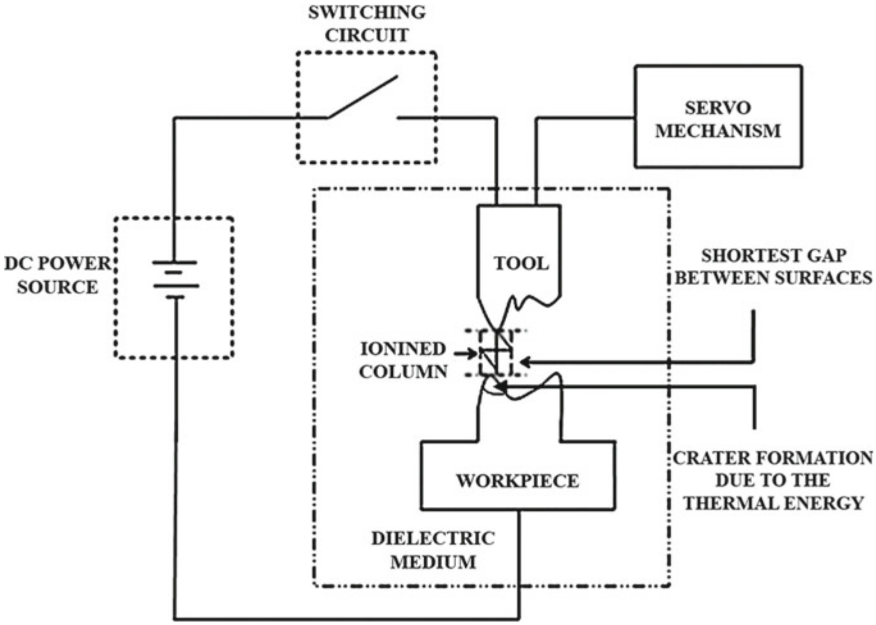


Fig. 1 EDM fundamental mechanism [10]

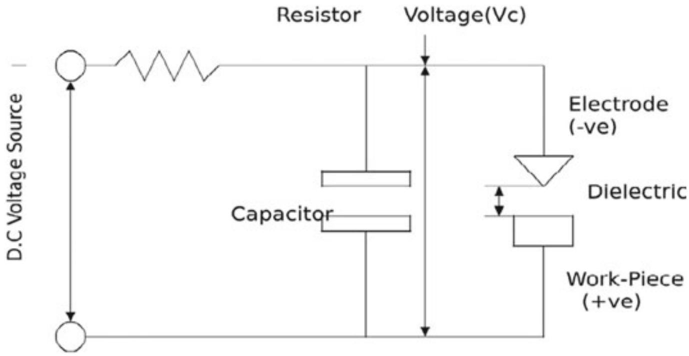


Fig. 2 The Lazarenko RC circuit [11]

removes the small particles from the discharge gap. When spark initiation occurs, the discharge energy is being affected by the electrical resistance. Early discharge will take place when the resistance is minimum. If resistance is high, before the spark occurs, a higher value of charge will be attained by the capacitor. To ensure the tool movement with a suitable rate and also to retract the tool in case of short circuit, a servo mechanism is taken into use, which maintain the gap voltage between the workpiece and the tool. The MRR commonly lies between 2 and 400 mm^3/min and the material removal per unit discharge is typically in the range of 10^{-6}–10^{-4}

depending upon the specific application [12]. Higher value of MRR was not possible to RC circuit. Higher MRR is only possible at the cost of surface finish.

3 Effect of Dielectric Fluid in EDM Machining

The characteristics of kerosene and distilled water have been examined by Jaswani over the pulse energy range from 72 to 288 mJ. While machining at high pulse energy range, higher MRR and lesser tool wear rate is obtained than in kerosene [13]. Also, good surface finish and poor machining accuracy are noticed with the use of distilled water. Jilani and Pandey evaluated the performance of a mixture of tap water and distilled water (25 and 75%) as a dielectric fluid in EDM and found that the performance of tap water is superior on MRR and good surface finish using tap water and distilled water [14] is achieved. Chow and others investigated on titanium (Ti) alloy in micro-slit EDM using pure water and powder of SiC, and concluded that Ti alloy gives high MRR and relatively less tool wear, using pure water [15]. The discharging energy can be effectively scattered by water and SiC powder which will help to attain a higher MRR and also in refinement of the surface roughness, which is not achievable with pure water. Machined burr is usually smaller in water and SiC powder than pure water. Using pure water, the burr formation on the slit edge is shown in Fig. 3. This is due to the small discharge impact that do not separate molten material completely. However, surface roughness enhances using mixed dielectric fluid of pure water and SiC powder. Powder of different materials is used in powder mixed EDM as a dielectric fluid. The ignition process is delayed by the particles due to the production of higher discharge probability and also because of lowering the breakdown strength. As a result, increase in MRR and SR is observed. Also improved sparking efficiency is observed with decrease in TWR. This happens because the gap distance enlarges due to conductive powders and discharges are dispersed throughout the surface more randomly [16]. Micro-cracks are minimized and recast layers also become thin. As a result, the resistance due to corrosion for the machined surface is being enhanced. This is also suggested by Kansal that powder mixed in dielectric fluid (PMEDM) seems likely to be more effective, particularly with process productivity as well as quality of surface of workpiece [17]. Arrangement with reverse polarity (negative tool electrode) is recommended to attain surface modification using powder mixed dielectric. Powders of different materials with grain sizes between 1 and 100 μm are used [18].

Narumiya analyzed that good surface finish is achieved with the powder of Si, SiC or Al with suspended oil than the surface machined without powder [19]. With a powder suspended kerosene dielectric, minimum tool wear was observed [20]. Sharp reduction in electrode wear and considerable improvement in SR (both *R*a and *R*z) have been observed when kerosene and deionized water is used as a dielectric fluid [21]. Fredriksson and Hogmark accomplish the machining of tool steel using silicone oil as a dielectric material on EDM. Also, the result of a hydrocarbon-based fluid and liquid nitrogen is compared [22]. It was found that when copper and graphite

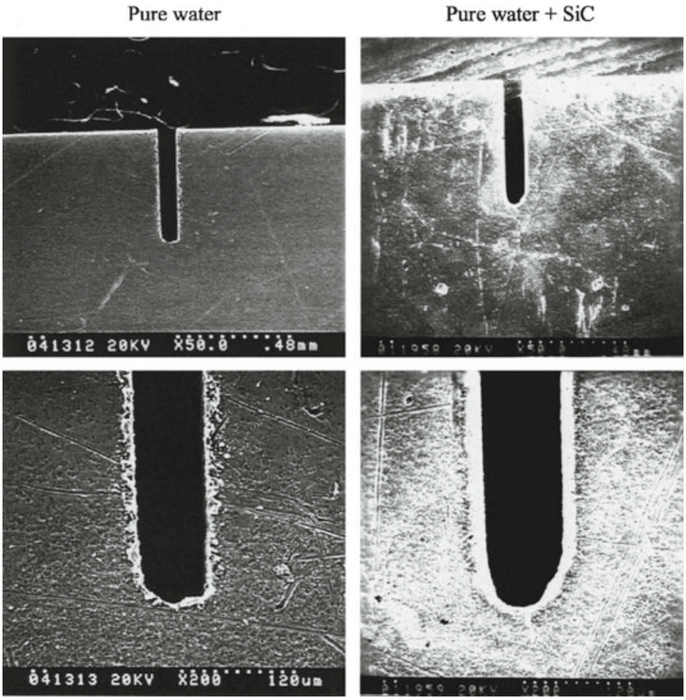


Fig. 3 The micro-slit profile using pure water alone and added SiC powder [15]

electrodes are used for machining at a distinct temperature, the microstructure and surface layer were greatly influenced by the different types of dielectric fluid rather than its temperature. Hardness below the recast layer (400–900 HK) is lowered at high temperature and this is the only effect of temperature change. Valaki et al. examined alternate dielectric fluid, that is, vegetable oil over the conventional fluid in EDM process and concluded that better response is seen with vegetable oil as an alternate dielectric fluid [23]. Khan et al. discussed the sustainability of vegetable oil and Jatropha curcas oil and observed that Jatropha curcas oil-based dielectric possessed some properties better than other dielectric fluids like kerosene while some does not show the good properties [24]. Shah et al. also claim that vegetable oil-based esters have good dielectric characteristics compared with another conventional dielectric [25]. In other experimentation the property of vegetable oil in terms of erosion mechanism is similar with the other dielectric fluid [26]. Mishra et al. investigated nonedible oil (Polanga oil) as a dielectric for EDM process. Polanga oil gives rise to higher productivity and improved process parameter in terms of MRR improvement by 0.86 times, and better surface finish by 16.64%. About 17% reduction in environmental impact through aerosol emission rate confirms with this oil [27]. Investigation related to different dielectric fluid can be further summarized in Table 2.

Table 2 Dielectric fluid used in EDM

Dielectric fluid	Investigation carried out
Water	Jilani and Pandey [14] evaluated the performance of tap water, mixture of tap water and distilled water as a dielectric fluid in EDM and found that performance of tap water is superior on MRR and good surface finish in tap water and distilled water
	Chow et al. [15] investigated for titanium (Ti) alloy using pure water and powder of SiC, and concluded that Ti alloy gives high MRR and relatively less tool wear, using pure water
	Jaswani [13] examined the comparison of the characteristics of water and kerosene over the pulse energy range from 72 to 288 mJ. While machining at high pulse energy range, higher MRR and lesser tool wear rate is obtained than in kerosene
Kerosene	Kozak et al. [21] studied the sharp reduction in electrode wear and considerable improvement in SR (both *R*a and *R*z), when kerosene and deionized water is used as a dielectric fluid
	Tzeng et al. [20] investigated using powder-suspended kerosene dielectric and observed that the tool wear rate is minimum
Vegetable oil	Valaki et al. [23] examined vegetable oil over the conventional fluid in the EDM process and concluded that better response is seen with vegetable oil as an alternate dielectric fluid in terms of performance
	Khan et al. [24] discussed the sustainability of Jatropha curcas oil and observed that Jatropha curcas oil-based dielectric possessed some properties better than other dielectric fluids like kerosene while some does not show the good properties
	Shah et al. [25] claimed that vegetable oil-based esters have good dielectric characteristics compared with the other conventional dielectric
	Singaravel et al. [26] examined the property of vegetable oil on Ti-6Al-4 V for EDM and shows better SR than conventional dielectric
	Mishra and Routara [27] investigated nonedible oil (Polanga oil) as a dielectric for EDM process. Polanga oil gives rise to higher productivity and shows improved MRR, better surface finish and reduction in environmental impact

4 Conclusion

The selection of dielectric fluid for EDM is a tough task as it has a great effect on process performance, environmental impact and economics. Many scholars tried to optimize different parameters to enhance the output responses of EDM in terms of MRR, SR, electrode wear, and so on using different dielectric fluids like gaseous dielectric, hydrocarbon oil, kerosene, and vegetable oil. It is observed that water-based dielectrics have similar or higher performance compared with hydrocarbon oil. Better response can be obtained by mixing of powder with different grain sizes. The literature shows that vegetable oils are successfully employed as dielectric fluid and shows the similar erosion mechanism compared with the other dielectric fluid.

Vegetable oil as a dielectric shows the minimum surface roughness, better environmental impact and operator safety that make it as a green process. For increasing the machinability characteristics using vegetable oil, more studies are required.

References

1. Tsai, K.M., Wang, P.J.: Predictions on surface finish in electrical discharge machining based upon neural network models. Int. J. Mach. Tools Manuf. **41**(10), 1385–1403 (2001)
2. Asgar, Md.E., Singholi, A.K.S.: IOP Conf. Ser. Mater. Sci. Eng. **404**, 012007 (2018)
3. Singh, K., Gianender, K., Agarwal, A.K., Ajit, Y.R.: Effect of dielectric fluids used on EDM performance: a review. Int. J. Emerg. Technol. Eng. Res. **5**(10) (2017). ISSN: 2454–6410
4. Valaki, J.B., Rathod, P.P., Khatri, B.C.: Environmental impact, personnel health and operational safety aspects of electric discharge machining: a review. Proc. Inst. Mech. Eng. Part B J. Eng. Manuf., 1481–1491
5. Razak, M.A., Abdul-Rani, A.M., Nanimina, A.M.: Improving EDM efficiency with silicon carbide powdered-mixed dielectric fluid. Int. J. Mater. Mech. Manuf. **3**(1), 40–43 (2015)
6. Yan, B.H., Tsai, H.C., Huang, F.Y.: The effect in EDM of a dielectric of a urea solution in water on modifying the surface of titanium. Int. J. Mach. Tools Manuf. **45920**, 194–200 (2005)
7. Amanullah, M., Islam, S.M.. Chami, S., Ienco, G.: Analyses of electro-chemical characteristics of vegetable oils as an alternative source to mineral oil-based dielectric fluid. In: IEEE International Conference on Dielectric Liquids, 2005. ICDL 2005, June 2005, pp. 365–368
8. Amanullah, M., Islam, S.M., Chami, S., Ienco, G.: Analyses of physical characteristics of vegetable oils as an alternative source to mineral oil-based dielectric fluid. In: IEEE International Conference on Dielectric Liquids, 2005. ICDL 2005, pp. 397–400
9. Srinivas Viswanth, V., Ramanujam, R., Rajyalakshmi, G.: A review of research scope on sustainable and eco-friendly electrical discharge machining (E-EDM). Mater. Today Proc. **5**, 12525–12533 (2018)
10. Jameson, E.C.: Electrical Discharge Machining, 1st edn. Society of Manufacturing Engineers, Michigan (2001)
11. McGeough, J.A.: Advanced Methods of Machining, 1st edn. Chapman and Hall, USA (1988). ISBN 0-412-31970-5
12. Kalpajian, S., Schmid, S.R.: Material Removal Processes: Abrasive, Chemical, Electrical and High-Energy Beam in Manufacturing Processes for Engineering Materials, p. 541. Prentice Hall, New Jersey (2003)
13. Jeswani, M.L.: Electrical discharge machining in distilled water. Wear **72**, 81–88 (1981)
14. Tariq, S.J., Pandey, P.C.: Experimental investigations into the performance of water as dielectric in EDM. Int. J. Mach. Tool Des. Res. **24**, 31–43 (1984)
15. Chow, H.M., Yang, L.D., Lin, C.T., Chen, Y.F.: The use of SiC powder in water as dielectric for micro-slit EDM machining. J. Mater. Process. Technol. **195**, 160–170 (2008)
16. Kansal, H.K., Singh, S., Kumar, P.: Parametric optimization of powder mixed electrical discharge machining by response surface methodology. J. Mater. Process. Technol. **169**(3), 427–436 (2005)
17. Kansal, H.K., Singh, S., Kumar, P.: Technology and research developments in powder mixed electric discharge machining (PMEDM). J. Mater. Process. Technol. **184**, 32–41 (2007)
18. Zhao, W.S., Meng, Q.G., Wang, Z.L.: The application of research on powder mixed EDM in rough machining. J. Mater. Process. Technol. **129**, 30–33 (2002)
19. Narumiya, H., Mohri, N., Saito, N., Ootake, H., Tsunekawa, Y., Takawashi, T., Kobayashi, K.: EDM by powder suspended working fluid. In: Proceedings of the ISEM, vol. 9, pp. 5–8. Nagoya, Japan (1989)
20. Tzeng, Y.F., Lee, C.Y.: Effect of powder characteristics on electro discharge machining efficiency. Int. J. Adv. Manuf. Technol. **17**(8), 586–592 (2001)

21. Kozak, J., Rozenek, M., Dabrowski, L.: Study of electrical discharge machining using powder-suspended working media. J. Eng. Manuf. Proc. Instrum. Mech. Eng. **217**, 1597–1602 (2003)
22. Fredriksson, G., Hogmark, S.: Influence of dielectric temperature in EDM of hot worked tool steel. Surf. Eng. **11**(4), 324–330 (1995)
23. Valaki, J.B., Rathod, P.P., Sankhavara, C.D.: Investigations on technical feasibility of Jatropha curcas oil based bio dielectric fluid for sustainable electric discharge machining (EDM). J. Manuf. Process. **22**, 151–160 (2016)
24. Khan, M.y., Rao, P.S., Pabla, B.S.: Investigations on the feasibility of Jatropha curcas oil based biodiesel for sustainable dielectric fluid in EDM process. Mater. Today Proc. (2019). https://doi.org/10.1016/j.matpr.2019.11.325
25. Shah, Z.H., Tahir, Q.A., Town, C.J.: Dielectric properties of vegetable oils. J. Sci. Res. **3**(3), 481–492 (2011)
26. Singaravel, B., Shekar, K.C., Reddy, G., Prasad, S.D.: Experimental investigation of vegetable oil as a dielectric fluid in electric discharge machining of Ti-6Al-4V. Ain Shams Eng. J. **11**, 143–147 (2020)
27. Mishra, B.P., Routara, B.C.: Evaluation of technical feasibility and environmental impact of calophyllum inophyllum (Polanga) oil based bio-dielectric fluid for green EDM. Measurement **159**, 107744 (2020). https://doi.org/10.1016/j.measurement.2020.107744

Optimization of Cylindrical Grinding for Material Removal Rate of Alloy Steel EN9 by Using Taguchi Method

Pravin Jadhav, Pranali Patil, and Sharadchandra Patil

Abstract Grinding is a machining process used to finish the component. The composition of abrasive grains forms the grinding wheel. The grinding tool made up of abrasive grains is used to remove tiny-sized material from the workpiece. The parts which are machined from an initial shape are generally cylindrical. Increasing the material removal rate (MMR) is often accompanied by tool wear. The primary objective of the study is to use the Alloy Steel EN9 in cylindrical grinding machining to determine the cutting speed, depth of cut, and feed rate on the process of performance as material removal rate. The experiment is conducted using the aluminum oxide (Al_2O_3) grinding wheel. In this work, the test is outlined using the Taguchi method and the gray relational analysis (GRA) method. For single optimization, it is found that the depth of cut affects more on MRR. Based on the experimental results for single optimization Alloy Steel EN9 for cylindrical grinding may be used with MRR. It is observed that the depth of cut is the most important factor by 92.05% and then the minimum influence due to cutting speed by 4.66% and feed rate by 0.94%. The maximum MRR obtained is 2.675 g/min, by using a cutting speed 1900 rpm, depth of cut 0.06 mm, and feed rate 0.04 mm/rev. MRR is linearly raised with a depth of cut. Finally, an attempt has been made for the estimation of the optimum cylindrical grinding machining conditions to produce the best desirable response within the experimental constraint.

Keywords Cylindrical grinding · Taguchi method · Alloy steel EN9 · Material removal rate

1 Introduction

Cylindrical grinding is the process of finishing of element used for a smooth surface and close tolerance. During grinding fine chips are separated from the workpiece, and this operation can be used to divine the grinding behavior, as well as to attain

P. Jadhav (✉) · P. Patil · S. Patil
Karmaveer Bhaurao Patil College of Engineering, Satara 415001, India
e-mail: pravin.jadhav@kbpcoes.edu.in

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_76

optimal operating process parameters. The workpiece object must have control axis of rotation, held in rigidity between the center in a chuck or a suitable holding fixture and the revolving grinding wheel is fed against it. The depth of cut is determined by the feed of the wheel or workpiece. The major elements of grinding operation are two wheels rotating in the same direction: grinding wheel and workpiece. The workpiece revolving and abrasive grinding wheel are fed forward-facing toward the workpiece. In cylindrical grinding process abrasive particles of grinding wheel tools remove material from the workpiece and improve the quality of the surface finish.

Many literature sources covered the application of optimization techniques to the cylindrical grinding process related to input parameters and output response parameters. Melwin et al. [1] performed experimentation on OHNS (AISI 0–1) rounds using a cylindrical grinding machine. The surface quality of OHNS steel was to be studied in the experimental work using the L9 orthogonal array for three levels. It was found that the optimum parameter of metal removal rate of OHNS cylindrical steel rounds was 0.02 mm depth of cut, 150 rpm of work speed, and 1 number of the pass during the experiment. Khan et al. [2] investigated the optimization of an in-feed centerless cylindrical grinding of SS material using gray relation analysis. The Taguchi method (L9 orthogonal array) was employed for the experimentation. The largest GRA value calculated is 0.9745. Mekala et al. [3] conducted a study on austenite SS material using a cylindrical grinding machine. The experimental design had been performed by Taguchi L9 orthogonal array used. The experiment was optimized by ANOVA and the *S*/*N* ratio. It was found that cutting speed was an influencing factor, whereas the depth of the cut is the second important parameter for better results. George et al. [4] presented experimental work with cylindrical grinding with different alloys of SS material with different hardness values and L9 orthogonal array. The surface roughness decreases as the hardness of material increases. Kumar et al. [5] performed experimental work employing a cylindrical grinding machine for optimal MRR and the influence of process factors. It was concluded that optimal grinding conditions for MRR were the depth of cut of 0.020 mm, cutting speed 41.07 m/min, and optimal MRR was 19.906 mm^3/s. Kolhar and Mench [6] experimented optimizing process parameter material removal rate using Alloy Steel EN24 on the CNC grinding machine. The experiment was carried out using Al_2O_3 and SiC type of wheel material. The results of the optimum machining parameters were found using an aluminum oxide having wheel. The aluminum oxide wheel gives a better material removal rate. Pal et al. [7] conducted a test with cylindrical grinding. The experiments were designed with the Taguchi method (L9 orthogonal array) for EN24, EN31, and die steel material. It was observed that a surface roughness value decreases as the cutting speed increases. Ganesan et al. [8] had done process optimization for the cylindrical grinding process and design of experiments is done with Taguchi's method for 304 SS material. It was observed that the cutting speed was a key parameter for process optimizing. Kumar et al. [9] experimented with CNC grinding machine and alloy steel EN24 to optimize process parameters for surface roughness with aluminum oxide and silicon carbide grinding wheels. It was found that the grinding wheel made up of silicon carbide (SiC) gives minimal surface roughness than the aluminum oxide wheel. Pai et al. [10] performed experimental work for the cylindrical grinding machine with Al-Si (MMC) material. The experimental design had been done with the Taguchi method (L27 orthogonal array). The surface roughness quality increased as the hardness of the material increased. Kumar et al. [11] carried out experimental work for the cylindrical grinding machine with EN47 material. The design of the experiment had been done with an L18 orthogonal array (Taguchi method). As the rotational speed of the workpiece increases, the signal-to-noise ratio increases. Kumar and Bhatiya [12] carried out an experimental analysis cylindrical grinding with EN15AM steel material using the Taguchi method. The best results were found at the 1800 and 155 rpm speed of the grinding wheel and workpiece, respectively. Rekha and Baskar [13] carried out an experimental study on cylindrical grinding with Al-Si316 stainless steel material using neural network (NN) and genetic algorithm (GA). The model was developed to know MRR and surface roughness value.

The literature survey shows that less work was carried on the single optimization using alloy steel EN9 for cylindrical grinding results of material removal rate (MRR) with Taguchi experimental design with an L27 orthogonal array. In this paper experimental work is carried out using the EN9 alloy steel and cylindrical grinding. The objective of the paper is to optimize results for material removal rate for the cylindrical grinding of alloy steel EN9 by using Taguchi method having an L27 orthogonal array.

2 Test Methodology

2.1 Response Parameters and Process Parameter

The productivity largely depends on the material removal rate (MRR). The selection of process parameter in cylindrical grinding depends upon the work material. The process parameters for experimental work are selected as cutting speed, depth of cut, and feed rate. MRR is a significant performance measuring parameter in the cylindrical grinding process. The following equation is used to calculate the material removal rate (MRR).

$$\mathrm{MRR} = \frac{W_i - W_f}{t}\ \mathrm{g/min},$$

In this study, W_i is the weight of the workpiece before machining, W_f is the weight workpiece after machining and t is the time of machining.

Table 1 Machining factors and levels

S. no.	Parameters with unit	Level 1	Level 2	Level 3
1	Cutting speed (V_c) in rpm	1700	1900	2200
2	Depth of cut (A_p) in mm	0.02	0.04	0.06
3	Feed rate (F) in mm/rev	0.04	0.06	0.08

2.2 Selection of Levels and Ranges for the Experiment

By referencing the literature, the levels for process parameters like cutting speed, depth of cut, feed rate were considered as shown in Table 1. Moreover, the ranges of the machining process parameter are decided as per the suggestions in the open literature review. Three levels of each process parameter are selected.

3 Design of Experiment

The design of experiment requires (DOE) careful planning. The product layout of the experiment and analysis of results are carried out. The design of experiment is done with the Taguchi technique to optimize the process of experimentation. The Taguchi method is involved in orthogonal arrays to frame the parameter influencing the levels and process. Also the data required to determine future effect on product quality are collected with a minimum number of experiments.

3.1 Selection of Orthogonal Array

As shown in Table 2, in the experimentation, three parameters and three levels of each are selected. Taguchi method is employed which has L27 orthogonal arrays. There are 27 experiments carried out to study the entire process of parameter space.

3.2 Experimental Procedure

The objective of this work is to study the influence of grinding parameters with process parameters. Alloy steel EN9 is selected as the workpiece material, having a diameter of 30 mm × 70 mm length after the turning process. The workpiece material was cut into pieces with an approximate length of 70 mm and utilized to finish material using center type cylindrical grinding. The Aluminium oxide (Al_2O_3) grinding wheel was selected as a tool.

Table 2 Orthogonal array for experiment

Experiment no.	Cutting speed (V_c) (rpm)	Depth of cut (A_p) (mm)	Feed rate (F) (mm/rev)
1	1700	0.02	0.04
2	1700	0.02	0.04
3	1700	0.02	0.04
4	1700	0.04	0.06
5	1700	0.04	0.06
6	1700	0.04	0.06
7	1700	0.06	0.08
8	1700	0.06	0.08
9	1700	0.06	0.08
10	1900	0.02	0.06
11	1900	0.02	0.06
12	1900	0.02	0.06
13	1900	0.04	0.08
14	1900	0.04	0.08
15	1900	0.04	0.08
16	1900	0.06	0.04
17	1900	0.06	0.04
18	1900	0.06	0.04
19	2200	0.02	0.08
20	2200	0.02	0.08
21	2200	0.02	0.08
22	2200	0.04	0.04
23	2200	0.04	0.04
24	2200	0.04	0.04
25	2200	0.06	0.06
26	2200	0.06	0.06
27	2200	0.06	0.06

3.3 Data Analysis Method (S/N *Ratio Analysis)*

There are three groups of qualities feature in the analysis of *S*/*N* ratio: the smaller the better, the higher the better, and the nominal the better. The *S*/*N* ratio for each level of process parameter is computed based on *S*/*N* analysis.

$$\frac{S}{N} = -10 \times \log\left[\frac{1}{n}\right]\sum_{i=1}^{n}\frac{1}{Y_i^2} \quad \text{For higher the better characteristics}$$

$$\frac{S}{N} = -10 \times \log\left[\frac{1}{n}\right]\sum_{i=1}^{n} Y_i^2 \quad \text{For lower the better characteristics}$$

$$\frac{S}{N} = -10 \times \log\left[\frac{1}{ns}\right]\sum_{i=1}^{n} Y_i^2 \quad \text{For normal the better characteristics}$$

Analysis of variance (*ANOVA*). The variance of the observations is calculated by a sum of squares (SS), degree of freedom (DOF), mean square (MS), and percentage of each factor. The procedure works by comparing the variance between groups mean versus the variance within groups with different characteristics.

4 Analysis of Machining Data

The experimental outcomes indicated in Table 3 are based on the optimal parameter combination level of the multiple performance characteristics. The machining of alloy steel EN9 using aluminum oxide (Al_2O_3) grinding wheel was carried out with different settings and combinations of process parameters as that of the L27 orthogonal array. MRR is computed by weighing their weights before and after machining and the time is measured for each experiment. The major influence of material removal rate on the mean value concerning cutting speed, depth of cut, and feed rate is shown in Fig. 1. The MRR value commonly rises with increasing feed rate, depth of cut, and cutting speed. From Fig. 1, it is observed that at 1700 rpm material removal rate increases as the depth of cut and feed rate increases. The rank exhibits the significance of each factor in terms of the response. Moreover, Table 4 shows the ranks and the delta values for numerous inlet values for MRR, which shows that the depth of cut has the largest effect on MRR than the cutting speed and feed rate. The result from Table 5 shows the confidence level of 95%, with the significance level of 5%. The depth of cut in grinding operation is most influenced by MRR by 92.05%. An optimal machining parametric setting for achieving the best result during cylindrical grinding machining with highest material removal rate has been found and summarized in Table 6 for alloy steel EN9. Table 7 shows the validation experiments conducted using the same experimental setup and measuring instruments.

5 Conclusion

Based on the experimental results achieved in the present study for single optimization using alloy steel EN9 for cylindrical grinding results of material removal rate, it is concluded that the depth of cut is the most significant factor by 92.05% and then least effect of cutting speed by 4.66% and feed rate by 0.94%. The maximum

Table 3 Experimental results for alloy steel EN9

Exp. no	Process parameter		Response parameter	
	Cutting speed (rpm)	Depth of cut (mm)	Feed rate (mm/rev)	Material removal rate (g/min)
1	1700	0.02	0.04	1.242
2	1700	0.02	0.04	1.268
3	1700	0.02	0.04	1.204
4	1700	0.04	0.06	1.603
5	1700	0.04	0.06	1.601
6	1700	0.04	0.06	1.719
7	1700	0.06	0.08	2.317
8	1700	0.06	0.08	2.429
9	1700	0.06	0.08	2.430
10	1900	0.02	0.06	1.400
11	1900	0.02	0.06	1.520
12	1900	0.02	0.06	1.768
13	1900	0.04	0.08	1.872
14	1900	0.04	0.08	1.875
15	1900	0.04	0.08	1.941
16	1900	0.06	0.04	2.675
17	1900	0.06	0.04	2.560
18	1900	0.06	0.04	2.510
19	2200	0.02	0.08	1.392
20	2200	0.02	0.08	1.457
21	2200	0.02	0.08	1.468
22	2200	0.04	0.04	1.567
23	2200	0.04	0.04	1.600
24	2200	0.04	0.04	1.771
25	2200	0.06	0.06	2.520
26	2200	0.06	0.06	2.601
27	2200	0.06	0.06	2.643

material removal rate obtained is 2.675 g/min and is obtained at cutting speed of 1900 rpm, depth of cut 0.06 mm, feed rate 0.04 mm/rev. The material removal rate linearly increased with increasing depth of cut. Finally, an attempt has been made to estimate the optimum machining conditions to produce the best possible response within the experimental constraint.

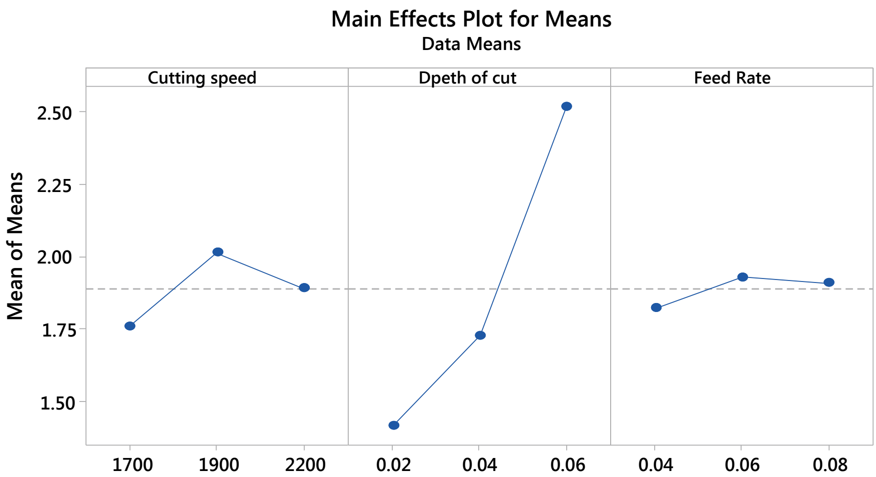


Fig. 1 Main effects plot for means of material removal rate for alloy steel EN9

Table 4 Response for the mean values of MRR for alloy steel EN9

Level	Cutting speed	Depth of cut	Feed rate
1	1.757	1.413	1.822
2	2.013	1.728	1.931
3	1.891	2.521	1.909
Delta	0.256	1.107	0.109
Rank	2	1	3

Table 5 ANOVA test for material removal rate for alloy steel EN9

Source	DF	SS	MS	% Contribution
Cutting speed	2	0.29614	0.14807	4.66
Depth of cut	2	5.86121	2.93060	92.05
Feed rate	2	0.05958	0.02979	0.94
Error	20	0.14997	0.00750	2.35
Total	26	6.36690		100

Table 6 Experimental results for optimal parametric combinations for cylindrical grinding for alloy steel EN9

Performance measures	Required quality characteristics	Process parameters		
		Cutting speed (rpm)	Depth of cut (mm)	Feed rate (mm/rev)
MRR (mm^3/min)	Higher—the—better	1900	0.06	0.06

Table 7 Validation experiments are conducted using the same experimental setup and measuring instruments

Performance measures	Required quality characteristics	Process parameters			Experimental values
		Cutting speed (rpm)	Depth of cut (mm)	Feed rate (mm/rev)	
MRR (g/min)	Higher—the—better	1900	0.06	0.06	2.677

References

1. Melwin, M., Sridhar, J., Manickam, M., Kalaiyarasan, V.: Optimization of cylindrical grinding process parameters of OHNS steel (AISI 0–1) rounds using design of experiments concept. Int. J. Eng. Trends Tech. **17**, 109–114 (2014)
2. Khan, Z.A., Siddique, A.N., Kamaruddin, S.: Optimization of in-feed centreless cylindrical grinding process parameters using grey relational analysis. Int. J. Eng. Res. Appl. **2**, 257–268 (2012)
3. Mekala, K., Chandradas, J., Chandraselaran, K., Kannan, T.T., Ramesh, E., Narasing Babu, R.: Optimization of cylindrical grinding parameters of austenitic stainless steel rods (AISI 316) by Taguchi method. Int. J. Mech. Eng. Rob. Res. **3**, 1–5 (2014)
4. George, L.P., Job, V., Chandran, I.M.: Study on surface roughness and its prediction in cylindrical grinding process based on Taguchi method of optimization. Int. J. Sci. Res. Publ. **3**, 1–5 (2013)
5. Kumar, K., Chattopadhyaya, S., Singh, H.: Optimal material removal and effect of process parameters of cylindrical grinding machine by Taguchi method. Int. J. Eng. Res. Stud. **2**, 1–5 (2012)
6. Kolhar, P., Mench, R.: Optimization of process parameters in grinding process to reduce the rework in case of piston using Taguchi technique. Int. J. Mech. Eng. **2**, 1–5 (2014)
7. Pal, D., Bangar, A., Sharma, R., Yadav, A.: Optimization of grinding parameters for minimum surface roughness by Taguchi parametric optimization technique. Int. J. Mech. Ind. Eng. **1**, 74–78 (2012)
8. Ganeshan, M., Karthikeyan, S., Karthikeyan, N.: Prediction and optimization of cylindrical grinding parameters for surface roughness using Taguchi method. J. Mech. Civ. Eng. **2**, 39–46 (2010)
9. Kumar, P., Kumar, A., Singh, B.: Optimization of process parameters in cylindrical grinding using response surface methodology. Int. J. Res. Mech. Eng. Technol. **3**, 245–252 (2013)
10. Pai, D., Rao, S., Shetty, R.: Application of Taguchi and response surface methodologies for metal removal rate and surface roughness in grinding of DRAC'S. Int. J. Eng. Manag. Sci. **3**, 1–8 (2012)
11. Kumar, M., Singh, S., Goyal, K.: To study effect of grinding parameters on surface roughness and material removal rate of cylindrical grinding of heat treated EN 47 steel. J. Mech. Eng. **ME 45**, 81–87 (2015)
12. Kumar, S., Singh Bhatiya, O.: Analysis and optimization of cylindrical grinding process on material removal rate of EN15AM steel. Int. J. Mech. Eng. **12**, 35–43 (2015)
13. Rekha, R., Baskar, N.: NN-GA based modelling and optimization of cylindrical grinding process. Int. J. Res. Mech. Eng. Technol. **36**, 269(1)–269(5) (2014)

Adaptation of 3D Printing Technology for Fabrication of Economical Upper Limb Prostheses

Vishal Francis, Sushil Kumar Singh, Raksha G. Bhonde, Yash H. Tichkule, Vaishnavi S. Gupta, and Swaraj P. Farande

Abstract Fabrication of prostheses with accurate size, comfort and patient-specific shape is the desired feature. Moreover, the need to fabricate economical prostheses is also crucial, especially for children who outgrow the prostheses over time. In this regard, the type of prostheses and selection of the fabrication process plays an important role as it can critically affect the cost. 3D printing technology offers tremendous design freedom as any complex geometry can be fabricated with ease as compared with other manufacturing processes. The technology also provides customization, which is one of the unique requirements for the fabrication of prostheses. The present paper discusses the feasibility of adaptation of 3D printing technology for research and development of the prosthetic hand. Moreover, a case study is provided for designing a prosthetic hand and utilization of 3D printing for its fabrication. It can be inferred that for the fabrication of customized prosthetic hand, 3D printing can be effectively utilized. It can provide an effective route for developing an economical yet functional prosthesis.

Keywords 3D printing · Prostheses · Fused filament fabrication

1 Introduction

According to the World Health Organization, there are around 40 million amputees in developing countries. Moreover, 0.5% of the total world population requires prostheses [1, 2]. Amputation hampers the person's confidence and affects their social relations and reduces the functionality to a great extent. The cost of the upper limb prosthetic is quite high, and also in many rural areas, the availability of prostheses is rare. Owing to these conditions, many amputees choose not to use prosthetic

V. Francis
School of Mechanical Engineering, Lovely Professional University, Phagwara, Punjab 144411, India

S. K. Singh (✉) · R. G. Bhonde · Y. H. Tichkule · V. S. Gupta · S. P. Farande
Mechanical Engineering Department, G. H. Raisoni College of Engineering, Nagpur 440016, India
e-mail: sushiliert1985@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_77

hands. Moreover, many available prostheses lack aesthetics and their weight is not appropriate as per the amputee. Amputees from the rural area do not have access to such facilities and rarely go for maintenance and follow-up checks. The condition is even worse for children of developing countries which outgrow the prostheses over time. Customization is another important characteristic of a good prosthetic hand; therefore, for developing a prosthesis upper extremity amputation is required. In this scenario, development of economical and reliable prosthetic hand can be a viable solution for rural areas. 3D printing offers great design freedom and can aid in developing any customized and complex shape geometry which is a prerequisite for prosthetic development [3]. Speed, customization, growth of amputees and comfort are a few factors that make 3D printing a major contender for prosthesis development. The conventional method takes weeks or even months to fabricate and calibrate; on the other hand, 3D printed prosthetics can be fabricated in a couple of days. Customized prostheses can be fabricated by the 3D printing process without any need for tooling to suit the specific need of the patient [4–8]. For growing children the prostheses have to be changed after a few years; in this regard the prosthesis should be economical. Low-cost 3D printed prostheses can be a viable option for many families. Moreover, 3D printed prostheses socket can be tailor-made as per the anatomy of the patient's hand, thereby providing greater comfort.

Figure 1 shows the different types of upper limb amputations which need prostheses. The prosthetic hands can be classified into various categories according to their functionality. Generally, there are three types of prosthetic hands available in the market. The first is passive in nature with no or limited functionality. Body powered is another type of prosthetic hands that do not require any electronics and can have a

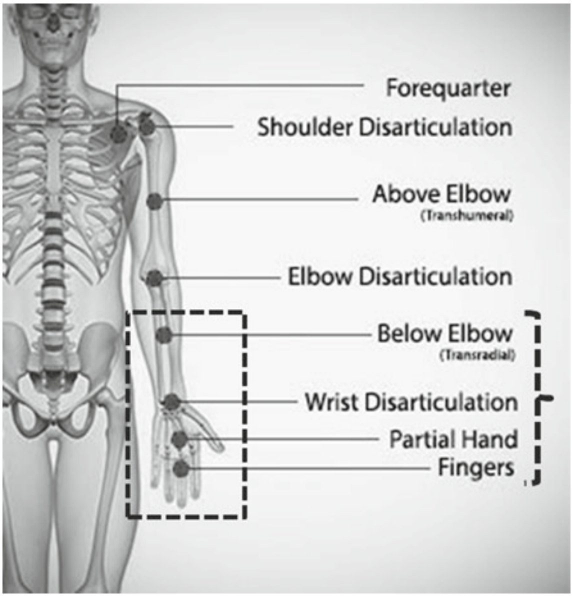


Fig. 1 Upper limb disarticulation

Table 1 Comparison of various types of prosthetic hand and their feasibility of 3D printing [17]

Type	Functionality	Pros	Cons	Can be 3D printed?
Passive	• Aesthetic device • Simple carrying and balancing of things	• Low cost	• Limited functionality	✓
Body Powered	• Gripping • Lifting • Manipulation	• Low cost • Easy maintenance • Less weight	• Limited degrees of freedom (DoFs)	✓
External powered (myoelectric)	• Gripping • Lifting • Manipulation • Rotation	• More DoFs	• Intensive training required • High cost	✓

limited degree of freedom [9–15]. External powered is another category of prosthetic hand which can have more degrees of freedom compared to other types of prosthetic hand. Table 1 shows a comparison of these three types of prosthetic hands. The externally powered device has more functionality but the cost is also very high. However, there is a feasibility of 3D printing of all three types of prosthetic devices.

Zuniga et al. have developed an economical prosthetic hand (body-powered) using 3D printing technology which was suited for light activities named Cyborg beast and proposed a fitting procedure [6]. Cuellar et al. proposed certain guidelines for 3D printing of non-assembly prosthetic hand. These guidelines can be used to develop a functional prototype in a single setup [16]. The objective of the present work is to design an economical, yet durable prosthetic hand using an extrusion-based 3D printing process with integrated electronics to increase the functionality. The following section discusses the extrusion-based 3D printing process.

2 Printing Technology

Three-dimensional printing is a layer-by-layer manufacturing technology that builds the part by depositing or scanning the material one layer at a time. The process starts with the development of a computer-aided design (CAD) model of the required geometry which is generally converted into. STL file format for preparing data for the 3D printer. The STL file is further sliced as per the decided layer thickness to prepare the tool path. However, it is of great importance that the orientation of the model is checked. As the build time and cost are influenced by the orientation, the printing parameters need to be adjusted as per the material used. The generic steps for 3D printing are illustrated in Fig. 2.

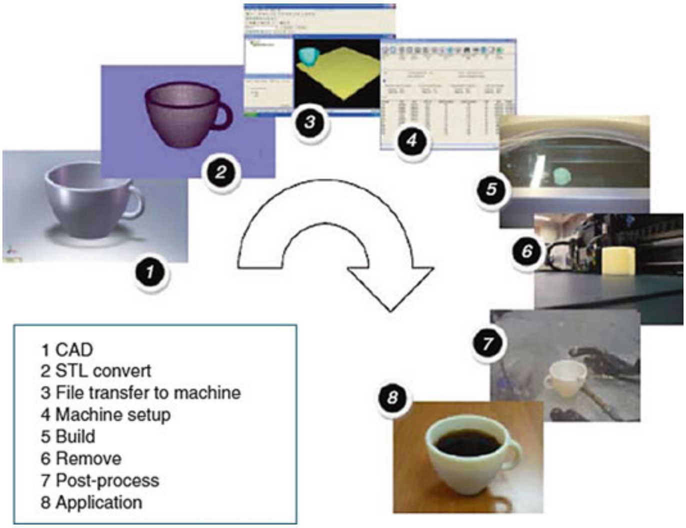


Fig. 2 Generic steps involved in the 3D printing process [18]

3 Fused Filament Fabrication (FFF)

FFF is one of the widely used 3D printing technology due to its numerous advantages. It works by depositing the semi-molten material onto the heated bed where it fuses with the neighboring deposited material. The part is built in a layer-by-layer fashion. Figure 3 illustrates the schematic of the FFF process. One of the benefits of FFF over other 3D printing technology is that only the material needed to build the part is deposited, which reduces the material wastage. The process is also economical

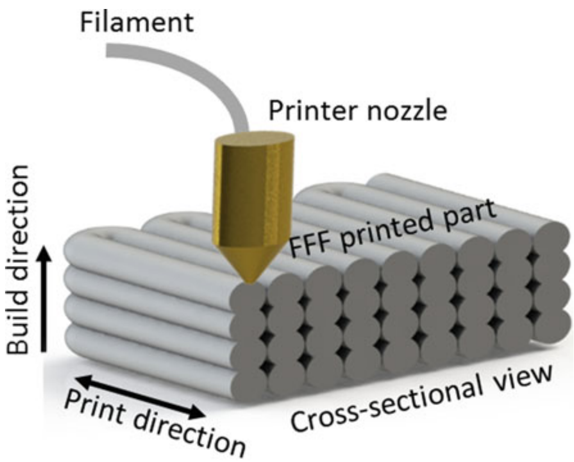


Fig. 3 Schematic of FFF process

compared to the other polymer processing methods. These advantages make them a suitable choice for the fabrication of the patient-specific and economical upper limb prostheses.

4 Case Study

In order to study the performance of an economical desktop 3D printer, a prosthetic hand was designed and fabricated. Accucraft i250+ printer was used for the study.

The prosthetic hand was fabricated with the combination of acrylonitrile butadiene styrene (ABS) and ABS/CF composite material. The selection of material and its composition plays an important role in the performance of the prosthetic hand [12–15, 19–21]. The dimensions used in the study of the index figure are illustrated in Fig. 4. The 3D modeling of the prosthetic hand was done on SOLIDWORKS.

Number of joints in fingers were taken as two. One slight advantage of having two joints is that having a single part for the middle and distal joints will allow for higher load capacity. Figure 5 shows the designed figures. The thumb has also been designed in a similar fashion. Most commercial and research prosthetic hands

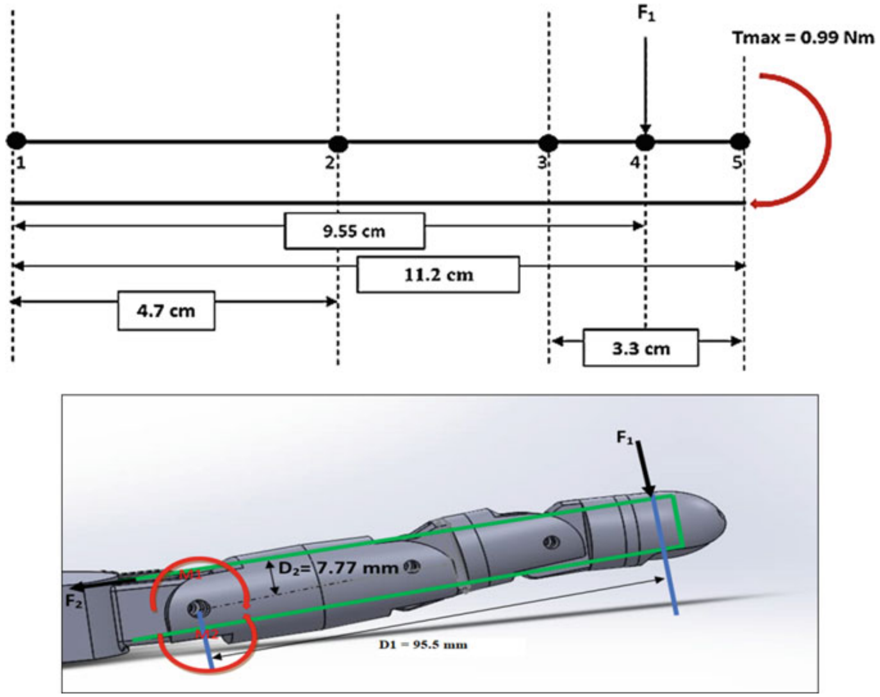


Fig. 4 Free body diagram and CAD model of index figure

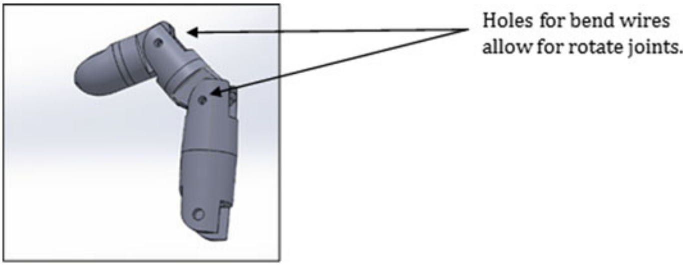
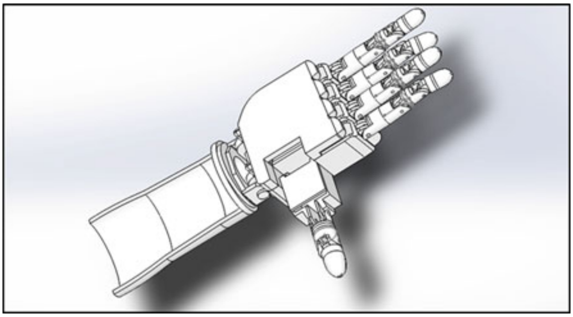


Fig. 5 Finger assembly

Fig. 6 Assembled view of the designed prosthetic hand



aim to provide at least two degrees of freedom in the thumb. This thumb, however, only provides a single degree of freedom—it can only open/close in a single way. Each finger connects to the palm by nickel alloys bed wires. And thumb connects with the bolt pin arrangement. Wrist/forearm is designed to place all the electronics components like breadboard circuit, battery and sensors. The forearm connects with palm by simple bolt pin arrangement hinge joint. The final assembled view of the prosthetic hand is illustrated in Fig. 6.

All fingers and thumb components were printed in ABS plastic and covers for palm and forearm sections were printed in ABS reinforced carbon fiber material using Accucraft i250d 3D printer. The final design consists of 21 individual 3D printed components.

NETFABB software converts files format into "STL" files and checks whether the part is suitable for printing without any error or not. One can resolve part errors in this software using an analysis tool and add tolerances to the parts. Figures 6 and 7 show the palm bottom part repair and conversion into STL file format in NETFABB software. It is a slicing software used in 3D printing. Slicing is the process of turning your 3D model into a file that your 3D printer can understand. In this software, G code files are generated for the required parts. Figure 6 shows assembled view of the designed prosthetic hand. Figure 7 shows the fabricated prosthetic hand with integrated EMG sensors. Adequate space is provided to incorporate the electronics

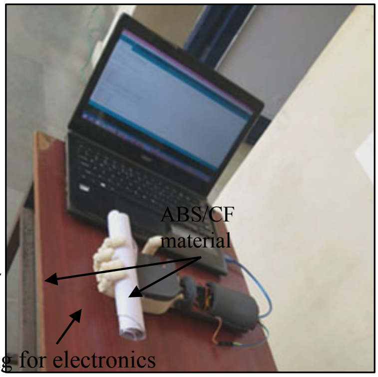


Fig. 7 3D printed prosthetic hand

in the forearm region of the prosthetic hand. The future work includes the testing of the design on volunteers and to incorporate any design iterations if needed.

5 Conclusions

The initial aim was to develop a solution for an economical, yet durable prosthetic hand with integrated electronics. The final system provides relatively good performance and characteristics for a prototype 3D printed model. An economical 3D printer was utilized to fabricate the prosthetic hand providing adequate space for integration of the electronics. Certain regions such as the wrist are at a high risk of breaking if the device is subject to moderate forces. In the real world, a practical prosthetic arm must be able to absorb sudden shocks and support heavy loads without failing. In the future, the design of a proper socket connection needs to be addressed. It can be stated that the 3D printing process can be adopted to fabricate patient-specific prosthetic devices.

References

1. Johnson, D., Ritter, S., Mehta, K.: Characteristics of a 3D-printed prosthetic hand for use in developing countries. Humanitarian Engineering and Social Entrepreneurship (HESE) Program School of Engineering Design, Technology, and Professional Programs, College of Engineering, The Pennsylvania State University Park, USA (2015)
2. Baril, M., Gosselin, C., de Jesus Lima, E., Arabiam, A.: Development of a 3D Printed Prosthetic Myoelectric Hand Driven by DC Actuators. Technology Department State University of Feira de Santana, BA, Brazil (2017)
3. Francis, V., Jain, P.K.: Experimental investigations on fused deposition modelling of polymer-layered silicate nanocomposite. Virtual Phys. Prototyping **11**(2), 109–121 (2016)
4. Dombroski, C.E., Balsdon, M.E., Froats, A.: The use of a low cost 3D scanning and printing tool in the manufacture of custom-made foot orthoses: a preliminary study. BMC Res. Notes

7, 443 (2014)
5. Muilenburg, A.L., LeBlanc, M.A.: Body-Powered Upper-Limb Components, pp. 28–38. Springer, New York, NY (1989)
6. Zuniga, J.M.: 3D printed antibacterial prostheses. Appl. Sci. **8**, 1651 (2018)
7. Zuniga, J.M., Peck, J.L., Srivastava, R., et al.: Functional changes through the usage of 3D-printed transitional prostheses in children. Disabil. Rehabil. Assist. Technol. **14**, 68–74 (2019)
8. Phillips, B., Zingalis, G., Ritter, S., et al.: A review of current upper-limb prostheses for resource constrained settings. In: Proceedings of the Fifth IEEE Global Humanitarian Technology Conference (GHTC), Seattle, WA, 8–11 Oct 2015, pp. 52–58. IEEE, New York
9. Zuniga, J.: The Cyborg Beast. https://www.unomaha.edu/college-of-education/biomechanics-core-facility/research/cyborg-beast/index.php
10. e-NABLE. The Raptor Hand. Enabling the Future. https://enablingthefuture.org/upper-limb-prosthetics/theraptor-hand/comment-page-1/ (2014)
11. Cuellar, J.S., Smit, G., Zadpoor, A., et al.: Ten guidelines for the design of non-assembly mechanisms: the case of 3D printed prosthetic hands. Proc. Inst. Mech. Eng. Part H J. Eng. Med. **232**, 962–971 (2018)
12. Singh, S.K., Singh, D., Kumar, A., Jain, A.: An analysis of mechanical and viscoelastic behavior of nano-SiO_2 dispersed epoxy composites. Silicon, 1–13 (2019). https://doi.org/10.1007/s12633-019-00335-x
13. Francis, V., Jain, P.K.: Advances in nanocomposite materials for additive manufacturing. Int. J. Rapid Manuf. **5**, 215–233 (2015)
14. Singh, S.K., Singh, S., Kohli, R., Jain, A., Kumar, A.: Effect of TiO_2 dispersion on mechanical properties of epoxy polymer. AIP Conf. Proc. **1728**, 020586 (2016)
15. Francis, V., Jain, P.K.: Investigation on the effect of surface modification of 3D printed parts by nanoclay and dimethyl ketone. Mater. Manuf. Process. **33**(10), 1080–1092 (2018)
16. Cuellar, J.S., Smit, G., Zadpoor, A., et al.: Ten guidelines for the design of non-assembly mechanisms: the case of 3D printed prosthetic hands. Proc. Inst. Mech. Eng. Part H J. Eng. Med. **2018**(232), 962–971 (2018)
17. Available at: https://www.mccleveop.com/you-have-a-choice-arizona-amputee-prosthetic-facilities/. Accessed 23 Sept 2019
18. Gibson, I., Rosen, D., Stucker, B.: Generalized additive manufacturing process chain. In: Additive Manufacturing Technologies. Springer, Boston, MA (2010)
19. Singh, S.K., Singh, S., Kumar, A., Jain, A.: Thermo-mechanical behavior of TiO_2 dispersed epoxy composites. Eng. Fract. Mech. **184**, 241–248 (2017)
20. Singh, S.K., Kumar, A., Jain, A.: Effect of nanoparticles dispersion on viscoelastic properties of epoxy–zirconia polymer nanocomposites. IOP Conf. Ser. Mater. Sci. Eng. **330**, 012001 (2018)
21. Singh, S.K., Kumar, A., Jain, A.: Improving tensile and flexural properties of SiO_2-epoxy polymer nanocomposite. Mater. Today Proc. **5**, 6339–6344 (2017)

Effect of EMG Denoising on Classification Accuracy of Sit to Stand Phases

Siddharth Bhardwaj, Abid Ali Khan, and Mohammad Muzammil

Abstract Electromyography (EMG) signals have been used in clinical diagnosis and rehabilitation owing to the information that the signal carries about motion intent. However, EMG signals are inherent to noise which degrades the performance of classifiers. In the present study, denoising of the EMG signal was studied with its effect on the classification accuracy of sit to stand (STS) phases. Four different phases of STS task were marked with the help of knee and trunk angular deviation data as acquired during the experimentation on five healthy participants. Two different denoising methods were considered; one method ($D1$) deals with seventh-order Daubechies wavelet denoising, while in the second method ($D2$), Teager–Kaiser energy operator (TKEO) was applied over the previously denoised EMG signal in $D1$. Method $D2$ was found to improve the overall accuracy of the K-nearest neighbors (KNN) classifier with the highest improvement in the true positive rate of intention phase (Phase II) of STS task.

Keywords Electromyography · Denoising · Wavelet · TKEO

1 Introduction

Measurement of human intention has been a long research topic in the development of robotic applications concerning human–machine interface. In this regard, electromyography (EMG) has gained increased attention in the past decade. EMG signal represents the electrical activity generated during contraction of skeletal muscle which contains rich information about human intent to motion [1]. The fact that EMG generation occurs approximately 20–80 ms before the actual limb movement takes place [2] makes it more appropriate to be used as a control signal in prosthesis [3], orthosis [4], and rehabilitation devices [5].

Various EMG processing algorithms concerning pattern recognition [6] have been developed to identify the user's movement intent and hence intuitive control of the

S. Bhardwaj (✉) · A. A. Khan · M. Muzammil
Department of Mechanical Engineering, Aligarh Muslim University, Aligarh, UP, India
e-mail: siddharth.bhardwaj@live.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_78

devices. However, it is important to first process the acquired raw EMG data into meaningful feature sets which are then classified to predict the desired motion and torque requirement [7].

Post-processing of EMG signal is important for improving the signal-to-noise ratio (SNR) of the acquired signal. Several studies have been conducted on the denoising of EMG signals concerning adaptive filters and frequency–time domain analysis such as wavelet denoising [8, 9]. However, broader bandwidth and random frequency of the signal make the denoising difficult. This in turn impedes the classification accuracy of the classifiers [10].

The present study is motivated by the limitation of methods in eliminating the noise from the EMG signal and classification of phases in sit to stand (STS) movement. Teager–Kaiser energy operator (TKEO) has been used in the past for improving the onset detection of EMG signal by reducing the baseline noise [11, 12]. In the present study, EMG denoising methods have been compared based upon the classification accuracy of STS phases. Wavelet denoising with the application of TKEO is compared with the unprocessed and wavelet denoised root mean square (RMS) feature of EMG of vastus lateralis muscle group.

2 Methodology

2.1 Participants

Five participants (male, age: 23.3 ± 2.7 years (mean ± SD)) volunteered the study. All the participants were university graduate students and had reported no previous history for neurological and musculoskeletal injuries at the time of experimentation. Prior to experiment, written consent was obtained from all the participants with approval from university ethics committee. All the participants were right leg dominant.

2.2 Design of Experiment

A control, repeated measure study was designed to evaluate the effect of EMG denoising technique on classification accuracy. Data for EMG activity of vastus lateralis muscle of the dominating leg, knee angular deviation and trunk angular deviation in sagittal plane was obtained for two consecutive trials separated by a rest period of 2 min. A trial consisted of voice signaling the participant to perform the STS task with his own natural speed without any hand support. The seat height for the participants were fixed to their respective knee height. The measured variables were synchronously recorded in the PC during the trials for offline analysis of the data.

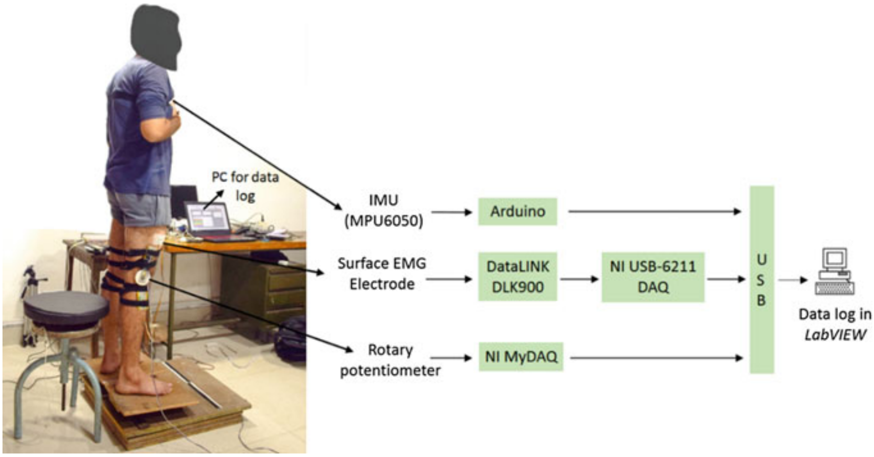


Fig. 1 Data acquisition setup

2.3 Data Acquisition

The EMG activity of vastus lateralis (VL) was measured using bipolar surface electrodes (SX230, Biometrics Ltd.). The electrodes were connected to a DataLINK signal conditioning unit (DLK900, Biometrics Ltd.) that outputs an analog single-channel signal to the NI-6211 DAQ (National Instruments Ltd.) sampled at 1000 Hz. Grounding electrode was placed at lunate bone of left wrist for reducing high-frequency DC artifacts.

To mark the phases in STS task, knee and trunk deviations were measured. Knee deviation was measured with the aid of rotating potentiometer, tied at the lateral epicondyle of the knee, working in conjunction with NI myDAQ at 1000 Hz. Trunk deviation was measured using inertial measurement unit (MPU 6050) connected to PC through Arduino (ATmega 328) microcontroller. The inertial measurement unit was attached to the chest of the participant measuring trunk flexion and extension in the sagittal plane. The multimodal sensorial setup was communicated with the PC using a custom-built LabVIEW program. Figure 1 shows the DAQ system used for the study.

2.4 Feature Extraction and Denoising

EMG signal was first processed to remove motion artifacts and electromagnetic interferences. The EMG signal was high-pass filtered using a Butterworth second-order IIR filter with a 20 Hz cut-off frequency and 50 Hz notch filter.

Two separate denoising methods were adopted and compared with the unprocessed (without denoising) EMG RMS for their effect on the classification accuracies. In the first method ($D1$), the EMG was denoised with seventh-order Daubechies wavelet (db07) function with four-level decomposition and universal soft threshold [13]. In the second method ($D2$), the Teager–Kaiser energy operator (TKEO) was applied to the previously wavelet denoised signal to further improve the SNR. Root mean square (RMS) was then evaluated as the EMG feature. A triangle-Bartlett windowing RMS filter was designed to calculate the RMS of the filtered and denoised EMG signal over a segment length of 125 samples.

2.5 Classification

K-nearest neighbors (KNN) with $K = 5$ was used as a representative classifier for classifying the four distinct phases of STS task [14]. These phases were determined based on the movement of body segments as estimated from the angular deviation of the trunk and knees [15]. The four phases were: Phase I ($P1$)—sitting phase, where the participant sits comfortably on the stool; Phase II ($P2$)—intention to stand from sitting posture; Phase III ($P3$)—transition phase, where participant lifts off from the seat and stands up; Phase IV (P4)—standing phase. EMG RMS of VL and knee deviation was taken as input factors to the classifier. The classification accuracy was estimated as the average of five-fold cross-validation on the data set.

3 Results and Discussion

The phases $P1$, $P2$, $P3$, and $P4$ consisted of $19 \pm 11\%$, $15 \pm 3\%$, $45 \pm 8\%$, and $21 \pm 12\%$ of the total STS duration, respectively. Figure 2 shows the confusion matrix for the KNN model used to classify the STS phases. The diagonal elements represent the degree of correctly predicted phases (true positive rate). The confusion is quantified by the falsely classified off-diagonal elements. Phase II ($P2$) was least predicted by the classifier among all the three cases, wherein different EMG denoising approaches were considered. The highest accuracy obtained in predicting $P2$ was 93% for the case of EMG denoised with combined wavelet and TKEO (D2).

Classification with wavelet denoised EMG gave similar result compared to unprocessed EMG. As depicted in Fig. 3, the highest overall accuracy was obtained for denoising method D2, where 96.4% of true phases were correctly classified.

Studies in general have shown improvement in classification accuracies after wavelet denoising of EMG [14, 16]; however, in the present study no such improvement was observed. Moreover, the true positive rates decrease for the wavelet denoised EMG ($D2$). The reason could be attributed to the different classifiers used in the previous studies. In addition, the present study only employed single-channel EMG, whereas most of the studies have considered multi-channel EMG

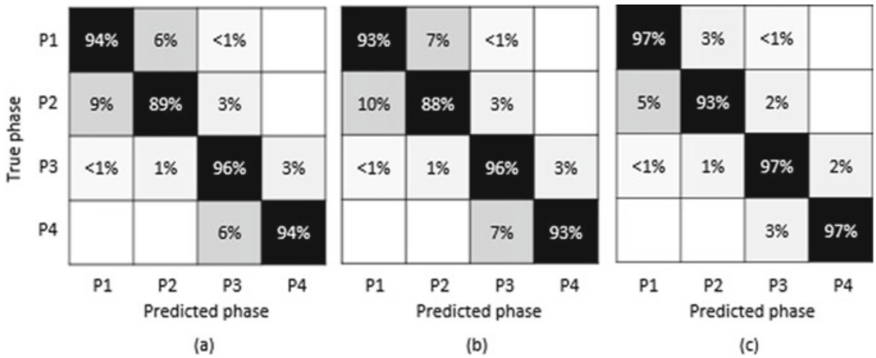
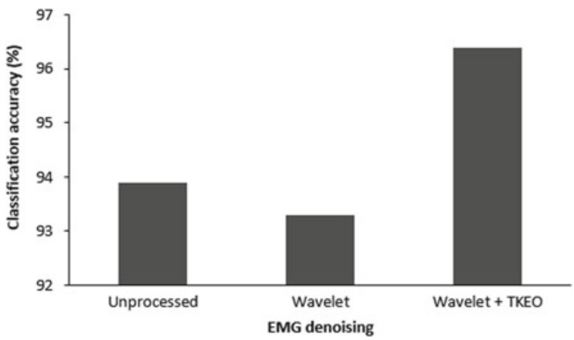


Fig. 2 Confusion matrices for (**a**) unprocessed, (**b**) wavelet denoised ($D1$), and (**c**) wavelet + TKEO denoised ($D2$) EMG RMS for the STS phase classification

Fig. 3 Overall classification accuracies



for improving the classification rates [17, 18]. The reason for choosing KNN in the current study was that the classifier generally depends upon the optimizing parameters.

Phase II ($P2$) is the most important phase concerning the measurement of intent in performing STS task. The classification accuracy may be further improved by considering a multimodal approach. Instead of using denoised EMG with knee deviation, a combination of EMG with other biomechanical factors (e.g. trunk deviation, ground reaction forces, multichannel EMG) may improve the classification accuracy of the classifier. Further, different EMG features also need to be tested for their classification accuracies with denoising methods $D1$ and $D2$.

4 Conclusions

In the present study, EMG together with the knee deviation was taken as the input to the classifier. Combination of wavelet denoising with TKEO has shown highest accuracy in depicting STS phases compared to unprocessed and wavelet denoised EMG. Highest true positive rate of 93% was achieved for $P2$ by using method $D2$. Considerations may be given to other classifiers and combinations of EMG with different biomechanical signals to further improve the classification rates.

Acknowledgements This work was supported by the Council of Scientific and Industrial Research (CSIR), New Delhi under Senior Research Fellow (SRF) scheme. File no. 09/112(0554)2K17.

References

1. Fleischer, C., Reinicke, C., Hommel, G.: Predicting the intended motion with EMG signals for an exoskeleton orthosis controller. In: 2005 IEEE/RSJ international conference on intelligent robots and systems, pp. 2029–2034. IEEE (2005). https://doi.org/10.1109/IROS.2005.1545504
2. Norman, R.W., Komi, P.V.: Electromechanical delay in skeletal muscle under normal movement conditions. Acta Physiol. Scand. **106**, 241–248 (1979). https://doi.org/10.1111/j.1748-1716.1979.tb06394.xhttps://doi.org/10.1111/j.1748-1716.1979.tb06394.x
3. Liu, J.: Adaptive myoelectric pattern recognition toward improved multifunctional prosthesis control. Med. Eng. Phys. **37**, 424–430 (2015). https://doi.org/10.1016/j.medengphy.2015.02.005https://doi.org/10.1016/j.medengphy.2015.02.005
4. Vaca Benitez, L.M., Tabie, M., Will, N., Schmidt, S., Jordan, M., Kirchner, E.A.: Exoskeleton technology in rehabilitation: towards an EMG-based orthosis system for upper limb neuromotor rehabilitation. J. Robot. **2013**, 1–13 (2013). https://doi.org/10.1155/2013/610589https://doi.org/10.1155/2013/610589
5. Giggins, O.M., Persson, U.M., Caulfield, B.: Biofeedback in rehabilitation. J. Neuroeng. Rehabil. **10**, 60 (2013). https://doi.org/10.1186/1743-0003-10-60https://doi.org/10.1186/1743-0003-10-60
6. Parajuli, N., Sreenivasan, N., Bifulco, P., Cesarelli, M., Savino, S., Niola, V., Esposito, D., Hamilton, T.J., Naik, G.R., Gunawardana, U., Gargiulo, G.D.: Real-time EMG based pattern recognition control for hand prostheses: a review on existing methods, challenges and future implementation. Sensors (Switzerland) **19** (2019). https://doi.org/10.3390/s19204596
7. Bhardwaj, S., Khan, A.A., Muzammil, M.: Electromyography in physical rehabilitation : a review. In: National Conference on Mechanical Engineering – Ideas, Innovations & Initiatives, pp. 64–69. Excel India Publisher, Aligarh (2016)
8. Phinyomark, A., Limsakul, C., Phukpattaranont, P.: A novel feature extraction for robust EMG pattern recognition. J. Comput. **1**, 71–80 (2009). https://doi.org/10.3109/03091902.2016.1153739https://doi.org/10.3109/03091902.2016.1153739
9. Ortolan, R.L., Mori, R.N., Pereira, R.R.J., Cabral, C.M.N., Pereira, J.C., Cliquet, A.J.: Evaluation of adaptive/non- adaptive filtering and wavelet transform techniques for noise reduction in EMG mobile acquisition equipment. IEEE Trans. Neural Syst. Rehabil. Eng. **11**, 60–69 (2003)
10. Chowdhury, R., Reaz, M., Ali, M., Bakar, A., Chellappan, K., Chang, T.: Surface electromyography signal processing and classification techniques. Sensors **13**, 12431–12466 (2013). https://doi.org/10.3390/s130912431https://doi.org/10.3390/s130912431
11. Tenan, M.S., Tweedell, A.J., Haynes, C.A.: Analysis of statistical and standard algorithms for detecting muscle onset with surface electromyography. PLoS ONE **12**, 1–14 (2017). https://doi.org/10.1371/journal.pone.0177312https://doi.org/10.1371/journal.pone.0177312
12. Solnik, S., DeVita, P., Rider, P., Long, B., Hortobágyi, T.: Teager-Kaiser operator improves the accuracy of EMG onset detection independent of signal-to-noise ratio. Acta Bioeng. Biomech. **10**, 65–68 (2008)

13. Bhardwaj, S., Khan, A.A., Muzammil, M.: Onset difference between vastus lateralis and knee extension during sit to stand task. AIP Conf. Proc. **2200**, 20027 (2019). https://doi.org/10.1063/1.5141197https://doi.org/10.1063/1.5141197
14. Phinyomark, A., Quaine, F., Charbonnier, S., Serviere, C., Tarpin-Bernard, F., Laurillau, Y.: Feature extraction of the first difference of EMG time series for EMG pattern recognition. Comput. Methods Programs Biomed. **117**, 247–256 (2014). https://doi.org/10.1016/j.cmpb.2014.06.013https://doi.org/10.1016/j.cmpb.2014.06.013
15. Bhardwaj, S., Khan, A.A., Muzammil, M.: Lower limb rehabilitation using multimodal measurement of sit-to-stand and stand-to-sit task. Disabil. Rehabil. Assist. Technol. 1–8 (2019). https://doi.org/10.1080/17483107.2019.1629701
16. Veer, K.: A technique for classification and decomposition of muscle signal for control of myoelectric prostheses based on wavelet statistical classifier. Measur. J. Int. Measur. Confed. **60**, 283–291 (2015). https://doi.org/10.1016/j.measurement.2014.10.023
17. Tsai, A.C., Luh, J.J., Lin, T.T.: A novel STFT-ranking feature of multi-channel EMG for motion pattern recognition. Expert Syst. Appl. **42**, 3327–3341 (2015). https://doi.org/10.1016/j.eswa.2014.11.044https://doi.org/10.1016/j.eswa.2014.11.044
18. Englehart, K., Hudgins, B., Parker, P.A.: A wavelet-based continuous classification scheme for multifunction myoelectric control. IEEE Trans. Biomed. Eng. **48**, 302–311 (2001). https://doi.org/10.1109/10.914793https://doi.org/10.1109/10.914793

Study of Consistency Establishment of Deviation in Quality Norms During Manufacturing of Crown Wheel Pinion

Jadhav Piyush Kishor, Anoop Kumar Shukla, and Meeta Sharma

Abstract Deviation in norms is a standard used to measure the manufacturing quality of product. The aim is to achieve desired quality output for the manufacturing process of crown wheel pinion, to expel the inconsistency for the variation of deviation standard. The manufacturing process is categorized into various subprocesses on which the quality of parameters depends. Due to the process errors, these DIN values are going beyond actual quality standard and it has to be as low as possible to improve the product functioning toward maximum efficiency. Various tests are performed over the manufacturing process to find out the root cause for inconsistency in quality standard of product. The analysis is conducted by varying the cutting tool speed and accuracy over the number of jobs done. Significant enhancement over the smoothness and manufacturing quality of product was observed, with the comparative analysis being done to verify the actual results with the conventional one.

Keywords DIN · Inconsistency · Conventional · Enhancement · Expel · Deviation in norms

1 Introduction

Deviation in norms is a key factor that is used to maintain the manufacturing quality of the product, and it depends on various parameters that assist during the manufacturing process, such as cutter tool blade cutting edge and cutter tool setting to its minimum tolerance for maximum accuracy over machining. The purpose is to achieve the desired quality output for the manufacturing of crown wheel pinion, which is a gear technology used in the axle. The manufacturing process is categorized as soft and hard, in which the DIN values are going beyond the actual quality standard. It should be as low as possible for the enhancement in manufacturing quality of the product. Over the years, experimental research on the deviation standard has

J. P. Kishor (✉) · A. K. Shukla · M. Sharma
Amity University Uttar Pradesh, Sector-125, Noida, India
e-mail: piyushjadhav200@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_79

been in progress; the theoretical and experimental investigation of characteristics of deviation in norms such as minimum tolerance, allowance, friction and wear for the product manufacturing has been carried out by numerous researchers. This standard allows the product manufacturing with increase in its surface quality and other design parameters to achieve the actual desired output [1, 2]. To further study on the quality parameters of the manufacturing process for crown wheel pinion, this study first analyzed the variation in cutting tool speed and accuracy over the number of jobs done during the process for determining factors that affect the consistency performance of quality at the stage of initial assembly; such as rise in temperature of cutter tool at a stage where it starts to lose the cutting accuracy over the number of jobs done. Then, the comparative analysis of the actual values with conventional was carried out at the stage of final assembly.

2 Crown Wheel Pinion

The crown wheel pinion is a gear technology used in the axle; it is a mechanical device that constitutes an important part of the power transmission system, and helps to transmit the energy coming from the power transmitting devices [3]. The crown wheel is attached to a pinion and other supporting planetary gears. With the help of this technology the perfect balance of power distribution as per the motion of wheels is provided, in which the outer wheel travels more distance than the inner wheel to maintain the stability and other driving factors. The crown and pinion go through the two different process of soft and hard, where the manufacturing process is carried out. In the soft process the dry cutting of both crown and pinion is done by setting both jobs holding fixture and cutting tool fixture to its minimum tolerance value, in order to get the maximum accuracy over the machining of product. There are other factors on which the manufacturing quality depends, such as physical handling during the machining process, job holding fixture and cutter tool run out check to its minimum tolerance for better accuracy (refer Fig. 1). The cutter tool setting is done by adjusting the cutting blades to its minimum micron value [4].

These blades have their own three sub-sides which are primarily categorized as *A*, *B* and *C*. *A* side is a cutting side, *B* is non-cutting side and *C* is the clearance side. Each side has their own tolerance limits set according to the size of cutting job. These blades are made of carbide cobalt, which is a group of 14 members and has a high content of carbon molecules [5–7] for more strength and long-lasting machining capability over a period of time. The following are some of the parameters on which the deviation in norms of the quality standards depends.

- f_p max—Tooth spacing error
- F_r—Pitch line runout
- F_p—Total index error

All these quality maintaining parameters have their own standard values, based upon the manufacturing quality and deviation in norm factors.

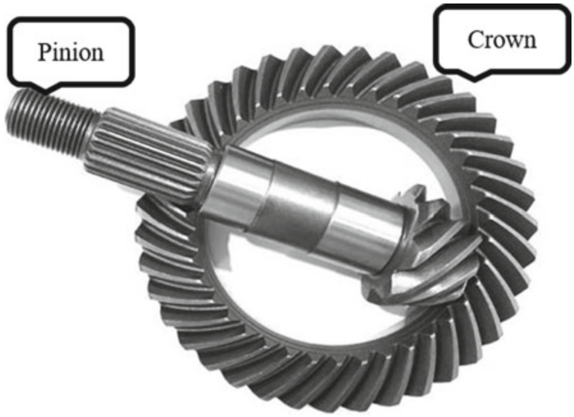


Fig. 1 Schematic diagram of crown wheel pinion

3 Soft Process for 31/7 325 Crown and Pinion

Soft process is dry cutting of both crown and pinion, where cutting tool selection is done according to the gear ratios selected. Cutting tool and job are placed over the multidirectional moving surface to achieve maximum accuracy for machining process. Spiron cutter is used for machining of both crown and pinion, and it varies for every crown and pinion according to their dimensions. Spiron cutter blades' machining is done by diamond cut wheel to achieve minimum tolerance and maximum accuracy.

3.1 Soft Process for 31/7 325 Crown (Before/After)

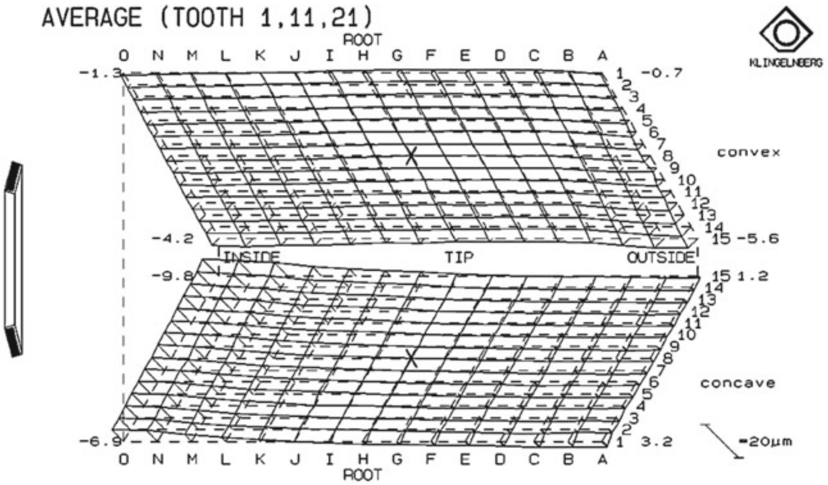
Cause identification for increase in DIN value has its dependency on various factors like cutter tool setting to its minimum mean line tolerance for achieving maximum machining accuracy standards. Furthermore, the cutting tool speed is a crucial parameter for maintaining deviation standard over the machining of crown wheel. Setting both the parameters to minimum tolerance value can improve the crown surface finish with decrease in DIN value (refer Table 1).

After the cutting process of crown 31/7 325, the DIN values are showing the fall toward the parametric values, as they are responsible for improving deviation standard. Cutter tool is set to minimum allowable tolerance and analysis on the accuracy of cutter tool for cutting job is done to improve the machining process in a job. The graphs show the drastic change in the DIN values, as the values are dependent on cutting accuracy and the cutting speed for the machining job.

The topographic graph shows the conventional results and the average of 1, 11, and 21 tooth has been taken for various parameters, like pitch line run out F_r, max tooth spacing error f_u, and total index error F_p, to validate the results without any

Table 1 Soft process for 31/7 325 crown after cutting DIN values

Tooth face		Convex						Concave						DIN		
Result	Type	f_p max		f_u max		F_P		f_p max		f_u max		F_P		F_r		Overall
Conventional	31/7 325 crown	21	7	26	7	72	7	21	7	26	7	72	7	55	7	7
		10.2	6	11.2	5	17.3	4	6.0	4	6.0	3	9.0	2	7.2	2	**5**
Actual	31/7 325 crown	7.7	5	10.1	5	15.4	3	5.1	4	8.2	4	8.8	2	9.4	3	**3**



S: (#6.2) 3 mm

Parameter	Nominal	Actual	Dev.	l.Tol.	u.Tol.	Unit
Sum of Squared		3226.1				µm^2
norm.chor.thickness	11.044	11.030	-0.014	-0.050	0.050	mm
(H8; R=138.030; Z=43.145)						mm
Mounting distance	84.0500	84.0500	0.0000			mm
Tooth height	17.377	17.468	0.091			mm
tip cone angle	75.712	74.772	-0.940			DEGREE
root cone angle	75.681	75.748	0.067			DEGREE

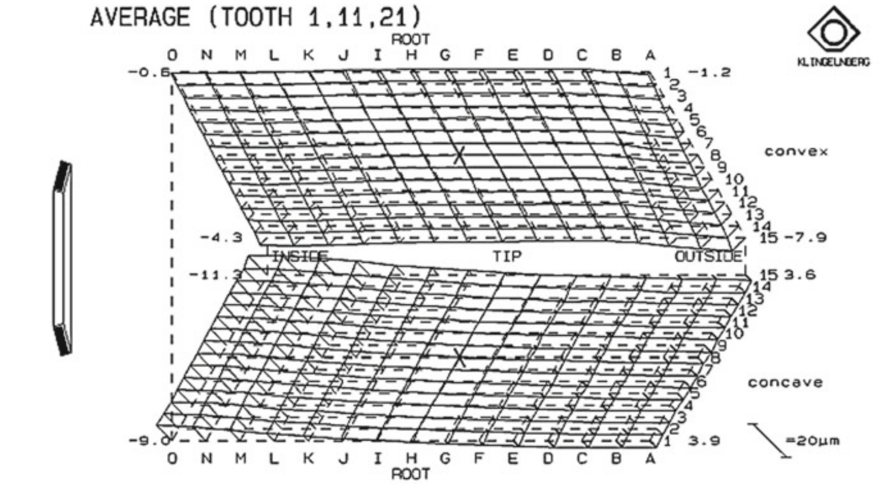
Fig. 2 Soft process 31/7 325 crown with conventional results

changes made to the machining process and has a DIN value of 5, which has to be as minimum as possible but should be less than 5 for maintaining the product manufacturing quality (refer Fig. 2).

3.2 Soft Process 31/7 325 Crown (Actual)

A brief study about the techniques involved during the machining and manufacturing of job, with some variation made to the cutting tool speed from 204.96 to 208.991 rpm has been made to find out the variation over the surface smoothness and job cutting accuracy [8, 9]. The results showed consecutive enhancement over the validation of results and helped to reduce the DIN value. The deviation standard set for the crown has to be less than 5 to maintain the machining quality of the product. After the changes made to the machining process, the DIN value is reduced by some extent and the enhancement for the quality of crown manufacturing during the process is shown (refer Fig. 3).

The topographic graph for actual parameters showing the results and the average of 1, 11, and 21 tooth has been taken for various quality standard measuring parameters like pitch line run out, tooth spacing, and total index error, to validate the results



S: (#6.2) 3 mm

Parameter	Nominal	Actual	Dev.	l.Tol.	u.Tol.	Unit
Sum of Squared		5599.3				µm^2
norm.chor.thickness	11.044	11.032	-0.012	-0.050	0.050	mm
(H8; R=138.030; Z=43.145)						mm
Mounting distance	84.0500	84.0500	0.0000			mm
Tooth height	17.377	17.484	0.107			mm
tip cone angle	75.712	74.767	-0.945			DEGREE
root cone angle	75.681	75.752	0.071			DEGREE

Fig. 3 Soft process 31/7 325 crown with actual results

without any changes made to the machining process. The DIN value is lowered to 3, which has to be as minimum as possible but less than 5 for maximum working efficiency over a long run.

3.3 Soft Process 31/7 325 Pinion (Before/After) DIN Validation

Comparative analysis of nominative and actual values for pinion 31/7 325 is done to validate the deviation standard variation during the machining process, and the cutter tool blade is set to its minimum tolerance value of less than **5** µm; furthermore, the cutter tool accuracy is analyzed for maintaining the DIN value over the number of jobs done [10]. All the variations are made to list out the causes that enhance the deviation standard values. The other influencing factors like job holding fixture adjustment with a maximum allowance up to **2.5** µm can improve the machining quality of pinion over the number of jobs done in a lot [11–13]. In the soft process the temperature adversely affects the cutting efficiency of cutter as it keeps on cutting the jobs, and sooner loses the deviation standard due to increase in temperature. The readjustment has to be done to maintain the cutting accuracy.

The topographic graph shows the conventional results and the average of 1, 3, and 5 tooth has been taken for various parameters like pitch line run out, tooth spacing, and total index error, to validate the results without any changes made to the machining process and has a **DIN** value of **4**. It has to be as minimum as possible but should be less than 5 (refer Fig. 4).

3.4 Soft Process 31/7 325 Pinion (Actual)

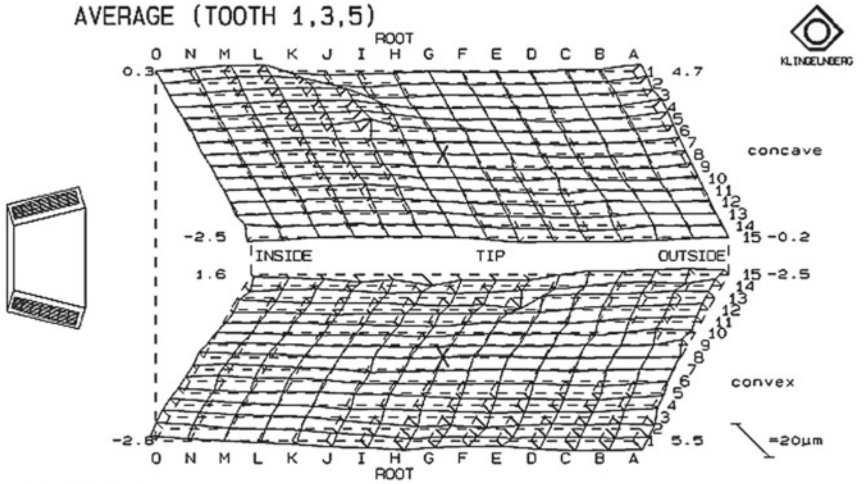
The topographic graph shows the actual results and the average of 1, 3, and 5 tooth has been taken for various parameters like pitch line run out, tooth spacing, and total index error, to validate the results without any changes made to the machining process and the DIN value is lowered to 3. It has to be as minimum as possible but should be less than 5 for maximum working efficiency over a long period of time (refer Fig. 5).

4 Conclusion

All the results validation is done on the basis of standard parameters given for the machining of both crown and pinion and their specific dimensions with respect to the requirement for manufacturing. The results shown are performed on the same platform to validate the root failure cause for losing the consistency in deviation standard during the machining process. As per the actual DIN values for both crown and pinion depict, the slight fall over the conventional values and taking into consideration the changes made for the machining process can help to reduce the DIN values and will improve the manufacturing quality of the product. This work will continue till the other influencing factors for losing the consistency over maintaining deviation standard gets defenestrate.

Table 2 Soft process for 31/7 325 pinion after cutting DIN values

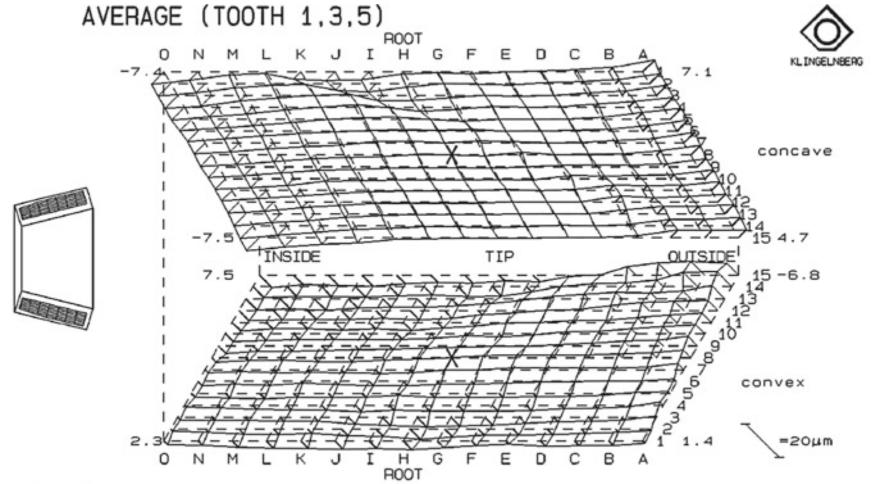
Tooth face		Convex						Concave						DIN		
Result	Type	f_p max		f_u max		F_P		f_p max		f_u max		F_P		F_r		Overall
Conventional	31/7 325 PINION	21	7	26	7	72	7	21	7	26	7	72	7	55	7	7
		5.6	4	6.4	3	9.0	2	5.6	4	9.7	5	11.6	3	7.8	2	**4**
Actual	31/7 325 PINION	8.9	5	15.8	6	13.8	3	7.5	5	11.3	5	12.2	3	11.9	3	**3**



S: (#6.1) 3 mm

Parameter	Nominal	Actual	Dev.	l.Tol.	u.Tol.	Unit
Sum of Squared		2227.2				μm^2
norm.chor.thickness	12.845	12.834	-0.011	-0.050	0.050	mm
(H8; R=41.553; Z=31.955)						mm
Mounting distance	166.1000	166.1000	0.0000			mm
Tooth height	17.034	17.144	0.110			mm
tip cone angle	15.701	15.771	0.070			DEGREE
root cone angle	13.743	13.970	0.227			DEGREE

Fig. 4 Soft process 31/7 325 pinion with conventional results



S: (#6.1) 3 mm

Parameter	Nominal	Actual	Dev.	l.Tol.	u.Tol.	Unit
Sum of Squared		5102.3				µm^2
norm.chor.thickness	12.845	12.823	-0.022	-0.050	0.050	mm
(H8; R=41.553; Z=31.955)						mm
Mounting distance	166.1000	166.1000	0.0000			mm
Tooth height	17.034	17.161	0.127			mm
tip cone angle	15.701	15.768	0.067			DEGREE
root cone angle	13.743	13.973	0.230			DEGREE

Fig. 5 Soft process 31/7 325 pinion with actual results

Acknowledgements This work is supported by the Gear factory Unit CVBU research program of TATA Motors (RAL-399-400 and P-40), Pune India.

References

1. Bonori, G., Pellicano, F.: Non-smooth dynamics of spur gears with manufacturing errors. J. Sound Vib. **306**(1–2), 271–283 (2007)
2. Gupta, K., Laubscher, R.F., Davim, J.P., Jain, N.K.: Recent developments in sustainable manufacturing of gears: a review. J. Clean Prod. **112**, 3320–3330 (2016)
3. Gupta, K., Jain, N.K.: Comparative study of wire-EDM and hobbing for manufacturing high-quality miniature gears. Mater. Manuf. Processes **29**(11–12), 1470–1476 (2014)
4. Neugebauer, R., Klug, D., Hellfritzsch, U.: Description of the interactions during gear rolling as a basis for a method for the prognosis of the attainable quality parameters. Prod. Eng. Res. Devel. **1**(3), 253–257 (2007)
5. Hyatt, G., Piber, M., Chaphalkar, N., Kleinhenz, O., Mori, M.: A review of new strategies for gear production. Procedia CIRP **14**, 72–76 (2014)
6. Fratila, D.: Evaluation of near-dry machining effects on gear milling process efficiency. J. Clean Prod. **17**(9), 839–845 (2009)
7. Lynwander, P.: Gear Drive Systems: Design and Application. CRC Press (2019)
8. Davis, J.R. (ed.): Gear Materials, Properties, and Manufacture. ASM International (2005)

9. Dizdar, S., Skoglund, P., Bengtsson, S.: Process, quality and properties of high-density P/M gears. Adv. Powder Metall. Part. Mater. **9**, 9–36 (2003)
10. Gupta, K., Jain, N.K.: Manufacturing of high quality miniature gears by wire electric discharge machining. In: DAAAM International Scientific Book, pp. 679–696 (2013)
11. Radzevich, S.P.: Dudley's Handbook of Practical Gear Design and Manufacture. CRC Press (2012)
12. Kawalec, A., Wiktor, J., Ceglarek, D.: Comparative analysis of tooth-root strength using ISO and AGMA standards in spur and helical gears with FEM-based verification (2006)
13. Karpuschewski, B., Knoche, H.J., Hipke, M.: Gear finishing by abrasive processes. CIRP Ann. **57**(2), 621–640 (2008)

Parametric Optimization of Gas Tungsten Arc Welding Using AHP-Based Taguchi Method

V. Naranje, Mohammad Nadeem Khalid, Avinash Kamble, and Mohammad Arif

Abstract In the present paper, AHP-based Taguchi approach is used to choose the perfect combination of welding process variables for the gas tungsten arc welding (GTAW) process of two different metals, MS (AISI 1040) and SS (AISI304). Initially, the Taguchi method is used to discover an optimum mix of process parameters. Since the Taguchi method could not address the multi-objective optimization problem, therefore the MODM method (AHP) is used to find the best combination of input process parameters based on the set criteria. Process variables considered for the study are travel speed of the weld, current, gas flow rate, and weld angle. During this study, methodology of this approach is explained in detail. This AHP-based Taguchi method helps to select the best combination of process parameters from among many different combinations of the process parameters.

Keywords AHP · Taguchi method · MODM · GTAW

1 Introduction

Gas-metal tungsten arc welding (GTAW) is a conventional welding process, also known as metal inert gas (MIG) welding. It was developed during World War II for the welding of aluminum and other non-ferrous materials. Later, it was used to manufacture a wide variety of different grades of steel. Owing to high production rate, it has been widely used for power generation, chemical, petrochemical, automobile, railways, naval, aerospace industries, and so on. Because of the distinct chemical compositions and mechanical characteristics of steel and other metals, it is a bit difficult to weld two separate metals and restrict the implementation of GMAW. It is therefore

V. Naranje · M. N. Khalid
Amity University, Dubai, UAE

A. Kamble
Maharashtra Institute of Technology Academy of Engineering, Pune, India

M. Arif (✉)
Sanskrti University, Mathura, Utter Pradesh, India
e-mail: arif.jamia@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_80

necessary to find the best mix of input welding process parameters that can provide the best welding quality. Researchers have recently used soft computing optimization tools such as genetic algorithms, neural networks, knowledge-based systems, and multi-objective decision-making (MADM) methods-based Taguchi approach to solve the multi-attribute decision-making problem. For example, the researchers used ANN [1], GTAW [2], GMAT geometry [3], weld modeling and control [4, 5], GRA and ANN for welding bead geometry in the gas metal arc (GMA) welding process. Naranje et al. [6] used the Taguchi approach to check the wear of deep drawing die. Yang et al. [7] used the Taguchi methodology and the AHP and MOORA methods to evaluate the overall reliable output of appropriate information-sharing approaches to the supply chain. In this work, AHP-based Taguchi method has been used to obtain the best mix of input process variables for welding of stainless steel (SS) AISI-304 and mild steel (MS) AISI-1040, using the GTAW technique.

2 Experimental Treatments

The very first step is to prepare the specimens of workpiece, the austenitic steel grades SS AISI-304 and MS AISI-1040 plates of steel separated into a part of 3 mm thick and machined in 1.5-inch wide and 5-inch long sections. The samples are cleaned using 80 grit emery paper. It has been used to remove the oxide as well as unwanted contaminants that lie on the upper layer of the steel-metal plate to make it ready for the welding. Experimental work has been done on Electra made TIG machine, the filler metal of SS and torch are used. Following are the specifications of the machine selected for the experimentation. (i) Voltage 70–440 V, current 10–300 mA, gas flow, 5–10 l/min, filer wire diameter 1.6–2.1 mm. Next step is to design work fixture. To identify the effect of weld angle on weld quality, the fixture has been manufactured with different angles of 400°, 800°, 120°. A welding test on the individual sheet was conducted to determine the suitable process parameter values. Based on the test results, the lowest and highest values of parameters shall be determined.

In addition, literature studies have shown that researchers use GTAW parameters. These parameters are weld travel speed, weld current, and gas flow. Studying the effect of welding parameters on the welding quality is useful. Based on an in-depth review of the literature and extended initial screening, tests were conducted to decide the parameters that substantially affect the GTAW welding outputs. After initial experimentation trial, a further filtration is carried out to determine the process parameters to weld SS 304 and MS 1014. It should be noted that the range of selected four process parameters is important, which will lead to an improvement of the weld quality. The weld samples generated in accordance with experimental scheme were designed to be cut into multiple test specimens. It can be used to examine the microscopic structure for checking the strength of weld, the nugget area (NA), and the heat impacted region of the welded joint. This is done using the Caliber Pro software. The design of experiments, range of selected process parameters for each experiment, and the finding of microstructure examination for all 18 tests are shown in Table 1.

Table 1 Experimental design and experimental outcome

S. no.	Weld travel speed	Weld current	Gas flow rate	Weld angle	RA	NA	HAZ
1	4	75	10	4	67,200	227,000	15,500
2	4	75	14	8	35,530	217,050	23,640
3	4	75	18	12	115,980	196,750	25,590
4	4	100	10	4	221,520	356,670	22,900
5	4	100	14	8	172,000	336,870	29,910
6	4	100	18	12	254,400	326,090	30,900
7	4	125	10	4	225,080	396,530	29,180
8	4	125	14	8	187,510	386,000	35,350
9	8	125	18	12	207,000	262,020	30,700
10	8	75	10	4	150,640	86,800	6990
11	8	75	14	8	40,130	79,000	10,520
12	8	75	18	12	41,670	62,270	10,160
13	8	100	10	4	289,430	202,850	19,350
14	8	100	14	8	181,000	205,590	23,040
15	8	100	18	12	184,490	195,000	20,840
16	8	125	10	4	307,400	248,460	32,870
17	8	125	14	8	240,430	255,220	32,620
18	8	125	18	12	210,000	262,020	30,700

A: Weld travel speed, B: Weld current, C: gas flow rate, D: Weld angle

2.1 Signal-To-Noise Ratio

The signal-to-noise (S/N) ratio can be considered for calculating performance deviations from the expected value in Taguchi technique. The signal-to-noise ratio is classified as: (i) nominal is best (NB); (ii) lower the better; (iii) higher the better (HB). The reinforcement zone is the highest performing function in this study. The objective is to maximize the response, and it can be calculated by using the formula: $S/N = -10 * \log(\Sigma(1/Y_2)/n)$ [8]. To create best weld, bead width and bead reinforcement should be the performance characteristic: the lower the better. The objective is to minimize the response, and it can be calculated using the formula, $S/N = -10 \log(\Sigma(Y_2)/n))$. Here '$n$' is the total number of measurements and 'y' is the measured ith value of the characteristics. The calculated S/N ratio for reinforcement, nugget area, and heat affected zone is given in Table 2.

Table 2 *S/N* ratio for performance variable

S. no.	*S/N* ratio for RA	*S/N* ratio for NA	*S/N* ratio for HAZ
1	107.121	107.121	−83.807
2	91.012	106.731	−87.473
3	101.288	105.878	−88.161
4	106.908	111.045	−87.197
5	104.711	110.549	−89.516
6	108.110	110.267	−89.799
7	107.047	111.966	−89.302
8	105.460	111.732	−90.968
9	106.319	108.367	−89.743
10	103.559	98.770	−76.890
11	92.069	97.953	−80.440
12	92.396	95.886	−80.138
13	109.231	106.144	−85.734
14	105.154	106.260	−87.250
15	105.319	105.801	−86.378
16	109.754	107.905	−90.336
17	107.620	108.138	−90.270
18	106.444	108.367	−89.743

2.2 ANOVA Analysis

In the present study, ANOVA is used to investigate to know which performance characteristics will play an important role in the quality of these two dissimilar metals. The results of the performance characteristic are given in Table 3. The calculated *P* value for the models created at 95% confidence level is regarded in this assessment.

3 Analytic Hierarchy Process (AHP)

AHP breaks down decision-making issues into a scheme of hierarchies of goals, characteristics, and options. The primary operation of AHP using geometric mean technique is as follows:

Step 1. Identify the goal, attributes, and alternatives. Create objective hierarchies, at the top level, second-level attributes, and alternatives at the last level.
Step 2. Decide the relative rating of the different attributes for the purpose of the problem. Make a matrix comparison by pair with a relative scale.
Step 3. Determine the comparative normalized weight (wj) of each attribute by calculating the geometric mean of the ith row and the normalization of the

Table 3 ANOVA table

Response parameters	Source	DF	Adj SS	Adj MS	*F*-value	*P*-Value	Remark
RA	A	1	909,214,085	909,214,085	0.66	0.431	Significant
	B	2	85,992,819,362	42,996,409,681	31.34	0	Significant
	C	2	14,037,130,751	7,018,565,376	5.12	0.025	Significant
	Error	12	16,461,530,588	1,371,794,216			
NA	A	1	77,469,574,106	77,469,574,106	910.29	0	Significant
	B	2	1.00E+11	50,204,872,704	589.92	0	Significant
	C	2	506,215,340	253,107,670	2.97	0.089	Significant
	Error	12	1,021,252,700	85,104,392			
HAZ	A	1	218,552,123	218,552,123	18.74	0.001	Significant
	B	2	922,600,900	461,300,450	39.56	0	Significant
	C	2	91,540,970	45,770,485	3.92	0.049	Significant
	Error	12	139,943,999	11,662,000			

geometric mean of the columns in the comparison matrix. Calculate and screen the consistency ratio (CR).

Step 4. Calculate for each choice of alternative the weighted average rate and choose the one with a score of height.

The work uses the AHP algorithm to select the best available system for each model. First, the structure of the hierarchy is established, and the main emphasis is placed on the top of the hierarchy (general goal), the process is in the middle of the hierarchy (C), and at the bottom level alternatives (S) are placed. In the proposed work, totally 18 alternatives were formed. Each parameter combination is an alternative, three criteria are selected for evaluating the weld quality: (i) reinforcement area (C1), (ii) nugget area (C2), and (iii) heat-affected zone (C3) of GTAW process. As per the ratio scale proposed by Saaty [9], the weights were assigned at each matrix element as shown in Table 4.

There are five steps to be followed in the AHP application: (i) describe the criteria; (ii) criterion for weight measurement; (iii) rate options; (iv) calculate the total score

Table 4 Weights assigned at each matrix element

Best weld	Reinforcement area	Nugget area	Heat-affected zone	Local weights
Reinforcement area	1	2	4	0.558156
Nugget area	0.50	1	3	0.319254
Heat affected zone	0.25	0.33	1	0.12259
Reinforcement area	1	2	4	0.558156
Nugget area	0.50	1	3	0.319254

for each option; and (v) build a linear model on the basis of the outcomes obtained. In the proposed experimental field, the criterion matrix is designed to optimize welding parameters, and the local weight is set as per the guidelines given by Saaty [9].

In this criterion matrix, the maximum weightage is assigned to the reinforcement area ($C1$). In addition, the nugget area of the weld ($C2$) and the heat-affected area ($C3$) are good factors considered to determine the quality of the weld, given the lower weight. Similarly, an alternative matrix pair was prepared for each of the three criteria. The calculated local weight for each response parameters is represented in Table 5.

In the end, the global weights are determined by combining the criteria matrix and the alternative matrices for each criterion using the conventional AHP method and the absolute values of the alternative local weights for each of the criteria are set out in Table 6. The overall combination of factors that maximize weight is considered for the ideal parametric combination to guarantee good welding quality.

Using the AHP method the number 8 experiment is ranked as 1 in which the optimum parameter combination is $A1$-$B3$-$C2$-$D2$. Table 7 shows the optimum parameter level value.

Table 5 Local Weight of alternative matrix with regard to all criteria

S. no.	Local weight of reinforcement area ($C1$)	Local weight of nugget area ($C2$)	Local weight of heat-affected zone ($C3$)
1	0.05730	0.0558	0.0536
2	0.04868	0.0556	0.0560
3	0.05418	0.0552	0.0564
4	0.05719	0.0579	0.0558
5	0.05601	0.0576	0.0573
6	0.05783	0.0575	0.0574
7	0.05726	0.0584	0.0571
8	0.05641	0.0582	0.0582
9	0.05687	0.0565	0.0574
10	0.05539	0.0515	0.0492
11	0.04924	0.0510	0.0515
12	0.04942	0.0500	0.0513
13	0.05843	0.0553	0.0548
14	0.05625	0.0554	0.0558
15	0.05634	0.0551	0.0553
16	0.05871	0.0562	0.0578
17	0.05757	0.0564	0.0578
18	0.05694	0.0565	0.0574

Table 6 AHP global weight and *S*/*N* ratio

S. no.	AHP global weight	*S*/*N* ratio	Rank
1	0.05637	−24.9791	12
2	0.05178	−25.716	11
3	0.05478	−25.2281	2
4	0.05725	−24.8448	10
5	0.05668	−24.9321	3
6	0.05767	−24.7807	15
7	0.05761	−24.7908	14
8	0.05720	−24.852	1
9	0.05682	−24.9106	5
10	0.05339	−25.4504	9
11	0.05008	−26.0071	18
12	0.04983	−26.0494	13
13	0.05699	−24.8845	8
14	0.05592	−25.0481	17
15	0.05582	−25.0647	4
16	0.05780	−24.762	7
17	0.05722	−24.8485	6
18	0.05686	−24.9046	16

Table 7 Optimum value of input process parameters

Factor symbol	Input process parameters	Values
A	Travel speed	4 cm/min
B	Current	125 A
C	Gas flow rate	14 l/min
D	Inclination	8°

4 Conclusion

The aim of this paper was to choose an ideal combination of process parameters under the given set of GTAW welding criteria for two different metals, using a multi-objective optimization framework-based Taguchi approach. From the experimental results, it is clearly observed that at a travel speed of 4 cm/s, 125 A current, and 14 l/min gas flow rate, angle of weld 8° is the best combination of process parameters to produce the good quality weld of two different metals, MS (AISI 1040) and SS (AISI-304), using GTAW process. The low travel speed of welding torch with medium weld voltage and all the current combinations produce good penetration and thick and uniform metal deposition is observed. AHP-based Taguchi approach is effectively used in the proposed research to take a complex decision to optimize the GTAW process parameters for the welding of two dissimilar metals. The AHP-based

Taguchi approach can be used to find an optimum combination of the parameters for the welding of different metals using the GMAW technique.

References

1. Kim, K.C., Chertov, A., Maev, R.G.: Neural network analysis for evaluating welding process. In: AIP conference proceedings 2003, pp 608–615
2. Di, L., Chandel, R.S., Srikanthan, T.: Static Modeling of GMAW process using artificial neural networks. Mater. Manuf. Process. **14**(4), 13–35 (1999)
3. Chan, B., Pacey, J., Bibby, M.: Modelling gas metal arc weld geometry using artificial neural network technology. Can. Metall. Q. **38**(1), 43–51 (1999)
4. Cook, G.E., Barnett, R.J., Andersen, K., Strauss, A.M.: Weld modeling and control using artificial neural networks. IEEE Trans. Ind. Appl. **31**(6), 1484–1491 (1995)
5. Andersen, G., Cook, E., Karsai, G., Ramasamy, K.: Artificial neural net-works applied to arc welding process modeling and control. IEEE Trans. Ind. Electron. **26**, 824–830 (1990)
6. Naranje, V.G., Karthikeyan, R., Nair, V.: Study of wear performance of deep drawing tooling. In: IOP conference series: materials science and engineering, vol 244 (2017)
7. Yang, T., Wen, Y.F., Wang, F.F.: Evaluation of Robustness of Supply Chain Information-Sharing Strategies Using a Hybrid Taguchi and Multiple Criteria Decision-Making Method. Int. J. Prod. Econ. **134**(2), 458–466 (2011)
8. Phadke, M.S.: Quality Engineering Using Robust Design. Prentice Hall (1989)
9. Saaty, T.L.: A scaling method for priorities in hierarchical structures. J. Math. Psychol. **15**(3), 234–281 (1977)

Parametric Evaluation of Lathe Boring Operation to Improve the Surface Finish of Gray Cast Iron (SG-260) Under Dry Condition

Dayanand A. Ghatge, R. Ramanujam, and Dipali Ghatge

Abstract The role of surface roughness is very important in machining processes. The surface finish and tolerances are most critical quality measures in various mechanical products. The main objective of this paper is to find out the effect of machining parameters on a surface roughness in a lathe boring operation in dry condition. This paper shows the study of surface roughness for boring of gray cast iron (250BHN) by using carbide tool under dry condition. The effect of boring parameters (tool nose radius, feed, spindle speed and depth of cut) was analyzed using analysis of variance. These variables were computed using Taguchi's design of experiments (DOE). The DOE gives the optimal values of speed, feed and depth of cut for tool nose radius of 0.4 and 0.8 mm. The three-factor three-level fractional experiments were conducted. This result shows that the effects of speed, feed, depth of cut and tool nose radius on surface finish are statistically significant. The results observed that using larger tool nose radius always gives a good surface finish. The results also revealed that the following level for each of the factors produces the smooth surface finish within the range of experiments: larger tool nose radius, lower feed, higher speed and lower depth of cut.

Keywords Boring operation · DOE · Machining parameters · Surface roughness · Dry machining

1 Introduction

Boring is the operation of enlarging and finishing a hole produced by forging, drilling, casting and punching. A hole cannot be created by boring operation. Lathe boring operation is similar to external turning operation and conducted by a single-point cutting tool or a boring bar. The following two methods can be used for performing

D. A. Ghatge (✉) · D. Ghatge
K.B.P. College of Engineering, Satara, Maharashtra 415001, India
e-mail: dayananad.ghatge@kbpcoes.edu.in

R. Ramanujam
Vellore Institute of Technology, Vellore 632014, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_81

the boring operation on lathe machine. The workpiece is rotated by a chuck or a faceplate and the tool is fitted to the tool post, which is fed into the work. This method is used for boring of small workpiece. Small hole is enlarged using single-piece forged tool. But for machining a big hole, a boring bar with a tool bit attached to it is found to be more appropriate. Cross-slide screw is used for adjusting the depth of cut and the longitudinal travel of the carriage helps to provide feed.

The carriage is used for clamping the work and a boring bar carrying the tool is placed between the centers and made to rotate. The feed is provided by the longitudinal movement of the carriage and the adjustment of the position of the tool 'insert' gives depth of cut. Boring is widely used for machining of mass production in the industry. Effective boring of advanced materials requires selection of operative parameters to maximize material removal rate while controlling surface integrity. In order to maximize the removal rate with the constraints such as surface finish, damage of workpiece and wear of boring tool, proper combination of depth of cut, feed and speed must be selected within their operating range [1]. The proper combination of parameters such as the cutting speed, feed and the depth of cut impacts the cost of the machining process [2]. Mostly the depth of cut is kept constant and the cutting speed and feed rate are changed for reducing the production cost and/or for improving the production rate.

When the machine and labor cost was less, the machining parameters were focused to improve the surface finish and accuracy. The surface finish plays very important role in many industrial products. The impact of three machining variables, namely feed rate, cutting edge angles and tool nose radius on surface finish, is predominant [3]. As the competition in the market grows closer, the demands on the quality of the customers have increased. The high surface finish values of mechanical products increase the competition in today's manufacturing industry. During the boring operation, the tool is subjected to the three different variables such as temperature, forces and sliding action between the tool and the workpiece. After a specific period of duration, these variables make an impact on the performance of the tool that gives unsatisfactory performance [1]. Thus, it is necessary to optimize the tool life of boring tool by considering the various parameters used during the operation.

The machining parameters during the boring operation such as cutting speed, feed and depth of cut should be optimized for improving the product quality, productivity and manufacturing cost per workpiece. The optimization of cutting parameters results in increasing the production rate. As the cutting speed optimizes or increases, the material removal rate increases. The skilled and experienced machine operators are helping the manufacturing industries by applying their expert knowledge in optimization of various cutting parameters and selection of proper cutting tools. Thus, the manufacturing industry is totally dependent on skilled and experienced machine operators [4]. The machining operations are many times finishing operations so that the quality of machined component plays a very important role in its working. In boring operations, the quality of surface finish is an essential requirement of many bored workpieces. Thus, surface finish value plays a significant role in product quality. So this paper focuses on parametric optimization of surface finish in boring operation. In this study, I consider the following working parameters: workpiece hardness (material), feed, cutting tool nose radius, depth of cut and spindle speed. Taguchi method is the robust design techniques which is widely used in industries for making the optimization process.

Machining without any coolant is called as dry machining. The dry machining reduces the health issues of workers and environmental impacts. The advantages of dry machining are no water pollution, no atmosphere pollution, no risk to health and significant reduction in machining cost [5]. Dry machining is applicable for machining of cast iron materials too difficult to cut aerospace alloys [6]. It is found that few machining processes such as turning, milling and boring are more suitable than other machining processes due to its easy chip removal process [7].

2 Experimental Method

The objective of this work is to find out the effect of boring operation parameters on surface roughness and surface damage. For this experimentation, variables to carry out the experimentation are studied. Also, from the literature review, it is found that tool nose radius, tool length of boring bar, spindle speed, feed and depth of cut of tool are the major factors that affect surface finish and surface integrity [8, 9]. So, tool nose radius, tool length, spindle speed, feed and depth of cut are the factors selected for experimentation. Then the experiments are planned for the process of boring a hole using procedure of Taguchi's orthogonal arrays, a modification to the technique of design of experiments [10, 11].

2.1 Design of Experiments

The scientific investigations are planned to know the effects of number of parameters of different factors on the property or process. A properly planned experiment not only gives the effect of individual factor but also interaction effects. In this method desired values of parameters are decided before beginning of the experiment and output from the experiments are then analyzed.

2.2 Experimental Setup

During the experimentation, the knowledge of the existing product/process is of significance for selection of process parameters which can influence on the outcome. A list of input parameters is obtained with the help of skilled and experienced operators working in the industry. The brain-storming sessions were conducted for selecting the process parameters. These experiments were performed on a lathe

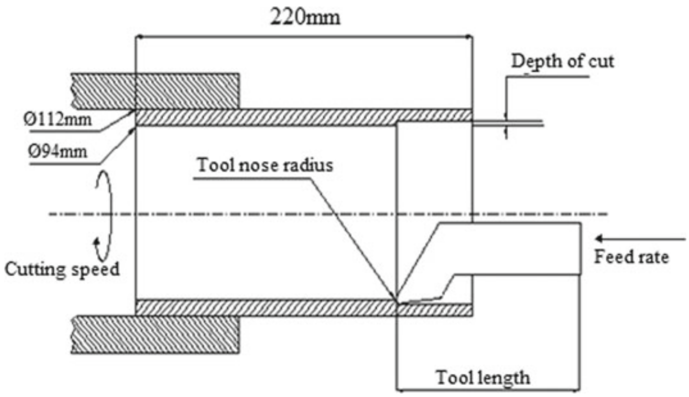


Fig. 1 View of boring operation

Table 1 Specifications of boring tool

Boring bar	Type	Tool length (mm)
CCMTO9T3	Sandvik make, square type	240

boring machine. The cemented carbide inserts were used in this experimentation. The Sandvik make, square type of 40 × 60 mm boring bar was mounted cantilevered in the tool post. Figure 1 shows the schematic diagram of experimental setup with all its operating variables (Table 1).

2.3 Experimental Procedure

Selection of key operating parameters is done through literature survey. And speed, feed, depth of cut and tool length are considered as control variables [12]. Selection of levels of the control variables: Three levels of control variables (−1, 0, 1) are selected. Table 2 gives the absolute values of variables.

Table 2 Factors and levels in the experiment

Level	Factors			
	Tool nose radius (mm)	Feed (mm/rev)	Depth of cut (mm)	Spindle speed (rpm)
	A	*B*	*C*	*D*
1	0.4	0.224	0.5	280
2	0.8	0.25	1	400
3	–	0.28	1.5	630

Three levels are taken into consideration because the influence of a factor result varies nonlinearly, whereas consideration of only two levels will lead to linear output [11]. L9 Taguchi's orthogonal array is opted for three factors and three levels [10].

Selection of workpiece

The workpiece used in this study is cylinder liner DAF-8. The material of cylinder liner was gray cast iron SG-260. The external diameter of cylinder liner DAF-8 was 112.1 mm and internal diameter was 101 mm and length was 220 mm. A Kirloskar Turnmaster—40 with speed range of 71–1600 rpm is used to cut the different parts. The hardness of workpiece material was 210–250 BHN.

Selection of boring bar

The cemented carbide inserts were used in this experimentation. The inserts were placed on Sandvik make, boring bar which was mounted in the tool post. The insert having tool nose radius of 0.4 and 0.8 mm were used during experimentation. The boring bar was mounted on the tool post cantileverly. The length of boring bar is 240 mm. The Sandvik make, square type 40 × 60 mm boring bar was used.

Selection of coolant

It was decided from the literature review and after consulting with the experts that there was no requirement of coolant to obtain a better surface finish [13, 14, 11].

Constant parameters used during experimentation

During the experimentation some of the parameters such as tool length, tool material, workpiece material and workpiece hardness were kept constant.

Measurement of surface finish

Surface finish was measured, using the surface roughness indicator instrument of M/S. Mitutoyo Corporation. A Mitutoyo Surftest-201P apparatus is used.

Repetition of experiment

The trial experiments were selected in a random order. After every trial, experimentation was repeated before attempting the next trial. One trial run per condition of the experiment is required. But variability in the results cannot be achieved in single run so that repetition of run was attempted which helped to improve the information in the data [11]. This also helps to confirm the original data points. During the day noise factor cannot be constant, and repeating the trials can help to expose their impact due to variance. Additional data achieved through repetitive trails can be examined for variance around the target value [10, 11]. Here, two repetitions of each experiment are carried out. The experimental setup may influence the result so that random order experimentation is adopted. As it is very difficult to change the boring bars, all three experiments are carried out for one boring bar once mounted on spindle (Figs. 2 and 3).

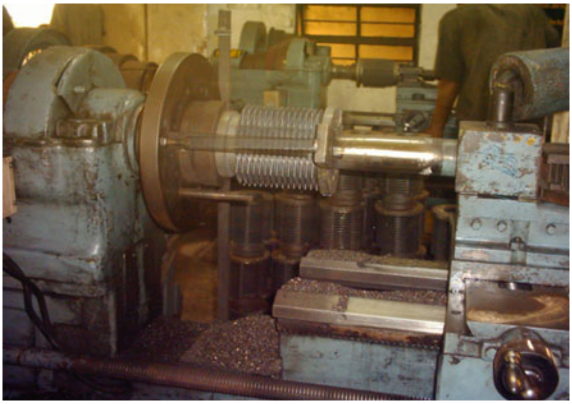


Fig. 2 View of boring operation

Fig. 3 Finished products after boring operation

3 Results and Discussion

Tables 3and4 show the responses, that is, surface roughness for all the sets of experiments conducted. ANOVA technique is commonly used for finding the relative significance of the respective factors on the behavior of the response variable. The number of experiment trials shows the effect of following parameters on surface roughness in finish lathe boring operation.

1. Tool nose radius
2. Feed
3. Speed
4. Depth of cut

In the present study two tool nose radii are undertaken for parametric evolutions.

Table 3 Observation table for surface roughness when tool nose radius, $r = 0.4$ mm

Expt. no.	Factors			R_a (µm) values for repetition			Avg. R_a (µm) value
	Feed (mm/rev)	Speed (rpm)	Depth of cut (mm)	1	2	3	
1	0.224	280	1.5	4.67	4.65	4.63	4.65
2	0.25	400	0.5	4.42	4.44	4.43	4.43
3	0.28	630	1	4.11	4.09	4.10	4.10
4	0.224	400	1	3.96	3.93	3.95	3.95
5	0.25	630	1.5	3.97	4.95	4.97	4.96
6	0.28	280	0.5	6.16	6.14	6.15	6.15
7	0.224	630	0.5	4.07	4.05	4.08	4.07
8	0.25	280	1	4.96	4.93	4.95	4.95
9	0.28	400	1.5	6.13	6.14	6.12	6.13

Table 4 Observation table for surface roughness when tool nose radius, $r = 0.8$ mm

Expt. no.	Factors			R_a (µm) values for repetition			Avg. R_a (µm) value
	Feed (mm/rev)	Speed (rpm)	Depth of cut (mm)	1	2	3	
1	0.224	280	1.5	2.51	2.53	2.49	2.51
2	0.25	400	0.5	2.44	2.50	2.47	2.47
3	0.28	630	1	2.23	2.24	2.23	2.23
4	0.224	400	1	1.98	1.96	2.00	1.98
5	0.25	630	1.5	2.68	2.66	2.65	2.66
6	0.28	280	0.5	3.17	3.18	3.16	3.17
7	0.224	630	0.5	2.19	2.21	2.19	2.20
8	0.25	280	1	2.61	2.60	2.63	2.61
9	0.28	400	1.5	3.11	3.13	3.10	3.11

3.1 Effect of Tool Nose Radius on Surface Roughness

Tables 3and4 show the comparative study between the surface roughness when tool nose radius is 0.4 and 0.8 mm, respectively. It also shows the effect of tool nose radius on surface roughness. In these tables all the parameters are kept constant except tool nose radius. It shows that the R_a values from Table 3 are greater than Table 4. It means the surface roughness from 0.4 mm nose radius gets poorer than the 0.8 mm nose radius. It can be observed that as tool nose radius increases, the surface roughness value goes on decreasing. In general, it helps to employ an insert with larger nose

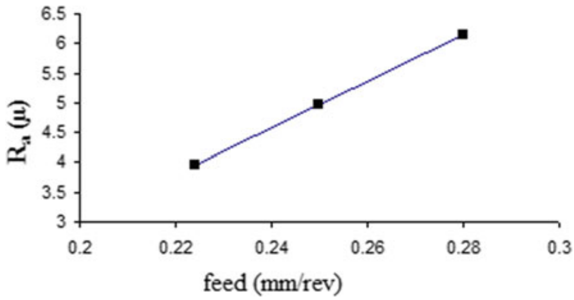


Fig. 4 Effect of feed on surface roughness when r = 0.4 mm

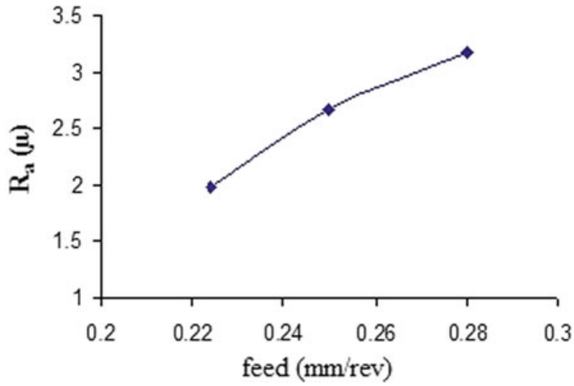


Fig. 5 Effect of feed on surface roughness when r = 0.8 mm

radius. The surface finish improves with the tool nose radius of 0.8 mm. So, it is beneficial to any company to use highest tool nose radius.

3.2 Effect of Feed on Surface Roughness

Figures 4 and 5 show the graph of effect of feed on surface roughness for tool nose radius 0.4 and 0.8 mm, respectively. These figures show the effect of feed on surface roughness. It can be observed that for both tool nose radii the impact of feed on surface roughness is the same, that is, as the feed value increases, the surface roughness value (R_a) also goes on increasing. At this point it is concluded that smaller feed gives the minimum surface roughness value.

3.3 Effect of Speed on Surface Roughness

Figures 6 and 7 show the graph of effect of speed on surface roughness for tool nose radius 0.4 and 0.8 mm, respectively. It was observed that for both tool nose radii the

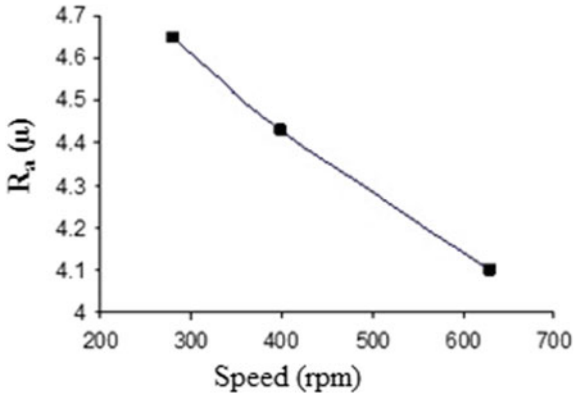


Fig. 6 Effect of speed on surface roughness when $r = 0.4$ mm

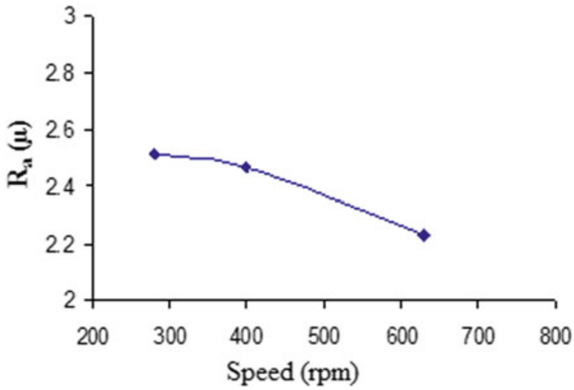


Fig. 7 Effect of speed on surface roughness when $r = 0.8$ mm

impact of speed on surface roughness is the same. It means as speed increases, the surface roughness value goes on decreasing. At this stage it is concluded that higher cutting speed gives the minimum surface roughness value. The graphs have indicated that the effect of cutting speed on the surface roughness is remarkably significant.

3.4 Effect of Depth of Cut on Surface Roughness

Figures 8 and 9 show the graph of the effect of depth of cut on surface roughness for tool nose radius 0.4 and 0.8 mm, respectively.

It was observed that for both tool nose radii the impact of depth of cut on surface roughness is the same. It can be seen from this graph that increase in depth of cut causes increase in surface roughness. At low depth of cuts tool penetration in the workpiece is less. This less penetration does not cause much resistance to tool progress through workpiece, so surface roughness is lower at low depth of cuts.

Fig. 8 Effect of depth of cut on surface roughness when $r = 0.4$ mm

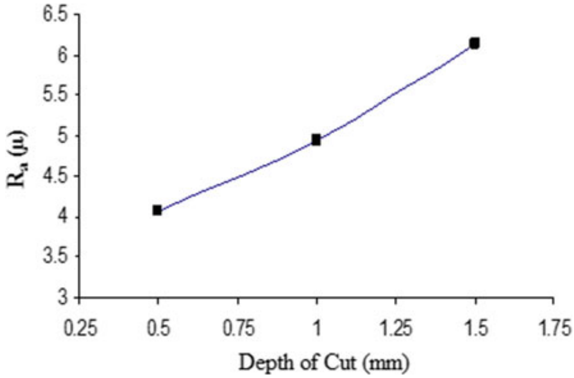
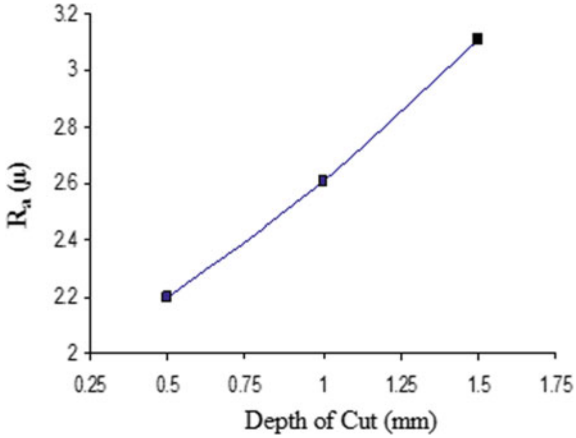


Fig. 9 Effect of depth of cut on surface roughness when $r = 0.8$ mm



At higher depth of cut, the tool penetrates more into the workpiece. This more penetration of tool into the workpiece causes surface disintegrations and more surface roughness.

3.5 Surface Roughness Measurement Instrument

In this experimentation work, Mitutoyo Surftest SJ-201P surface roughness tester was used for measurement of surface roughness. The Mitutoyo Surftest SJ-201P is most commonly used for measuring surface roughness in machine shops.

4 Conclusions

In this work, lathe boring operation has been optimized using Taguchi's design of experiment method. The experiments were carried out on gray cast iron FG-260 as workpiece material and four machining parameters: feed, speed, depth of cut and tool nose radius.

Conclusions for the investigations of the work for lathe boring operation are as follows:

1. The results found that a higher tool nose radius provides better surface finish than lower tool nose radius, that is, surface finish is directly proportional to the tool nose radius.
2. The smaller values of feed produce good surface finish.
3. The surface roughness values showed that a higher speed of spindle gives a good surface finish.
4. As the depth of cut increases, the surface roughness also increases.
5. As compared to other cutting parameters, the feed affects the most and the speed affects the least on surface roughness.
6. Larger tool nose radius, lower feed, higher speed and lower depth of cut are proven to be the appropriate combination for smoothening the surface within the range of experiments.

References

1. Beauchamp, Y., Thomas, M.: Investigation of cutting parameter effects on surface roughness in lathe boring operation by use of a full factorial design. Comput. Ind. Eng. **31**(3/4):645–651 (1996)
2. Feng, C-X (Jack): An experimental study of the impact of turning parameters on surface. In: Roughness' proceedings of the 2001 industrial engineering research conference, Paper No. 2036, pp 1–7 (2001)
3. Freiheit, T., Jack Hu, S.: Impact of Machining Parameters on Machine Reliability and System Productivity. Department of Mechanical Engineering. The University of Michigan, pp 1–21 (2002)
4. Prasadand, A.V.S.R.K., Rao, P.N.: Optimal selection of process parameters for turning operations in a CAPP system. Int. J. Prod. Res. **35**(6), 1495–1522 (1997)
5. Sreejith, P.S., Ngoi, B.K.A.: Dry machining: machining of the future. J. Mater. Process. Technol. **101**, 287–291 (2000)
6. Klocke, F., Eisenblatter, G.: Dry Cutting. Ann. CIRP **46**(2), 519–526 (1997)
7. Canter, N.: The possibilities and limitations of dry machining. Tribol. Lubr. Technol. 40–44 (2009)
8. Rasch, F.O., Rolstadas, A.: Selection of optimum feed and speed in finish turning. Ann. C.I.R.P. **154**: 787–792 (1971)
9. Agapiou, J.S.: The optimization of machining operation based on a combined criterion, Part 1: The use of combined objectives in single pass operations. Trans. ASME **114**, 500–507 (1992)
10. Kothari, C.R.: Research Methodology—Methods and Techniques, 2nd edn. Wishwa Prakashan, New Delhi (1990)

11. Roy, R.: A primer on the Taguchi method. Society of Manufacturing Engineering (1990)
12. Mitaland, A., Mehta, M.: Surface finish prediction models for fine turning. Int. J. Prod. Res. **26**(12):1861–1876 (1988)
13. Hinduja, S.: Calculation of cutting conditions for turning operations. Proc. Inst. Mech. Eng. **199**(B2), 81–92 (1984)
14. Ozel, T., Zeren, E.: Effects of cutting edge geometry, workpiece hardness, feed rate and cutting speed on surface roughness and in finish turning of hardened AISI H13 steel. Int. J. Adv. Manuf. Technol. **25**, 262–269 (2005)

Impact of Casting Parameters on Surface Roughness and Hardness of Squeeze Cast Beta Brass

Mohd Talha Khan, Deepak Singh, and Udit Vasishtha

Abstract In the present study endeavor has been made to research the castability of brass alloy, that is, beta brass using squeeze casting process. The castability was assessed by examining the impact of squeeze casting parameters, namely pouring temperature at 950, 975 and 1000 C levels, squeeze pressure of 80, 120 and 160 MPa and dwell time of 15, 30 and 45 s, on surface roughness and hardness using Taguchi design of experimentation method. Signal-to-noise ratio, smaller is better for surface roughness and larger is better for hardness, is used for the analysis. The results of the study showed that the optimum condition in order to get minimum surface roughness for squeeze cast Beta Brass is pouring temperature with 950 C, squeeze pressure with 120 MPa and dwell time with 30 s as most significant parameter. The optimum condition in order to get maximum hardness for squeeze cast Beta Brass is pouring temperature with 1000 °C, squeeze pressure with 120 MPa and dwell time with 15 s, with squeeze pressure as most significant parameter.

Keywords Squeeze casting · Beta brass · Surface roughness · Hardness

1 Introduction

Squeeze or pressure die-casting comprises both the casting and forging process, which is done with the assistance of high pressure, applied during solidification of molten metal. These result in the change of melting point of alloys which upgrade the solidification rate and refine the micro as well as macrostructure of cast alloys [1]. The two types of squeeze casting processes used are direct SC and indirect SC. In case of direct SC process, pressure to the entire surface of molten metal is applied during freezing, whereas in case of indirect SC process, the injection of molten metal into die cavity takes place using piston of small diameter. Most of the research work is carried out for squeeze casting of aluminum and zinc alloys, and the effect of parameters like solidification time and temperature on mechanical

M. T. Khan (✉) · D. Singh · U. Vasishtha
Moradabad Institute of Technology, Moradabad, U.P., India
e-mail: talha2207@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_82

properties of aluminum and zinc alloys is investigated [2, 3]. The other significant parameters for squeeze cast aluminum alloy (AC2A) found were squeeze pressure, die preheating temperature and compression holding time shown improvement in mechanical properties of squeeze cast aluminum alloy (AC2A) [4]. The squeeze casting process is extensively used by the researchers to study the castability of alloys. Due to limited research in the field of brass alloys [5], though brass have good corrosion resistant properties and wide use in decorative items, investigation is carried out by taking Beta Brass and the impact of casting parameters on surface roughness and hardness using squeeze casting process is evaluated.

2 Research Methodology

The investigation is carried out with the help of Taguchi design of experimentation method.

2.1 Taguchi Method

It is a set of experimentation technique which gives a systematic and efficient methodology for optimization of the process. This method is used for achieving product and process conditions that are minimally sensitive to the different causes of variation. This results in high-quality products along with low costs for development and manufacturing. Signal-to-noise ratio serves as objective functions for optimization, and orthogonal array provides set of balanced experiments and are two major tools used for carrying out robust design. The S/N ratio characteristics are classified as follows:

(a) Nominal is best characteristics
(b) Smaller is better characteristics
(c) Larger is better characteristics [6]

A three-level L9 orthogonal array is selected with nine experimental runs.

2.2 Selection of Control Parameters

The castability was assessed by examining the impact of squeeze casting parameters, namely pouring temperature, squeeze pressure and dwell time based on the literature review. Pouring temperature has significant impact on fluidity of molten alloy as well as toughness of casting product. The combination of high squeeze pressure and dwell time leads to high heat transfer rate and reduce shrinkage and porosity [7, 8] (Table 1).

Table 1 Control parameters and their level selected for the experimentation

S. No.	Control factor	Level 1	Level 2	Level 3
	Pouring temperature (°C)	950	975	1000
	Squeeze pressure (MPa)	80	120	160
	Dwell time (s)	15	30	45

3 Experimentation

The resistance furnace is used to melt the Beta Brass. The ingot is first broken down into small pieces by a power hack saw and is used to produce molten Beta Brass in resistance furnace. The furnace temperature can be taken from a digital meter. The temperature of the molten metal is taken with the help of a thermocouple inside the crucible while pouring. The metal is allowed to solidify under the application of external force, applied by hydraulic press in the mold and hence a casting is formed. For the specimen preparation, the C-part is handled through three significant operations, that is, turning, grinding and polishing. In the first stage, turning operation is performed through a turret lathe with the assistance of a single-point cutting tool of diameter 10 mm resulting in a cylindrical shape of C-part. In the second stage, one flat surface of the specimen is subjected to grinding operation. Grinding is done by emery papers of suitable grade ranging in between 400 and 1500 grits. Fine polishing of metallographic specimen is required for the purpose of removing scratches from the surface of the specimen. The fine scratches introduced during the last grinding operation are removed and ultimately it results in producing a highly polished scratch-free surface. The specimen is hold against a rotating flat disc on which a polishing cloth is impregnated with suitable polishing media (alumina powder). The disc polisher consists of a 20 cm balanced polishing disc mounted on a steel spindle. The speed of the disc continuously varied from 450 to 1200 RPM. The specimen is shown in Fig. 1.

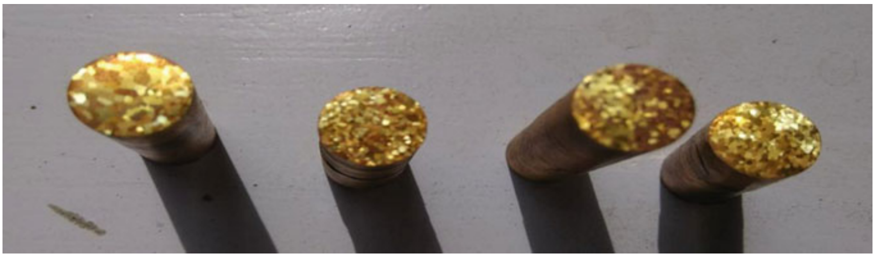


Fig. 1 Specimen showing its polished surface and hardness

3.1 Surface Roughness Testing

Surface roughness may be defined as the irregularities per unit length (usually μm). Roughness is expressed in terms of height, its width and its distance on the surface along which it is estimated. Surface roughness test is done on the initial casting with the help of surface roughness tester. The tests are performed on the basis of the ISO4287 standards with the average R_a value, characterized as the arithmetical mean of the deviations of the roughness profile from the central line along the estimation. Average of ten observations was obtained for each specimen. In the present research work, surface roughness of the die casting components is measured using a surface roughness tester (SJ–201P) of Mitutoyo Corporation, Japan [9].

3.2 Hardness Testing

According to [10] hardness is characterized as resistance to permanent indentation. It is not a fundamental property; it depends upon the shape of indenter and load applied. In hardness test, computerized Vickers testing machine is utilized, which has a pyramid-shaped diamond indenter. Hardness is indicated by VHN. Pyramid apex angle is 136°. ASTM E92-82, 2003 norms are followed and maintained, while performing the experiments, according to which 1 kgf load is applied for 10 s.

4 Results and Discussion

The investigation of obtained quality characteristics of castings produced as per the experimentation planning has been presented. The value of surface roughness along with *S*/*N* ratios for casting at different pouring temperature and dies are presented in Table 2. Figures 2, 3 and 4 show the effect of pouring temperature, squeeze pressure and dwell time on surface roughness.

From Figs. 2, 3 and 4, it is found that the optimum condition in order to get minimum surface roughness for squeeze cast Beta Brass is pouring temperature with 950 °C, squeeze pressure with 120 MPa and dwell time with 30 s.

From Table 3, it can be seen that dwell time has the most significant impact on surface roughness among all three process parameters. The value of hardness and *S*/*N* ratios is presented in Table 4. Figures 5, 6 and 7 show the effect of pouring temperature, squeeze pressure and dwell time on hardness. From Figs. 5, 6 and 7, it is found that the optimum condition in order to get maximum hardness for squeeze cast Beta Brass is pouring temperature with 1000 °C, squeeze pressure with 120 MPa and dwell time with 15 s. From Table 5, it can be seen that squeeze pressure has the most significant impact on hardness among all three process parameters.

Table 2 Experimental results for surface roughness and *S*/*N* ratios

Casting No.	Pouring temperature (°C)	Squeeze pressure (MPa)	Dwell time (s)	Surface roughness (μm)	*S*/*N* ratio(dB)
1	950	80	15	5.82	−15.2985
2	950	120	30	4.11	−12.2768
3	950	160	45	5.80	−15.2686
4	975	80	30	4.87	−13.7506
5	975	120	45	4.31	−12.6895
6	975	160	15	7.66	−17.6846
7	1000	80	45	6.33	−16.0281
8	1000	120	15	6.43	−16.1642
9	1000	160	30	5.28	−14.4527

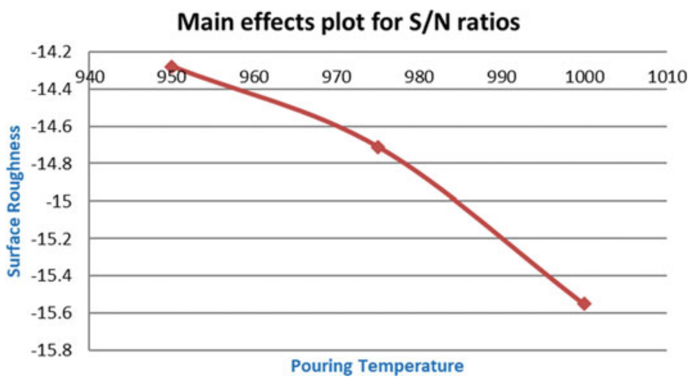


Fig. 2 Pouring temperature vs surface roughness

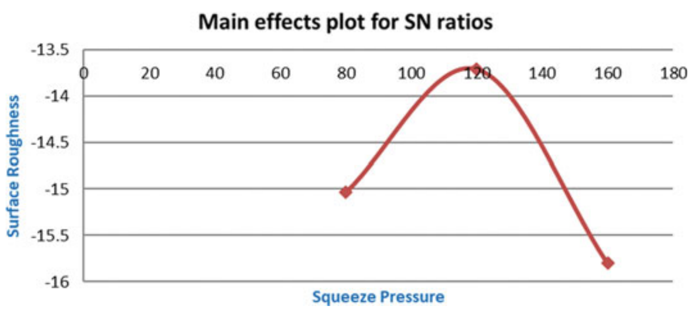


Fig. 3 Squeeze pressure versus surface roughness

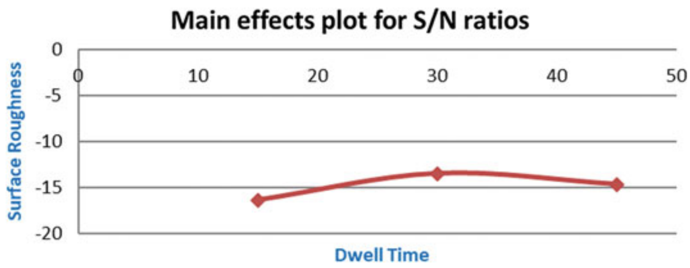


Fig. 4 Dwell time versus surface roughness

Table 3 Response table for *S*/*N* ratios for surface roughness

Level	Pouring temperature (°C)	Squeeze pressure (MPa)	Dwell time (s)
1	−14.28	−15.03	−16.38
2	−14.71	−13.71	−13.49
3	−15.55	−15.80	−14.66
Delta	1.27	2.09	2.89
Rank	3	2	1

Table 4 Experimental results for hardness and *S*/*N* ratios

Casting No.	Pouring temperature (°C)	Squeeze pressure (MPa)	Dwell time (s)	Hardness (VHN)	*S*/*N* ratio (dB)
1	950	80	15	186	45.3903
2	950	120	30	219	46.8089
3	950	160	45	205	46.2351
4	975	80	30	195	45.8007
5	975	120	45	189	45.5292
6	975	160	15	189	45.5292
7	1000	80	45	183	45.2490
8	1000	120	15	253	48.0624
9	1000	160	30	203	46.1499

5 Conclusion

The following conclusions are made from the investigation:

1. The optimum condition in order to get minimum surface roughness for squeeze cast Beta Brass is pouring temperature with 950 °C, squeeze pressure with 120 MPa and dwell time with 30 s.

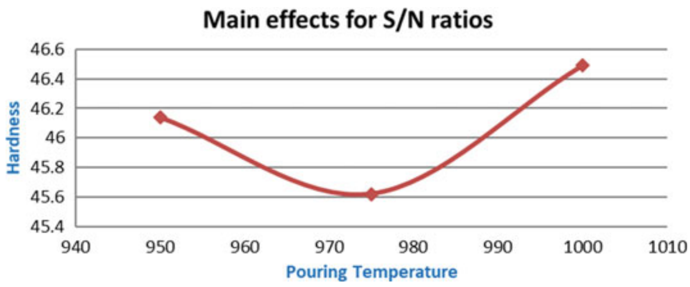


Fig. 5 Pouring temp. versus hardness

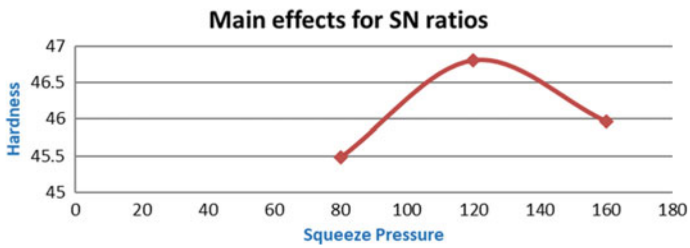


Fig. 6 Squeeze pressure versus hardness

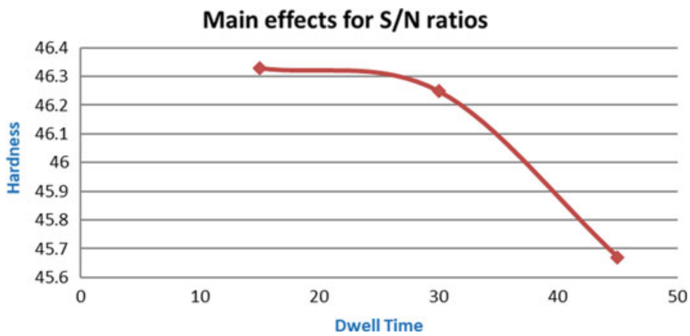


Fig. 7 Dwell time versus hardness

Table 5 Response table for *S*/*N* ratios for hardness

Level	Pouring temperature (°C)	Squeeze pressure (MPa)	Dwell time (s)
1	46.14	45.48	46.33
2	45.62	46.80	46.25
3	46.49	45.97	45.67
Delta	0.87	1.32	0.66
Rank	2	1	3

2. Dwell time has the most significant impact on surface roughness amongst all three process parameters.
3. The optimum condition in order to get maximum hardness for squeeze cast Beta Brass is pouring temperature with 1000 °C, squeeze pressure with 120 MPa and dwell time with 15 s.
4. Squeeze pressure has the most significant impact on hardness among all three process parameters.

Acknowledgements The authors would like to thank MHSC, Moradabad for composition testing of brass alloy and MIT, Moradabad for providing research facilities.

References

1. Arul, K., Manoj, T., Thanikasalam, K., Elanchezhian, J.: Investigation of squeeze casting on metal matrix composite [Al-Sic (P)REINFORCED]. Int. J. Adv. Eng. Res. Dev. **2**(3), 390–396 (2015)
2. Yang, L.J.: The effect of casting temperature on the properties of squeeze cast aluminium and zinc alloys. J. Mater. Process. Technol. **140**, 391–396 (2003)
3. Yang, L.J.: The effect of solidification time in squeeze casting of aluminium and zinc alloys. J. Mater. Process. Technol. **192**(193), 114–120 (2007)
4. Senthil, P., Amirthagadeswaran, K.S.: Optimization of squeeze casting parameters for non-symmetrical AC2A aluminium alloy castings through Taguchi method. J. Mech. Sci. Technol. **26**(4), 1141–1147 (2012)
5. Singh, D., Chhabra, M., Tirth, V.: Optimization of process parameter to enhance the impact strength of squeeze cast brass alloy. MIT Int. J. Mech. Eng. **5**(1), 43–48 (2015)
6. Adke, M.N., Karanjkkar, S.V.: Optimization of die-casting process parameters to identify optimized level for cycle time using Taguchi Method. Int. J. Innov. Eng. Technol. **4**(4), 365–375 (2014)
7. Vijian, P., Arunachalam, V.P.: Optimization of squeeze casting process parameters using Taguchi analysis. Int. J. Ad. Manuf. Technol. **33**, 1122–1127 (2007)
8. Vali, S.N., Sureshkumar, S., Athiya, M.A., Manigandan, K., Fayazdeen, H.: A review on die-casting process parameters. Int. J. Sci. Res. Rev. **7**(3), 169–172 (2018)
9. Maleki, A., Shafyei, N.: Effects of squeeze casting parameters on the microstructure of LM13 alloy. J. Mater. Process. Technol. **209**(8), 3790–3797 (2009)
10. Kuhn, H., Medlin, D.: ASM Handbook. Material Testing and Evaluation, vol 8. ASM Publisher (2000)

Impact of Step Size, Spindle Speed and Sheet Thickness on Forming Force in SPIF

Ajay Kumar, Parveen Kumar, Vishal Gulati, Yajvinder Singh, Vinay Singh, and Ravi Kant Mittal

Abstract Single Point Incremental Forming (SPIF) is a viable and flexible forming technique that has great potential to fulfil the need of various emerging areas like automobile and aerospace sectors. In addition, this technique has the ability to trigger the revolution in rapid prototyping and batch-type production of sheet material components. The flexibility and the ability to be economical can save the energy that in turn makes this process ready for green manufacturing. The prediction and measurement of forming forces during the SPIF process determine the size of forming machinery and additional hardware along with preventing the failures of facilities. This work focuses on the investigation of some significant input factors of this die-less process on maximum axial forming forces. The detailed knowledge about the impact of input factors would help the researchers and engineers to increase the viability of this process on an industrial scale. Results showed that components can be formed by minimal axial forces (886 N) when a combination of lower sheet thickness (0.8 mm, in this case) and lower step size (0.2 mm, in this case) are taken into account. Thicker sheets can be formed with smaller forming forces by employing higher spindle speed, and energy can be saved up to a larger extent.

A. Kumar (✉)
Department of Mechanical Engineering, Faculty of Engineering and Technology, Shree Guru Gobind Singh Tricentenary University, Gurugram 122505, Haryana, India
e-mail: ajay.kumar.30886@gmail.com

P. Kumar
Department of Mechanical Engineering, National Institute of Technology, Kurukshetra 136119, Haryana, India

V. Gulati · Y. Singh
Department of Mechanical Engineering, Guru Jambheshwar University of Science & Technology, Hisar 125001, Haryana, India

V. Singh
Department of Mechanical Engineering, Jagannath University, Bahadurgarh, NCR 12450, Haryana, India

R. K. Mittal
Department of Mechanical Engineering, Birla Institute of Technology and Science, Pilani 333031, Rajasthan, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_83

Keywords Incremental sheet forming · Single point incremental forming · Forming force · AA-2024 · Input parameters

1 Introduction

Sheet material forming is a manufacturing process that allows producing user-ready parts with negligible wastage. Sheet forming processes can produce the components having sufficient strength, better surface finish and close tolerances. The force required to deform the material, under consideration, is normally quite larger during forming processes. Therefore, heavy machinery and forming tools need to be executed to produce sufficient deformation. Furthermore, the use of forming hardware of high capacity leads to the increase in the cost of the process that makes the process uneconomical if components are not produced up to the quantity that reaches at least the breakeven point of the process. Conventional sheet material forming techniques have limited formability that renders the requirement of cutting-edge methods to increase the versatility of the formed components. Moreover, the global market is inviting the expansion of obsolescence of techniques and methods for producing the parts, taking the requirements of customers [1]. This promotes the adoption of batch-type and customized production in manufacturing industries. Customized production needs some special techniques that are able to manufacture components with lower cycle time and setup cost [2–4]. Traditional forming techniques, such as deep drawing, need devoted tools and dies for specific requirements of shapes of components to be formed. Hence, conventional methods of forming do not satisfy the cutting-edge requirements of customized production [5–7]. Therefore, the necessity of evolving a creative and adjustable forming technique becomes stronger and compelling that enables the customized production and rapid prototyping of sheet material components economically [8, 9].

The Incremental Sheet Forming (ISF) technique is acquiring the significance for customized and batch-type production as it has various capabilities to target and solve various issues and problems of sheet forming sectors economically. In addition, ISF renders indispensable factors like lightweight components, high productivity, flexibility in shapes and sizes of parts, and greater preciseness of process for manufacturing customized components economically [10, 11]. ISF involves progressive plastic deformation of the material, which is under consideration, by the stratagem action of the forming tool that is regulated by a numerically controlled mechanism. Generally, Computer Numerical Control (CNC) milling machine, articulated industrial robot, or purpose-built ISF machines are used for accomplishing the ISF process [12].

Single Point Incremental Forming (SPIF) is a subclass of the ISF process which is also known as “negative incremental forming” or “die-less forming”. The SPIF technique eliminates the use of any kind of die for producing components of sheet materials. Lesser lead time and lower tooling cost allow the SPIF technique to become suitable for producing the components in batches economically and efficiently [13].

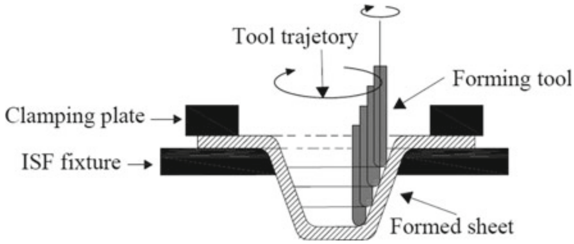


Fig. 1 Single point incremental forming [1]

Moreover, the absence of specific dies and punches, which otherwise are essential in traditional forming techniques, increases the versatility and flexibility of the SPIF technique. The forming tool deforms the sheet material layer by layer by following a predetermined trajectory of the required shape. Figure 1 shows the schematic of the SPIF technique. The applications of the ISF process are very wide including aerospace, automotive, architecture, medical and prototyping [14].

Smaller forming forces are required to produce deformation during SPIF as compared to traditional sheet forming techniques because the deformation is purely local during incremental forming. The capacity and size of the forming machinery define the level of power consumption and the initial cost of forming setup. Hence, energy can be saved up to a large context by using negative incremental forming. Furthermore, the determination of maximum forming forces required for producing components from specific material under a specific set of parameters delineates the capability of the forming machinery that should be employed for this process. Therefore, assured utilization of forming setup can be promised by investigating and determining maximum forming force [15].

In SPIF, forming force can be measured by load cells or force dynamometers using various methods. Most of the researchers [14–23] have employed a table-type dynamometer fixing it between the machine table and the sheet clamping device or fixture as shown in Fig. 2. Kumar et al. [14] also studied the impact of various process variables on axial forming forces on AA2024 sheets using a forming tool of hemispherical shape. Conical frustums of various wall angles (52°, 56°, 60°, 64°) were formed using a helical tool path. The combination of larger tool diameter and sheet thickness resulted in the increment of required forming significantly which

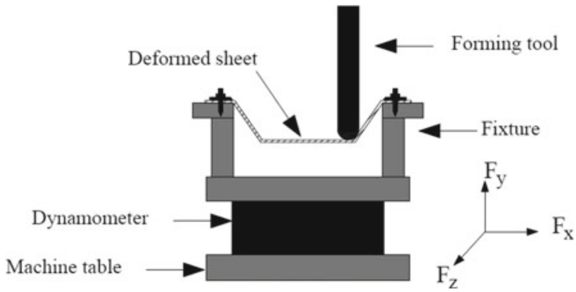


Fig. 2 The schematic of measurement of forming force during SPIF

becomes a crucial parameter for machinery employed for the SPIF operation and hence should be taken care of. Forming forces were raised by 20.03%; tool radius was raised from 3.76–7.83 mm for a wall angle of 64°. Kumar et al. [15] focused on the influence of interactions of tool radius—tool shape and wall angle—tool shape on forming forces on AA2024 sheets. Flat-end and hemispherical tools were used for producing deformation using a helical tool path. It was observed that forces were increased by 17.46% when a tool radius of 5.80 mm of flat-end was employed as compared to a hemispherical shape. The increase in tool radius (from 3.76 to 7.83 mm) resulted in the decrement of forces by 35.49%. Use of a flat-end tool with higher wall angle led to an increase in axial forces and sheet failure. Uheida et al. [16] studied the impact of feed rate and spindle speed on vertical forming forces on titanium grade 2 sheets of 0.8 mm thickness using a hemispherical-end forming tool of 10 mm to produce Varying Wall Angle Conical Frustum (VWACF). Results showed that, although, forming force decreased with the increase in spindle speed but sheet fracture was noticed after spindle speed of 4000 rpm. Alsamhan et al. [17] optimized the SPIF process for forming forces taking step size, feed rate, sheet thickness and tool radius into account on AA1050-H14 sheets. Furthermore, a model was established to estimate the forces by artificial intelligence techniques. Sakhtemanian et al. [18] developed a theoretical model for predicting the energy that can be converted to heat from the ultrasonic vibrations used in the study. In addition, the temperature attained by a forming tool was also analysed. The forming forces were decreased significantly when ultrasonic vibrations were used. This held good with all levels of feed rate and step size. Long et al. [19] studied the influence of feed rate, material of sheet (AA1050-H14, AA5052-H34), vibration amplitude (0, 6, 9, 12, 15, 18 μm), ultrasonic power and tool radius on forming force and temperature induced during the ultrasonic-assisted SPIF process. The reduction in forming forces was lower when higher feed rate was used because less ultrasonic energy could be transmitted into work material per unit time. Honarpisheh et al. [20] investigated forming force, thickness distribution and geometrical accuracy of bimetal sheets of AA1050 and copper (C-10100). The results showed that the axial forming forces increased from 1464 and 1357 to 1636 N and 1730 N for mm to 16 mm. Moreover, the error between simulation and experimental results (forming force) was 9.6%. Zhai et al. [21] investigated the effects of spindle speed, sheet thickness and step size on forming forces during Ultrasonic-assisted ISF (U-ISF) and ISF on AA1050-O sheets to produce pyramidal frustums. Forming forces were found to reduce up to 40% when ultrasonic amplitude was increased from 0 to 10 μm. Moreover, the forming forces increased gradually in the initial stages because of work hardening effects and then became stable due to the equilibrium between work hardening and sheet thinning. Kumar et al. [22] studied the impact of various process variables for axial forming forces and optimized the SPIF process using the Taguchi method for AA6063 and AA2024 sheets. Results showed that forming forces were found to be reduced by 14.20% when a hemispherical tool of 11.60 mm was used in place of a flat-end tool of the same diameter keeping other factors constant. A statistical model was also developed for estimating the axial forming forces which was validated with further experimentation work. Authors also explored the gradient of force curve that could be employed as a spy variable for the safe implementation of the SPIF operation.

Kumar and Gulati [23] studied the impact of various process variables for axial forming forces and thickness reduction and optimized the SPIF process using the Taguchi method on AA2014 sheets. Conical frustums were formed using two different tool path approaches, viz. profile and helical, and these are well described byAjay [1], Kumar and Gulati [13, 22]. Forming forces were observed to be raised when tool radius, step size and sheet thickness. Lubricants were found to affect forces negligibly as compared to the impact of other factors taken into account. A statistical model was proposed for predicting the forming which was further validated experimentally. Chang et al. [24] developed an analytical model for predicting forming forces in single pass SPIF, multi-pass SPIF and incremental hole flanging processes and validated the same with experimental results by varying impact factors like sheet thickness, wall angle, step size and tool diameter for AA5052 and AA3003 alloys sheets to produce VWACF and VWAPF.

It has also been observed in the literature [13, 25, 26] that the axial forming forces (Fz) are much greater than the other two components of forming forces (i.e. Fx and Fy). Therefore, a secure implementation of forming machinery and forming tools can be ensured by determining the maximum axial forces required to execute the SPIF process. The knowledge about the effects of input factors on forming forces would lead to an efficient prediction of failures of components as well as machinery used for executing the process. Furthermore, the prediction of forming forces helps in controlling the process online and estimating the power needed by forming machinery.

This paper aims at filling this gap by investigating the impact of step size, spindle speed and interactions of these with the sheet thickness. To the best of the authors' knowledge, the interactions of these parameters have not been studied on AA2024 sheets during the SPIF process so far. AA2024 is a popular aluminium alloy which is known for its favourable characteristics in sheet metal applications like lightweight, high strength, corrosion resistance, etc. Table 1 represents the chemical compositions of AA2024 sheets extracted by using an optical emission spectrometer (Foundry Master, Oxford Instruments, Uedem, Germany). Table 2 represents the levels of

Table 1 Chemical compositions of AA2024 sheet

Element	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
Weight %	91.50	0.10	4.60	0.30	1.70	0.80	0.50	0.10	0.20

Table 2 The levels of input variables under investigation

Variable	Level 1	Level 2	Level 3	Level 4
Sheet thickness (mm)	0.8	1.2	1.6	–
Step size (mm)	0.2	0.5	0.8	1.2
Spindle speed (rpm)	Free	500	1000	1500

impact factors investigated in the current work. Castrol Alpha SP 320 oil has been used as a lubricant during forming operation. While varying the set of input factors, other parameters were kept constant according to previous work [15].

2 Materials and Methods

Experimental tests were performed using a CNC milling machine, hemispherical tool, SPIF fixture and strain gauge-based load-cell. The working area of the fixture was 200 mm × 200 mm. The experimental setup (Fig. 3) is equipped with a load dynamometer and a data logger system to record the online values of forming force along an axial downward direction (Fz) of the forming tool. Conical frustums (120 mm major diameter, 70 mm depth) of constant wall angle of 64° have been formed taking a hemispherical tool and a helical tool path into account. The DelcamTM software was used for preparing numerical instructions for forming conical frustums on CNC milling after modelling it in SOLIDWORKS® software.

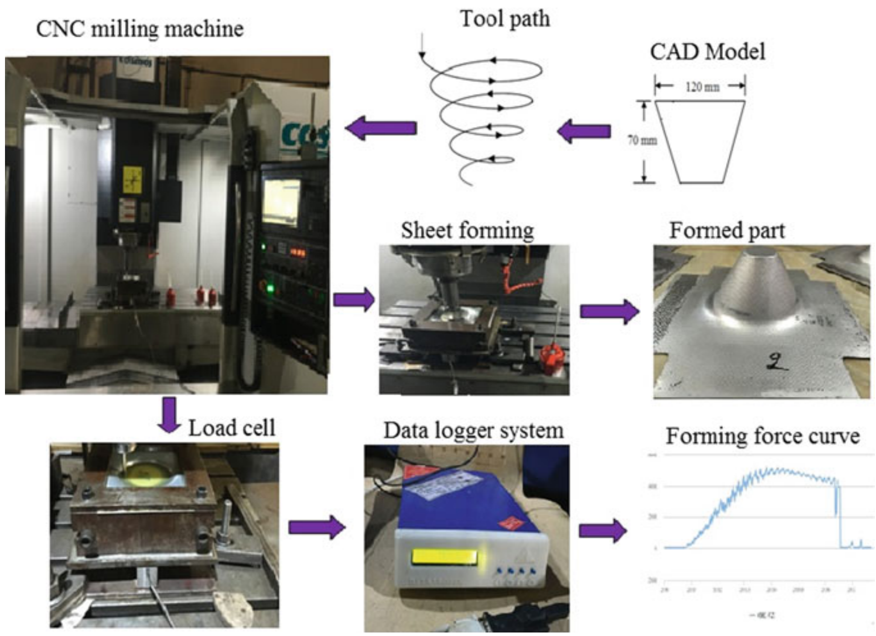


Fig. 3 Experimental setup and measurement of forming force

3 Results and Discussion

The recorded values of the maximal vertical downward forces (Fz_max.) are depicted in Table 3. The influence of the interaction of sheet thickness and step size is depicted in Fig. 4. The maximal axial force was increased dramatically when the amount of sheet thickness and step size was raised because the larger step size results in deforming the material in a large amount at an instant. For higher sheet thickness, a large amount of material is deformed which requires much forming load to produce local deformation. When a combination of higher levels of these two factors is employed, the forming force increases very rapidly and hence, becomes the limiting factor of the forming tool and machinery that should obviously be avoided. On the other hand, the implementation of higher step size leads to a reduction in forming time due to the fact that larger size can finish the required depth in lesser contours. The combination of a higher level of step size and a lower level of sheet thickness resulted in the failure of sheet material well below the deigned depth (at 43 mm) because less amount of material is available (for low sheet thickness, 0.8 mm in this case) for deformation, and larger step size (1.2 mm, in this case) produces excessive thinning over the forming of the depth of components.

The influence of the interaction of sheet thickness and spindle speed is depicted in Fig. 5. The maximal axial force was found to reduce dramatically when the spindle speed was raised because the high spindle speed led to an increment in friction at the tool-sheet interface. Hence, the ductility of the material is raised due to the increase in temperature caused by increased friction. This trend of reducing forces continued with all levels of spindle speed and step size. It was also noticed that higher

Table 3 Experimental results for the designed conditions on maximal axial forces

(a) Effects of step size and sheet thickness				(b) Effects of spindle speed and sheet thickness			
Run	Step size	Sheet thickness	Fz_max. (N)	Run	Spindle speed	Sheet thickness	Fz_max. (N)
1	0.2	0.8	886	1	Free	0.8	1042
2	0.2	1.2	917	2	Free	1.2	1151
3	0.2	1.6	959	3	Free	1.6	1292
4	0.5	0.8	967	4	500	0.8	968
5	0.5	1.2	999	5	500	1.2	1072
6	0.5	1.6	1048	6	500	1.6	1208
7	0.8	0.8	1075	7	1000	0.8	892
8	0.8	1.2	1121	8	1000	1.2	991
9	0.8	1.6	1184	9	1000	1.6	1112
10	1.2	0.8	1218	10	1500	0.8	821
11	1.2	1.2	1271	11	1500	1.2	906
12	1.2	1.6	1345	12	1500	1.6	1006

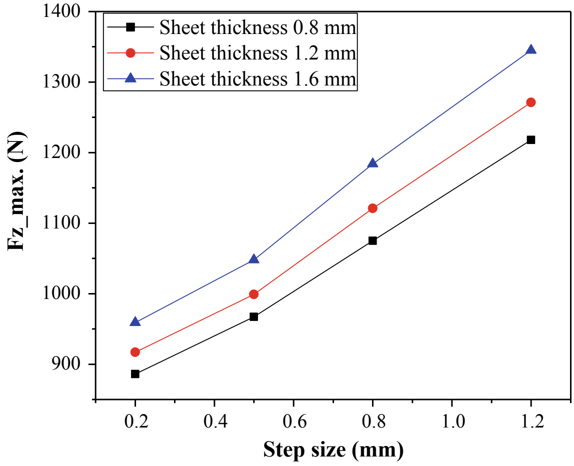


Fig. 4 Influence of sheet thickness and step size on maximal axial forces

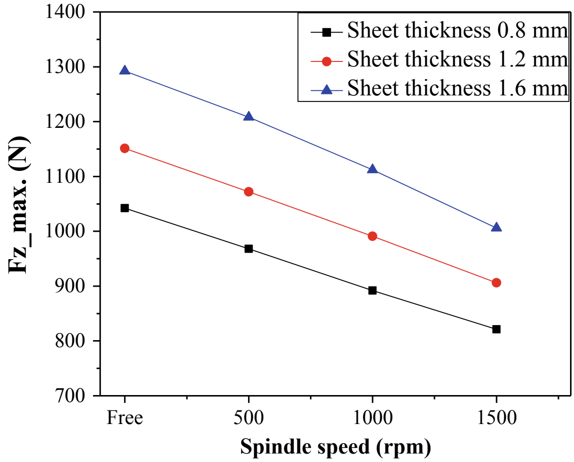


Fig. 5 Influence of sheet thickness and spindle speed on maximal axial forces

spindle speed (1500 rpm, in this case) resulted in producing chips during the forming operation which led to the deterioration of surface quality of formed components. On the other hand, higher spindle speed (1500 rpm, in this case) enabled the forming of thicker sheets (1.2 and 1.6 mm, in this case) at reduced forming force (906 and 1006 N, respectively) as compared to the condition when the spindle was at the "free to rotate" setting. Hence, thicker sheets can be formed with smaller forming machinery by employing higher spindle speed and energy can be saved up to a larger extent.

4 Conclusion

In this work, interactions of input variables have been studied during the SPIF process. To accomplish the objectives, conical frustum benchmark components have been produced using a helical tool path. It was observed that the investigated factors were of great significance that can affect and control the process. The combination of high levels of step size and sheet thickness increases the required force dramatically and that becomes a limiting factor for the capacity of forming machinery. Thicker sheets can be formed with smaller forming forces by employing higher spindle speed, and energy can be saved up to a larger extent. The combination of higher step size and lower sheet thickness results in sheet failure. The increase in spindle speed can raise the formability of the material at the expense of surface quality of formed components. Future work would target the investigation of the effects of interactions of input variables on formability and surface roughness of formed components.

References

1. Ajay, Mittal, R.K.: Incremental sheet forming technologies: principles, merits, limitations, and applications, 1st edn. CRC Press, Taylor and Francis. ISBN: 978-0-367-27674-4. United States (2020)
2. Kumar, A., Gulati, V.: Experimental investigation and optimization of surface roughness in negative incremental forming. Measur J Int Measur Confederation **131**, 419–430 (2019)
3. Kumar, A., Gulati, V., Kumar, P.: Investigation of surface roughness in incremental sheet forming. In: Procedia Computer Science, International Conference on Robotics and Smart Manufacturing 2018, vol. 133, pp. 1014–1020. Elsevier (2018)
4. Kumar, A., Gulati, V., Kumar, P.: Effects of process parameters on surface roughness in incremental sheet forming. In: Materials Today Proceedings, International Conference on Composite Materials, Manufacturing, Experimental Techniques, Modeling and Simulation 2018, vol. 5(14), pp. 28026–28032. Elsevier (2018)
5. Jeswiet, J., Micari, F., Hirt, G., Bramley, A., Duflou, J., Allwood, J.: Asymmetric single point incremental forming of sheet metal. CIRP Ann Manuf Technol **54**, 88–114 (2005)
6. Bagudanch, I., Centeno, G., Vallellano, C., Garcia-Romeu, M.L.: Forming force in single point incremental forming under different bending conditions. Procedia Eng **63**, 354–360 (2013)
7. Gulati, V., Kumar, A.: Investigation of some process parameters on forming force in single point incremental forming. Int Res J Eng Technol **4**(4), 784–791 (2018)
8. Manju, Gulati, V., Kumar, A.: Process parameters and thickness reduction in single point incremental forming. Int Res J Eng Technol 7(1):473–476 (2020)
9. Centeno, G., Bagudanch, I., Martínez-Donaire, A.J., Garcia-Romeu, M.L., Vallellano, C.: Critical analysis of necking and fracture limit strains and forming forces in single-point incremental forming. Mater. Des. **63**, 20–29 (2014)
10. Suresh, K., Bagade, S.D., Regalla, S.P.: Deformation behavior of extra deep drawing steel in single-point incremental forming. Mater. Manuf. Process **30**(10), 1202–1209 (2015)
11. Kumar, A., Gulati, V., Kumar, P., Singh, V., Kumar, B., Singh, H.: Parametric effects on formability of AA2024-O aluminum alloy sheets in single point incremental forming. J Mater Res Technol **8**(1), 1461–1469 (2019)
12. Kumar, A., Gulati, V., Kumar, P., Singh, H., Singh, V., Kumar, S., Haleem, A.: Parametric investigation of forming forces in single point incremental forming. In: International conference

on "advances in materials and manufacturing applications (IConAMMA 2018)" Amrita Vishwa Vidyapeetham, Bengaluru Campus, Karnataka, India. 16th–18th August, 2018
13. Kumar, A., Gulati, V.: Forming force in incremental sheet forming: a comparative analysis of the state of the art. J. Braz. Soc. Mech. Sci. Eng. **41** (2019)
14. Kumar, A., Gulati, V., Kumar, P.: Investigation of process variables on forming forces in incremental sheet forming. Int. J. Eng. Technol. **10**(3), 680–684 (2018)
15. Kumar, A., Gulati, V., Kumar, P.: Experimental investigation of forming forces in single point incremental forming. In: Shanker, Kripa, Shankar, Ravi, Sindhwani, Rahul (eds) International Conference on Future Learning Aspects of Mechanical Engineering 2018, LNME, pp. 423–430. Springer (2019)
16. Uheida, E.H., Oosthuizen, G.A., Dimitrov, D.: Investigating the impact of tool velocity on the process conditions in incremental forming of titanium sheets. In: Procedia Manuf. **7**, 345–350 (2017)
17. Alsamhan, A., Ragab, A.E., Dabwan, A., Nasr, M.M., Hidri, L.: Prediction of formation force during single-point incremental sheet metal forming using artificial intelligence techniques. PLoS ONE **14**(8), e0221341 (2019)
18. Sakhtemanian, M.R., Honarpisheh, M., Amini, S.: A novel material modeling technique in the single-point incremental forming assisted by the ultrasonic vibration of low carbon steel/commercially pure titanium bimetal sheet. Int J Adv Manuf Technol **102**, 473–486 (2019)
19. Lon, Y., Li, Y., Sun, J., Ille, I., Li, J., Twiefel, J.: Effects of process parameters on force reduction and temperature variation during ultrasonic assisted incremental sheet forming process. Int. J. Adv. Manuf. Technol. **97**, 13–24 (2018)
20. Honarpisheh, M., Keimasi, M., Alinaghian, I.: Numerical and experimental study on incremental forming process of Al/Cu bimetals: Influence of process parameters on the forming force, dimensional accuracy and thickness. J. Mech. Mater. Struct. **13**(1), 35–51 (2018)
21. Zhai, W., Li, Y., Cheng, Z., Sun, L., Li, F., Li, J.: Investigation on the forming force and surface quality during ultrasonic-assisted incremental sheet forming process. Int. J. Adv. Manuf. Technol. **106**, 2703–2719 (2020)
22. Kumar, A., Gulati, V.: Experimental investigations and optimization of forming force in incremental sheet forming. Sādhanā **43**, 159 (2018)
23. Kumar, Gulati (2020) Optimization and investigation of process parameters in single point incremental forming. Indian J. Eng. Mater. Sci. ISSN: 0975-1017 (Online); 0971-4588 (Print), Accepted
24. Chang, Z., Li, M., Chen, J.: Analytical modeling and experimental validation of the forming force in several typical incremental sheet forming processes. Int. J. Mach. Tools Manuf **140**, 62–76 (2019)
25. Oleksik, V., Pascu, A., Gavrus, A., Oleksik, M.: Experimental studies regarding the single point incremental forming process. Acad. J. Manuf. Eng. **8**, 51–56 (2010)
26. Fiorentino, A.N.T.O.N.I.O., Ceretti, E.L.I.S.A.B.E.T.T.A., Attanasio, A.L.D.O., Mazzoni, L.U.C.A., Giardini, C.: Analysis of forces, accuracy and formability in positive die sheet incremental forming. Int. J. Mater. Form. **2**(1), 805 (2009)

Straightness Accuracy Estimation of Different Cavity Geometries Produced by Micro-electrical Discharge Milling

Shrikant Vidya, Reeta Wattal, P. Venkateswara Rao, and Nagahanumaiah

Abstract The purpose of this paper is to present the results of an investigation on the straightness achievable on three cavities: channel, square and cross-channel (square pillars). The steps included machining of cavities in series of three having a nominal dimension of 1000 μm on a steel sample using 200 μm tungsten carbide electrode in micro-electrical discharge-milling (μ-ED-milling). An Olympus optical microscope was utilized to examine the geometry of micro-cavities. The Least Square Method (LSM), which is commonly used in metrology for fitting reference elements, has been used. The LSM solutions for the primary set of data points obtained through Olympus Analysis Five software measurements were calculated to find the achievable straightness. It was found that straightness tolerance of square pillars (19.19 μm) is better than microchannels (31.33 μm) and far better than square geometries (50.66 μm).

Keywords Micro-EDM · Micro-geometries · Straightness · Optical microscope

1 Introduction

In the context of micro manufacturing, metrology plays an extremely important role. Tolerancing is linked closely together with metrology, and it acts as a bridge between the process chain and the product specification. As per the standards [1], the complete surface of a feature must be contained inside at least two untying coverings of ideal shape. The minimum variation permissible for any part is termed as form tolerance. Among several form tolerances, straightness assessment has been presented here.

S. Vidya (✉) · R. Wattal
Department of Mechanical Engineering, Delhi Technological University, New Delhi, India
e-mail: skvrsm@gmail.com

S. Vidya
School of Mechanical Engineering, Galgotias University, Greater Noida, Uttar Pradesh, India

P. V. Rao
Department of Mechanical Engineering, Indian Institute of Technology, New Delhi, India

Nagahanumaiah
Central Manufacturing Technology Institute, Bengaluru, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_84

Straightness is the state where an element of a feature is a straight line representing a tolerance zone within which the measured element must lie [2].

There is a growing trend is the fabrication of components and devices with functional micro features and sizes. Therefore, the fabrication of micro-nano scale patterns or devices having accurate dimensions and superior surface finish becomes a challenge to manufacturers and researchers. The addition of advanced and high-precision material removal technologies like milling, EDM, ECM and laser-based machining processes ensures the production of micro parts in lot scale. Among others, the Micro-EDM process employs short-pulsed low energy discharge to remove material in the order of ~0.05–500 μm^3 and create micro-patterns over different conductive materials of varying hardness [3]. The small volumetric material removal and advanced capabilities of precise and rapid control of relative movement between electrodes in micro-ED-milling provide significant opportunities for manufacturing of micro-dies, microstructures like micro-holes, micro slots, micro gears and even complex 3D structures [3].

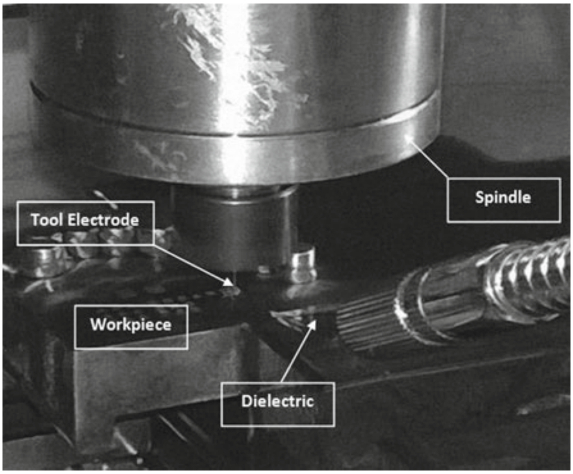
In context to micro manufacturing, very few studies dealt with the estimation of form tolerances. Kao et al. [4] fabricated micro holes using abrasive jet machining and analysed five form characteristics, the diameter, cylindricity, straightness, taper and roundness of the micro-holes. The form measurement ability of the micro-hole was determined by gauge R&R test and the tolerance was calculated. Nagahanumaiah et al. [2] studied the achievable form tolerances on two Rapid Tooling methods: stereolithography (SLA) and direct metal laser sintering (DMLS). They found that SLA samples have relatively poor form accuracy but better dimensional accuracy than DMLS samples. Badar et al. [5] demonstrated a region elimination adaptive search-based sampling technique to minimize the measurement data and calculated the straightness of the machined structures.

In μ-ED-milling, most of the literature reported the optimization of the process for material removal rate, tool wear, physical behaviour, profile compensation, etc. similar to the facets considered in micro-EDM die sinking. As per the authors' knowledge, form tolerance estimation of the geometries produced by micro-electrical discharge-milling has not been reported so far. This investigation studies the straightness achievable on three cavities: channel, square and square pillar (cross-channel) using the Least Square Method (LSM).

2 Experimental Details

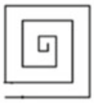
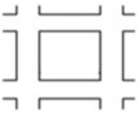
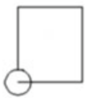
The experiments were performed at CSIR-CMERI on *Micro Machining Centre: DT110 of Micro Tools*, over EN-24 alloy steel using a 200 μm diameter cylindrical tungsten carbide electrode. The cylindrical electrode is mounted onto the machine spindle that rotates and moves simultaneously on the basis of the defined constant step over tool path strategy (Fig. 1). Both the workpiece and the tool are immersed in the *Olio HEDMA 111 of SARIX* serving as a liquid dielectric. The electrode rotates and travels in a predefined path to produce unlike micro-cavities, i.e. square

Fig. 1 Experimental setup



(length = 1000 µm), channels (length = 2000 µm and width = 200 µm) and square pillars (length = 1000 µm). Table 1 shows the tool path strategy adopted to machine the micro-geometries. Three cavities of each selected geometry having a depth of 500 µm were machined using multiple passes (varying for different geometries) at a discharge voltage of 140 V, capacitance of 0.4 µF and a spindle speed of 3000 rpm.

Table 1 Tool path strategy adopted

Geometry	Tool paths
 Square	
 Channel	
 Square Pillar	

In all the experiments, straight polarity is adopted as it gives better material removal rate and lesser tool wear [6]. A lower threshold value is chosen as it is more sensitive towards noticing short-circuiting [7].

Olympus optical microscope was employed to examine the geometry of machined micro-cavities. The Least Square Method (LSM), which is commonly used in metrology for fitting reference elements, has been used. The primary data points obtained at different locations of geometries through Olympus Analysis Five software were analysed to find the least square solutions. Calculations of the deviations e_i from the reference element were performed for each data position, and maximum deviations in the positive ($e_{max(+)}$) and negative ($e_{max(-)}$) directions were identified. After taking into account these points along with primary data points, the straightness form tolerances were estimated.

3 Straightness

Straightness is the state where an element of a feature is a straight line representing a tolerance zone within which the measured element must lie [2].

The assessment line for straightness is

$$y = y_0 + l_0 x \tag{1}$$

The deviation is articulated in the form:

$$e_i = y_i - (y_0 + l_0 x_i) \tag{2}$$

The least square (LS) solutions are given as

$$l_0 = \frac{(N \sum x_i y_i) - \sum x_i \sum y_i}{(N \sum x_i^2) - \left(\sum x_i^2\right)} \tag{3}$$

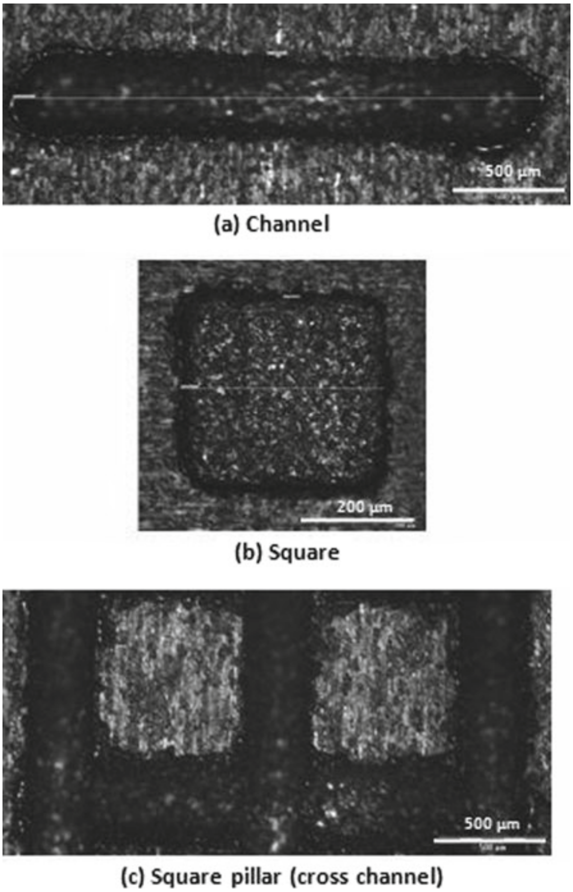
$$y_0 = \frac{(\sum y_i - l_0 \sum x_i)}{N} \tag{4}$$

Straightness tolerance:

$$h_{\text{straightness}} = \frac{\left|e_{\text{MAX}(+)}\right| + \left|e_{\text{MAX}\,(-)}\right|}{\sqrt{1 + l_0^2}} \tag{5}$$

The microscopic images of the machined geometries over the EN-24 steel sample are shown in Fig. 2. The samples were analysed through Olympus Analysis Five software as shown in Fig. 3.

Fig. 2 Microscopic images of the geometries machined on EN24 sample by μ-ED-milling



3.1 Straightness of Microchannels

In this experiment, three microchannels of length 2000 μm have been made into a patterned form. Then their microscopic views are taken, and the dimension at ten different locations each 200 μm apart are measured with the help of Olympus Analysis Five software (Fig. 3a). Table 2 shows the measurement data (*Y* coordinates) for fixed intervals of *X* for the microchannels. The straightness tolerance of each channel is calculated separately and then their average value is reported. Then, the straightness tolerance is calculated using the above procedures listed by Eqs. (1)–(5).

For channel 1

The least square solutions for this data set are given by

$$l_0 = [\ 10 \times (200 \times 436.70 + 400 \times 427.52 + 600 \times 425.69 + 800$$

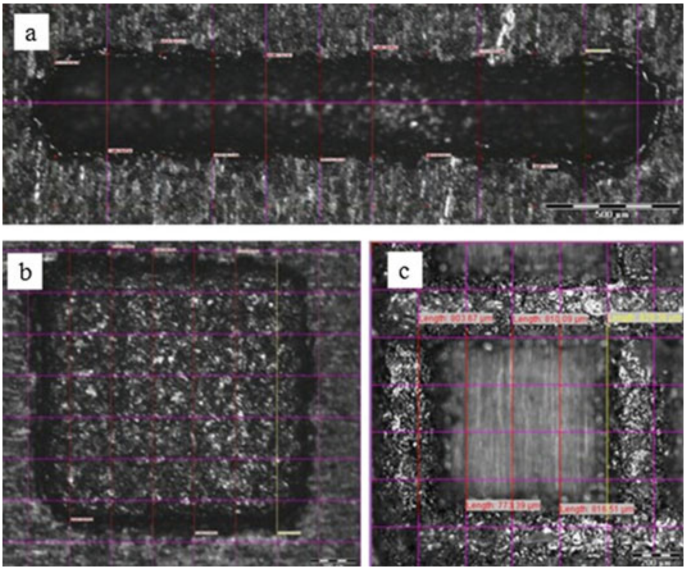


Fig. 3 Method to find the dimension at different locations through Olympus analysis five software: (**a**) microchannel, (**b**) square geometry and (**c**) square pillar

Table 2 Dimensions of microchannel at different points

X (μm)	Y (measurement) (μm)	X (μm)	Y
0	434.86	1200	409.17
200	436.70	1400	409.17
400	427.52	1600	422.02
600	425.69	1800	431.19
800	416.51	2000	447.71
1000	405.50		

$$\times 416.51 + 1000 \times 405.50 + 1200 \times 409.17 + 1400 \times 409.17$$
$$+1600 \times 422.02 + 1800 \times 431.19 + 2000 \times 447.71)]$$
$$-[(200 + 400 + 600 + 800 + 1000 + 1200 + 1400 + 1600 + 1800 + 2000)$$
$$(436.70 + 427.52 + 425.69 + 416.51 + 405.50$$
$$+409.17 + 409.17 + 422.02 + 431.19 + 447.71)]$$
$$/\left[10 \times \left(200^2 + 400^2 + 600^2 + 800^2 + 1000^2 + 1200^2\right.\right.$$
$$\left.+1400^2 + 1600^2 + 1800^2 + 2000^2\right)$$
$$-(200 + 400 + 600 + 800 + 1000 + 1200$$
$$\left.+1400 + 1600 + 1800 + 2000)^2)\right]$$

and

$$y_0 = [(436.70 + 427.52 + 425.69 + 416.51 + 405.50 + 409.17 \\ +409.17 + 422.02 + 431.19 + 447.71) - 0.00266909 \\ (200 + 400 + 600 + 800 + 1000 + 1200 + 1400 + 1600 + 1800 + 2000) \\ /10 = 420.182$$

Then the corresponding deviation (e_i) is calculated as

$$e_1 = 436.70 - (420.182 + 0.00266909 \times 200) = 15.984$$
$$e_2 = 427.52 - (420.182 + 0.00266909 \times 400) = 6.270$$
$$e_3 = 425.69 - (420.182 + 0.00266909 \times 600) = 3.906$$
$$e_4 = 416.51 - (420.182 + 0.00266909 \times 800) = -5.807$$
$$e_5 = 405.50 - (420.182 + 0.00266909 \times 1000) \\ = -17.351(\text{Max.}-\text{ve error})$$
$$e_6 = 409.17 - (420.182 + 0.00266909 \times 1200) = -14.215$$
$$e_7 = 409.17 - (420.182 + 0.00266909 \times 1400) = -14.749$$
$$e_8 = 422.02 - (420.182 + 0.00266909 \times 1600) = -2.432$$
$$e_9 = 431.19 - (420.182 + 0.00266909 \times 1800) = 6.204$$
$$e_{10} = 447.71 - (420.182 + 0.00266909 \times 2000) = 22.190\ (\text{Max. +ve error}))$$

Therefore, $e_{\max(+)} = 22.190$, and $e_{\max(-)} = -17.351$.
Hence, straightness tolerance

$$h_{\text{straightness}} = \frac{|e_{\text{MAX}\,(+)}| + |e_{\text{MAX}\,(-)}|}{\sqrt{1 + l_0^2}} = \frac{22.190 + 17.351}{\sqrt{1 + 0.00266909^2}} = 39.54\ \mu\text{m}$$

Similarly, for *channel 2*, $h_{\text{straightness}} = 23.29\ \mu\text{m}$
and for *channel 3*, $h_{\text{straightness}} = 31.16\ \mu\text{m}$.
So, the average straightness tolerance of a microchannel is estimated as 31.33 μm.

3.2 Straightness of Square Geometries

In this experiment, three square-shaped micro-geometries of side length 1000 μm have been made into a patterned form. Then their microscopic views are taken and the dimensions at five different locations each 200 μm apart are measured with the

Table 3 Dimension of square geometry at different points

X (µm)	Y (measurement) (µm)
0	1224.77
200	1238.53
400	1235.78
600	1277.06
800	1236.70
1000	1211.93

help of Olympus Analysis Five software (Fig. 3b). Table 3 shows the measurement data (Y coordinates) for fixed intervals of X for square geometry. The straightness tolerance of each channel is calculated separately and then their average value is taken. Then, the straightness tolerance is calculated using the above procedures listed by Eqs. (1)–(5).

For square 1

The LS solution is $l_0 = 0.00768824$.

The assessment line is $y_0 = 1235.387$.

Deviations $e_1 = 1.605$, $e_2 = -2.682$, $e_3 = 37.060$, $e_4 = -4.838$, and $e_5 = -31.145$.

So, $e_{\max(+)} = 37.060$ and $e_{\max(-)} = -31.145$.

Hence, $h_{\text{straightness}} = \frac{37.060+31.145}{\sqrt{1+0.00768824^2}} = 68.20$ µm.

Similarly,

For square 2, $h_{\text{straightness}} = 45.73$ µm.

For square 3, $h_{\text{straightness}} = 38.05$ µm.

So, the average straightness tolerance of square-shaped micro-geometries is estimated as 50.66 µm.

3.3 Straightness of Square Pillars (Cross-Channels)

The microscopic views of cross-channels are taken, and the dimensions at four different locations each 200 µm apart are measured with the help of Olympus Analysis Five software (Fig. 3c). Table 4 shows the measurement data (Y coordinates) for fixed intervals of X for the square pillar. Then, the straightness tolerance is calculated using the above procedures listed by Eqs. (1)–(5).

3.3.1 For Square Pillar 1

The LS solution is $l_0 = 0.087165$.

The assessment line is $y_0 = 763.755$.

Table 4 Dimensions of square pillar at different points

X (μm)	Y (measurement) (μm)
0	803.67
200	773.39
400	810.09
600	816.51
800	829.36

Deviations $e_1 = -7.798$, $e_2 = 11.469$, $e_3 = 0.456$, and $e_4 = -4.127$.
So, $e_{\max(+)} = 11.469$ and $e_{\max(-)} = -7.798$.
Hence, $h_{\text{straightness}} = \frac{7.798+11.469}{\sqrt{1+0.087165^2}} = 19.19\ \mu\text{m}$.
Similarly,
For *square pillar 2*, $h_{\text{straightness}} = 17.73\ \mu\text{m}$.
For *square pillar 3*, $h_{\text{straightness}} = 20.64\ \mu\text{m}$.
So, the average straightness tolerance of square pillars (cross-channels) is estimated as 19.19 μm.

4 Results and Discussion

The calculated straightness errors in these micro-geometries are summarized in Table 5. It is reported that straightness tolerance of square pillars is superior to that of microchannels and far better than that of square geometries, whereas square geometries have better accuracy in terms of linear dimensions as compared to microchannels and square pillars [3]. The reasons for these variations may be the variations in discharge pattern, selection of the number of passes and machining path, tool rotation and machining parameters.

In the case of square pillars, machining occurs in multiple and repetitive passes leading to the removal of burrs and hence the least straightness error. During machining of square cavities which is a type of polygon machining, there is a greater variation in discharge pattern and more effect of centrifugal force of tool rotation which leads to the higher formation of burrs and molten particles at the edges causing higher straightness error. While in case of microchannels, there is the involvement of a lesser number of repetitive machining passes and more centrifugal effect as compared to cross channels which leads to the occurrence of more burrs and deposition at edges than that in cross-channels. Hence, the straightness error in cross-channels is more as

Table 5 Estimated straightness in micro-geometries

Feature	Microchannel	Square	Square pillar (cross-channel)
Straightness (μm)	31.33	50.66	19.19

compared to cross channels. So, from Table 5, it is evident that the straightness error is maximum in case of a square followed by square pillars and then cross-channels.

5 Conclusion

Form tolerances play a vital role in view of accuracy necessities for micro and rapid manufacturing usage. This work was focused on studying straightness achievable in cavities machined through micro-ED-milling. This study among different cavities suggested that the straightness accuracy of square-shaped cavity samples is relatively poor. This investigation presents a basis of equivalent knowledge and possesses the following implications:

1. Evaluation of the potentials of unlike micro-manufacturing processes for assessment and selection of appropriate development.
2. Allocation of tolerance based on manufacturing abilities, so that the designs have similar quality with the manufacturing process that can lead to less iteration.

The reliability of the tolerance estimation can be improved by the application of a region elimination search-based sampling method. A similar and advanced proposition can be used for enhancing the competencies of a superior process and taking account of new procedures to come out with a broad record of micro and rapid manufacturing process capabilities.

Acknowledgements This research has been performed at Micro Systems Technology Laboratory at CSIR-CMERI, Durgapur. The authors recognize the support of all staffs of the laboratory.

References

1. ASME Y14.5M: Dimensioning and tolerancing. The American Society of Mechanical Engineers, New York, NY (1994)
2. Nagahanumaiah, Ravi, B.: Rapid tooling form accuracy estimation using region elimination adaptive search based sampling technique. Rapid Prototyp. J. **13**(3), 182–190 (2007)
3. Vidya, S., Vijay, Barman, S., Chebolu, A., Nagahanumaiah, A., Das, A.K.: Effects of different cavity geometries on machining performance in micro-electrical discharge milling. ASME-J. Micro Nano-Manuf. **3**(1), 011007 (2015)
4. Kao, C.C., Shih, A.J.: Form measurements of micro-holes. Meas. Sci. Technol. **18**(11), 3603–3611 (2007)
5. Badar, M.A., Raman, S., Pulat, P.S.: Intelligent search based selection of sample points for straightness and flatness estimation. ASME J. Manuf. Sci. Eng. **125**(2), 263–271 (2003)
6. Lee, S.H., Li, X.P.: Study of the effect of machining parameters on the machining characteristics in EDM of WC. J. Mater. Process Technol. **15**(3), 344–355 (2001)
7. Mikrotools Pvt. Ltd.: Programming Manual of Integrated Multi-Process Machine Tool (Model DT-110). Mikrotools Pvt. Ltd., Singapore, 1 (2006)

Deform 3D Simulation Analysis for Temperature Variation in Turning Operation on Titanium Grade 2 Using CCD-Coated Carbide Insert

Rahul Sharma and Swastik Pradhan

Abstract In machining, tool life plays a significant role in proclaiming the manufacturing process appropriate for the fabrication of a product with desired properties. Machining experiments require complex conduct and testing setups. DEFORM 3D is an adequate tool that provides a limitless range of factors and conditions along with a graphical analysis of results. Simulation has been carried out for the turning operation on titanium grade 2 using a CVD-coated tungsten carbide insert using DEFORM 3D software. The effect of cutting speed as well as feed on the cutting tool-chip interface temperature has been studied and validated with experiments with an error percentage of 3%. It is perceived that the increase in cutting speed and feed both has raised the tool-chip interface temperature.

Keywords Cutting temperature · Coated carbide · DEFORM 3D · Finite element simulation · Titanium grade 2

1 Introduction

Turning is the most common machining operation used in industries for the manufacturing of products with desired properties. The nature of the material used in manufacturing also plays an important role. Due to less weight to strength ratio, modern metals like Titanium has a prevalent variety of applications in the arena of industries, medical equipment, marine parts, etc. [1]. Titanium alloys have low thermal conductivity and high reactive nature because of which machining of such metals with traditional techniques becomes very difficult. The raised temperature during machining reduces the tool life, so the temperature analysis is of great significance in a way to increase the machinability [2]. Abundant research has been carried out to date but the experimental setup, testing, and analysis methods are extremely expensive. So the modern finite element analysis using various software becomes very effective. These simulation methods provide a nodal observation for various

R. Sharma · S. Pradhan (✉)
School of Mechanical Engineering, Lovely Professional University, Phagwara, Punjab 144411, India
e-mail: swastik.rock002@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_85

parameters and plot them graphically. The platform like DEFORM 3D enables us to analyze, compare, and make conclusions for any elemental mesh in the workpiece, cutting insert and chips. It permits us to use a wide range of input factors and their levels. Numerous research has been conducted in this area to enhance tool life and machinability [3, 4]. Tounsi and otho [5] have done machining to deduce the most effective parameter in the machining process. They have considered a cutting tool, machine chuck along with workpiece under observation, and found that vibration is the most effective variable to be considered during machining [5]. Maity and Pradhan [6] have studied the types of chips produced during the machining at a cutting speed of 160 m/min and feed was taken as 0.14 mm/rev. They have taken a constant depth of cut of 0.75 mm during their experiments [6]. Enomoto and Sugihara [7] have used Aluminum alloy as the workpiece material and performed the milling operation using a micro-textured insert. They considered surface finish as the required factor of judging the performance and declared that lubrication has improved the finishing capability of the cutting insert [7]. Caliskan and Kucukkose [8] have done milling of Ti6Al4V using CN/TiAlN coated tools. They declared the adhesive and abrasive wear as the main reason for tool failure [8]. Zetek et al. [9] concluded that the edge radius of 15 μm is not the standard parameter that all producers are using but all the parameters must be in an optimal value. Moreover, if this is used in polishing and other processes, it can increase the tool life [9]. Sima and Ozel [10] have performed experiments on titanium alloy and tried to modify the material depending upon the temperature. They conducted experiments using coated and uncoated cutting inserts. Finite element analysis is performed in DEFORM software and material flow stress is predicted [10]. Umbrello [11] has done the FEM analysis for the high-speed machining of Ti6Al4V. He has considered tool wear rate, cutting force, and obtained shapes of the chip into consideration. All the simulation results have been validated with experimental results [11]. Ribeiro et al. [12] declared that the increase in cutting speed results in tool wear which in return reduce its life. They directed experiments on titanium and 90 m/min was found as the promising cutting condition [12]. Schulze and Zanger [13] determined the surface veracity of the machined titanium surface in simulation using DEFORM software. They declared that the strain rate and cutting temperature reduced with an upsurge in the cutting velocity. Material constant was used in FEA simulation [13]. Maity and Pradhan [14] used DEFORM 3D software for the simulation of titanium alloy. In the machining process, they have used a micro-grooved insert and all the DEFORM 3D simulations show a fractional covenant with the experimental results [14]. Nagaraj et al. have done a simulation of Nickel-based superalloy in a drilling operation and the analysis has been done on effective stress/strain, temperature, and force. They conclude that the thrust force increased with an increase in the feed rate. They made a good synchronization between experiment and simulation results [15]. Parida et al. have performed the numerical and experimental analysis of AISI 316 steel. They declared the cutting force and feed rate as the most effective factors in force and chip morphology. They validate the simulation with experimental data having a percentage error of 10% [16].

In this paper, the temperature variation analysis has been carried out for the turning operation of titanium grade 2 using DEFORM 3D software and the results are compared with experimental results. FEA simulation has been conducted using the L9 orthogonal layout. Two variable parameters, cutting speed and feed rate, have been taken. The cutting depth, size of workpiece, and cutting time has been taken as fixed parameters. The results are calculated in terms of temperature. All the simulation results have been verified with experimental outputs. After that, the effect of various machining parameters has been studied.

2 FEM Simulation

The simulation process has been carried out in DEFORM 3D software. All the process parameters are defined. After selecting turning as a machining operation and SI units, the process setup has been done. The three cutting speeds 325, 550, and 930 rpm have been taken. The second variable parameter is feed and three levels of feed rate have been taken as 0.04, 0.06, and 0.08 mm/rev. The depth of cut has been selected as constant in all the simulations and that is 0.5 mm. The complete simulation process mainly comprises three parts as shown in Fig. 1.

In the pre process, the selection of machining operation, problem ID, and machining type has been decided. After this, the process setup is given that requires the machining conditions like cutting speed in rpm, the diameter of the workpiece, depth of cut, and feed rate. Then it leads to the tool setup for which a 3D design of cutting tool SNMA 120408 HK1500 has been prepared in SOLIDWORKS in (.STL) format taking the standard dimensions of 12.7 × 12.7 mm side, 4.76 mm of thickness, and 0.8 mm radius at cutting edge. The material of this rigid type of cutting insert is tungsten carbide which is taken directly from the library file provided by the DEFORM 3D software.

The direction of the movement of insert for cutting is given in +Y and the linear direction of feed has been selected in −X direction. Then the preprocessor section leads to the mesh generation of the cutting insert. After this, the plastic-type of the workpiece's shape and material are also selected from the library file of DEFORM 3D software as Titanium Grade 2 (Ti6Al4V). The workpiece is fixed from all the directions. Mesh count generated for both the workpiece and the cutting insert is 25,000. After generating the mesh in the workpiece, simulation control has been given in terms of the number of simulation steps. The last phase of the preprocessor is to verify and generate the database file in a selected directory. Figure 2 shows

Fig. 1 Main parts of simulation in DEFORM 3D

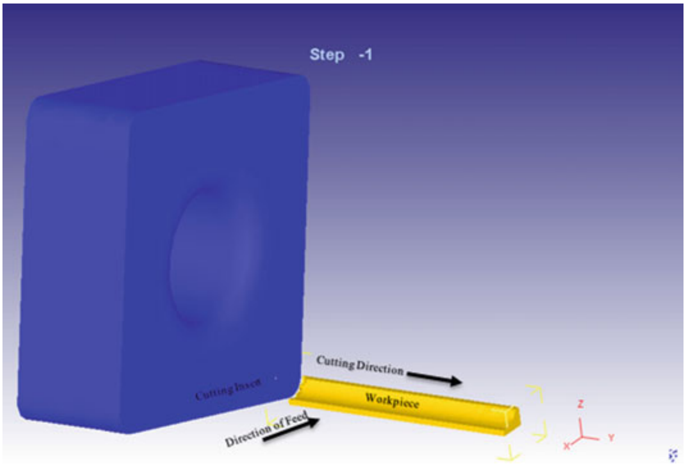


Fig. 2 Selected workpiece and cutting insert for mesh generation

the selected cutting tool and workpiece in DEFORM 3D software along with the selected direction of cutting and feed. Figure 3 shows the mesh generation in both the cutting tool as well as the workpiece.

The simulator is the main part in which the machining operation occurs in the software. In this, all the calculations have been done for various outputs and at all the nodes and mesh generated in the cutting insert and the workpiece. It gives the detail of the step number for which the calculation is run in a summary form. It also provides the simulation graphics option to visualize the current and crossed step

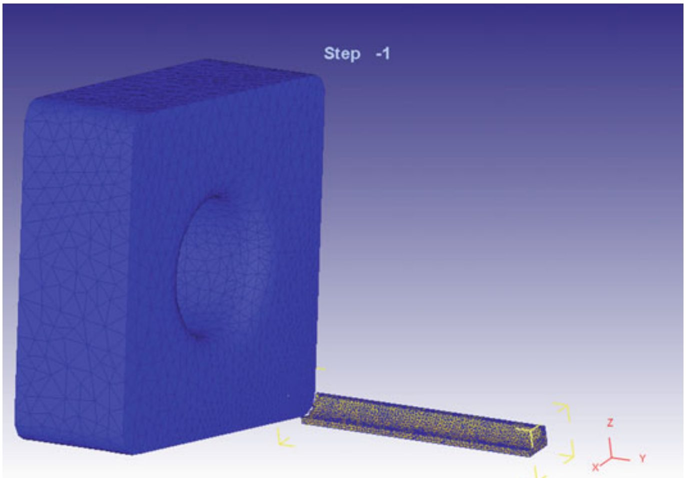


Fig. 3 Generation of mesh in workpiece and cutting insert

details. The last part of DEFORM 3D software is the post processor in which all the values and results have been stored in database files which are then used for the simulation analysis purpose in the post-processor part of the software.

3 Result and Discussion

In DEFORM 3D simulation, cutting speed and feed rate are two variable process factors. The three levels of cutting speed 325, 550, and 930 rpm have been taken. Similarly, the given values of feed rate are 0.04, 0.06, and 0.08 mm/rev. The depth of cut has been taken uniformly in all the simulations and that is 0.5. The diameter of the titanium alloy rod is 50 mm and length is 10 mm. All the experiments and simulations have been conducted at a room temperature of 20 °C. Figure 4 shows the observation of tool-chip interface temperature as 426 °C at step 925 for the simulation run number 7. In this way, all the tool-chip interface temperatures have been observed and tabulated. Table 1 shows all the values of the considered process parameters and their levels. It also gives the value of observed output temperature after simulation in DEFORM 3D software.

When all these simulation output observed values are compared with the measured values from the experiments, an error percentage of 3% has been calculated using Eq. 1, which is in the range of acceptance [17]. Figure 5 shows the comparison graph between the observed temperature values of a simulation run in DEFORM 3D software and the actual experimental measured temperature. All the runs have matched been with an acceptable range of values.

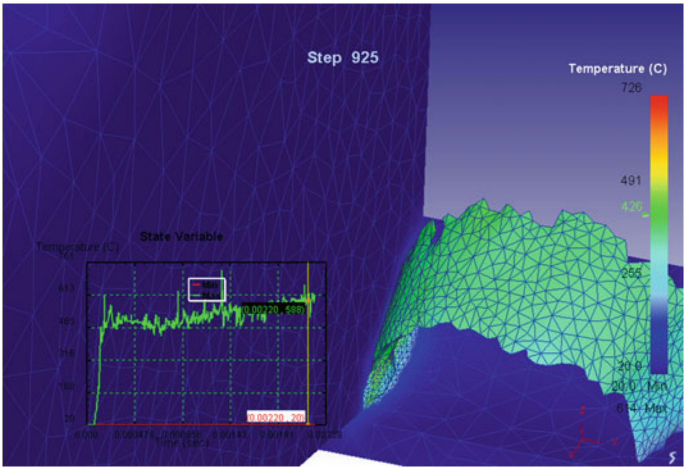


Fig. 4 Measurement of tool-chip interface temperature in DEFORM 3D software

Table 1 Observed output temperature in simulation and experiments

S. No.	Speed (rpm)	Feed (mm/rev)	Simulation output temperature (°C)	Experimental output temperature (°C)
1	325	0.04	270	268
2	325	0.06	182	125
3	325	0.08	271	273
4	550	0.04	151	136
5	550	0.06	435	447
6	550	0.08	191	163
7	930	0.04	426	421
8	930	0.06	350	334
9	930	0.08	512	519

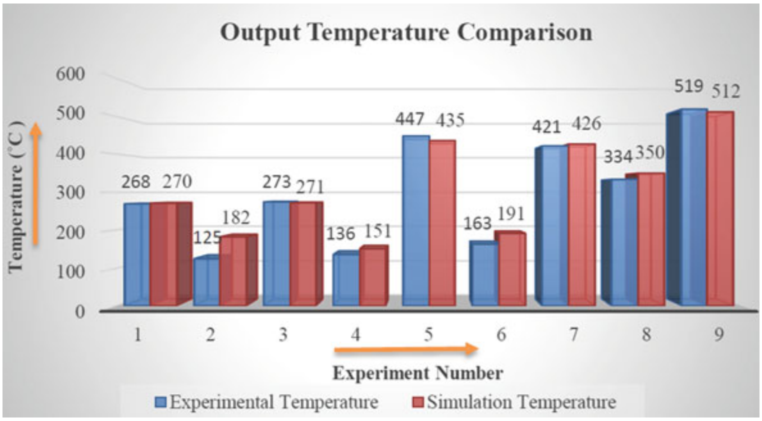


Fig. 5 Temperature comparison graph for simulation and experimental data

$$\text{Error Percentage (\%)} = (\text{Simulation Temperature} - \text{Experimental Temperature}) / (\text{Simulation Temperature}) \times 100 \quad (1)$$

When a comparison graph has been plotted between the speed and temperature to study their effect, an increase in temperature has been observed. When the cutting speed is less, the cutting tool-chip interface temperature is less as well. The maximum temperature has been observed at a speed of 930 rpm. Here, the increased cutting speed will engender more friction between the tool and the workpiece which ultimately intensifies the temperature. Figure 6 shows a change in temperature with respect to speed. The value of the depth of the cut is constant. It shows that when the feed rate was 0.04 and 0.08 mm/s, the value of temperature first decreased and then increased when the speed was raised above 525 rpm. Similarly, for the feed rate 0.06 mm/s, a sudden rise in temperature has been observed up to the speed limit of

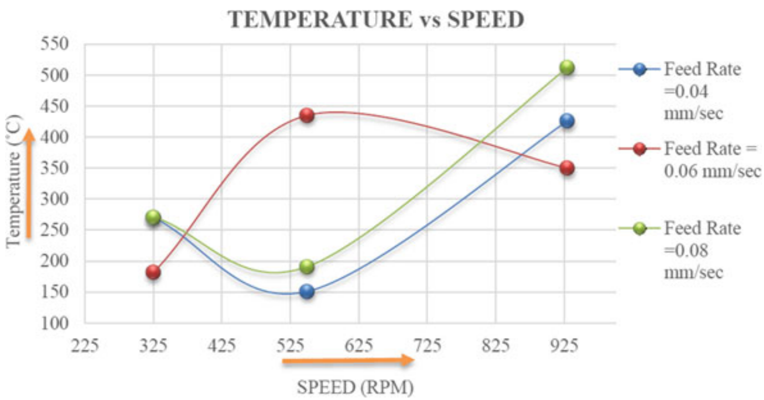


Fig. 6 Variation in temperature with speed for three levels of feed rates

525 rpm. After that, when the speed increased, the temperature dropped. It might be due to the softening effect because of the increase in temperature. Figure 7 shows the effect of feed on temperature. It is clearly shown that at a speed of 325 and 930 rpm, the temperature decreased first and then increased when the feed given was above 0.06 mm/s. For the speed 550 rpm, the temperature increased then decreased when given feed was above 0.06 mm/s. The maximum temperature is obtained at speed 930 rpm in all sets of experiments. It is due to an increase in friction while increasing speed. From these two graphs, it can be perceived that the cutting tool-chip interface temperature has raised with the increase in cutting speed and feed. All the observed values in the simulation match with the experimental values with an error percentage of only 3%. So, the simulation of the turning operation on titanium grade 2 using DEFORM 3D software is quite accurate. Now, various conditional experimentations and precise results can be obtained. Moreover, it will save time and expenses to set up.

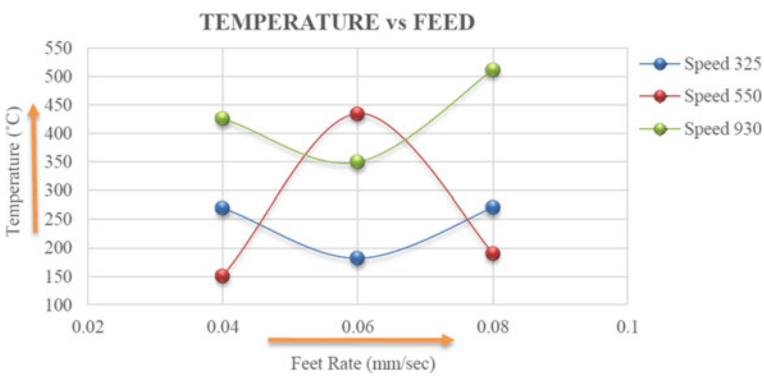


Fig. 7 Variation in temperature with feed for three levels of speed

4 Conclusion

- This study has been supported for the turning operation on titanium grade 2 using a CVD-coated tungsten carbide insert using DEFORM 3D software.
- The effect of cutting speed and feed on the cutting tool-chip interface temperature has been observed.
- Further comparison has been made for obtained experimental and simulation data.
- It is established that an increase in cutting speed and feed both have raised the tool-chip interface temperature. A few changes in the increase of temperature have been observed at speed 525 rpm and feed 0.06 mm/s.
- The simulation result data has been validated with experimental results having an error percentage of only 3% only. So, DEFORM 3D is an admirable tool to predict the additional values which are time-consuming and expensive also in actual experimentation.

Acknowledgements The study and analysis have been supported by the National Institute of Technology Rourkela, Odisha, India

References

1. Arrazola, P., Ugarte, D., Dominguez, X (2008) A new approach for the friction identification during machining through the use of finite element modeling. Int. J. Mach. Tools Manuf. **48**(2):173–183
2. Yen, Y.-C., Jain, A., Altan, T.: (2004) A finite element analysis of orthogonal machining using different tool edge geometries. J Mater Process Technol **146**(1):72–81
3. Zouhar, J., Piska, M.: Modelling the orthogonal machining process using cutting tools with different geometry. MM Sci. J. **3**:48–51
4. Ee, K., Dillon, Jr., O., Jawahir, I.: Finite element modeling of residual stresses in machining induced by cutting using a tool with finite edge radius. Int. J. Mech. Sci. **47**(10):1611–1628 (2005)
5. Tounsi, N., Otho, A.: Identification of machine–tool–workpiece system dynamics. Int. J. Mach. Tools Manuf. **40**(9):1367–1384
6. Maity, K., Pradhan, S.: Study of chip morphology, flank wear on different machinability conditions of titanium alloy (Ti–6Al–4V) using response surface methodology approach. Int. J. Mater. Form. Mach. Process. **4**(1), 19–37 (2017)
7. Enomoto, T., Sugihara, T.: Improving anti-adhesive properties of cutting tool surfaces by nano-/micro-textures. CIRP Ann. **59**(1):597–600 (2010)
8. Çalışkan, H., Küçükköse, M.: The effect of a CN/TiAlN coating on tool wear, cutting force, surface finish and chip morphology in face milling of Ti6Al4V superalloy. Int. J. Refract. Metals Hard Mater. **50**, 304–312 (2015)
9. Zetek, M., Česáková, I., Švarc, V.: Increasing cutting tool life when machining Inconel 718. Proc Eng **69**, 1115–1124 (2014)
10. Sima, M., Özel, T.: Modified material constitutive models for serrated chip formation simulations and experimental validation in machining of titanium alloy Ti–6Al–4V. Int. J. Mach. Tools Manuf. **50**(11), 943–960 (2010)

11. Umbrello, D.: Finite element simulation of conventional and high speed machining of Ti6Al4V alloy. J. Mater. Process. Technol. **196**(1–3), 79–87 (2008)
12. Ribeiro, M., Moreira, M., Ferreira, J.: Optimization of titanium alloy (6Al–4V) machining. J. Mater. Process. Technol. **143**, 458–463 (2003)
13. Schulze, V., Zanger, F.: Numerical analysis of the influence of Johnson-Cook-material parameters on the surface integrity of Ti–6Al–4V. Proc. Eng. **19**, 306–311 (2011)
14. Maity, K., Pradhan, S.J.S.: Investigation of FEM simulation of machining of titanium alloy using microgroove cutting insert. Silicon **10**(5), 1949–1959 (2018)
15. Nagaraj, M., Kumar, A., Ezilarasan, C., Betala, R.: Finite element modeling in drilling of Nimonic C-263 alloy using deform-3D. Comput. Model. Eng. Sci. **118**(3), 679–692 (2019)
16. Parida, A., Rao, P., Ghosh, S.: Numerical analysis and experimental investigation in the machining of AISI 316 steel. Sadhana **45**(1):1 (2020)
17. Pradhan, S., Indraneel, S., Sharma, R., Bagal, D.K., Bathe, R.N.: Optimization of machinability criteria during dry machining of Ti-2 with micro-groove cutting tool using WASPAS approach. Mater Today Proc. (2020)

Estimation of Surface Roughness in Turning Operations Using Multivariate Polynomial Regression

Hrishabh Jha, Ashutosh Panpalia, Devanshu Suneja, Geetanshu Ashpilya, Hitesh Kumar, and Vijay Gautam

Abstract Surface Roughness plays a huge role in determining the durability of components. Surfaces are required to be within desired limits of roughness values to ensure high performance. Being able to predict the surface roughness without using stylus-based instruments reduces the tool changing and measuring time hence decreasing the overall machining time. The experiment suggests a statistical approach to predict the surface roughness before the machining operation based on the previous performance of the tool. The cumulative length of the chips generated was used along with the three cutting parameters, i.e. cutting speed, feed, and depth of cut to predict the surface roughness of the material depending on the number of operations performed on the lathe machine. An algorithm based on multivariate polynomial regression was used to predict the surface roughness of the material corresponding to the usage based on the experiments that were conducted on the Mild Steel Rod by using an HSS tool. This dynamic prediction will help determine the right time to change the tool according to the given machining parameters and hence increase the tool life.

Keywords Surface roughness · Tool life · CNC turning · High-speed steel · Error analysis

1 Introduction

The three turning parameters, i.e. cutting speed, feed, and depth of cut help determine the surface roughness of the material. Surface roughness is estimated by analysing the deviations of the normal vector for a real surface of its ideal form. The surface is rough in case of large deviations and smooth for small deviations. Rough surfaces have higher coefficients of friction than smooth surfaces and wear more quickly [1, 2]. Irregularities on the surface may form nucleation sites for cracks or corrosion and therefore, roughness is an important aspect of measuring the performance of a

H. Jha (✉) · A. Panpalia · D. Suneja · G. Ashpilya · H. Kumar · V. Gautam
Department of Mechanical Engineering, Delhi Technological University, Rohini, Delhi, India
e-mail: hrishabhjha.dtu@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_86

mechanical component. There is often a trade-off between the manufacturing cost of a component and its performance in the application as the manufacturing cost usually increases with decreasing roughness of a surface [3, 4]. Therefore, the point of this experiment was to determine the working limits of the tool on any specified working condition on a lathe.

Data handbooks provided by Virasak and Chapin [5, 6] were considered to obtain the working range of the cutting parameters for the specified material for conducting experiments and help find a pattern to determine the fall of the surface finish of the workpiece after numerous experiments done by the same tool. The experiments were conducted with just under 50 data points that were randomly generated using Python random function to create a basic yet accurate multivariate polynomial regression fit for predicting the surface roughness increase for any condition (working range) as the tool becomes used/old.

In recent years, multivariate modelling techniques have been employed with the aim of analysing, describing, and generally interpreting multidimensional data obtained from the experiments [7]. The simultaneous study of multiple variables affecting the surface roughness in turning operation is done using scikit-learn which is a library for the Python programming language. The easy implementation of polynomial regression and the accuracy/metrics of predictions in the data set were executed using features from the scikit-learn package on the Python interface [8]. Polynomial Regression is done when the response variable (surface roughness) has a non-linear response to the variables under study.

This polynomial regression equation works under the impression to give the surface roughness value according to the number of turns run by the tool that was estimated by the use of peripheral length, along with the three major cutting parameters to analyse the trend of variation of surface roughness. Peripheral Length corresponds to the length of the chip removed from the workpiece after the consecutive operation. In turning operation, it is the distance covered in a helical path travelled by the tool relative to the workpiece. This is used to create a perspective of the total usage of the turning tool.

Surface roughness measurement techniques can be based as Direct contact methods (it involves the use of stylus instruments, which require contact with the surface to be investigated) and Non-direct contact methods (it uses optical instruments and experimental or soft computing techniques to investigate the surface) [9–11]. Stylus instruments have limited flexibility in handling various parts. The procedure is a post-process approach, which is not easy to automate and introduces more idle time as the measurement is slow and increases the overall time of the process. The prediction model predicts the surface roughness without having to remove the workpiece from its operation for measurement by stylus-based instruments.

The use of indirect contact methods is hence implemented to predict the surface roughness. Mahfouz et al. [12] carried out a comparative study utilizing three artificial intelligence techniques to predict surface roughness obtaining the differential evolution algorithm to be the most effective method. Based on the group method of data handling and the differential evolution population-based algorithm for modelling, Onwubolu [13] presented a hybrid modelling approach to predict the surface roughness for turning operations. The experimental data was fed, and an 80:20 test-train data split was done using the scikit-learn Python library generating the drop in the surface finish with 80% data and using 20% data to determine the variation from the path.

Ho et al. [14] established a correlation between the features of the surface image and the actual surface roughness by using computer vision. Shiraishi et al. [15, 16] employed an optical method to measure surface roughness by using double laser beams and ultrasonic beams, respectively, by measuring the reflected intensities. Singh et al. [17] developed a correlation between the friction noise, contact force and surface roughness to analyse the dependency of the Noise to Signal factors using neural networks. Computational intelligence techniques which include an artificial neural network and adaptive Neuro-fuzzy inference system were used by Samanta et al. [18] to determine a surface roughness prediction model using which combines the learning capability of the network and the effective handling of imprecise information in fuzzy logic, also compared with the prediction models based on multivariate regression analysis. All these methods are ways to replace the use of a stylus or any other measurement technique that may result in increased production time and wastage of resources. The purpose of the experiment here was to create a multivariate polynomial regression which can be used to predict the surface roughness of the material corresponding to the number of experiments performed with the same tool without actually removing the workpiece from the device and measuring it. This idea saves the overall production time, cost, and efforts of the operator.

Error analysis is a very prominent term to reduce the error of the model and increase accuracy. Predictive modelling is the process of taking known results and developing a model that can predict values for new data. It uses historical data to predict future values. Data, when staggered on the plot, might give us the relation between the two variables as a curvilinear relation [19]. A primarily used simple approximation method is the polynomial regression. Therefore, a second-degree polynomial regression model is used to obtain more accurate results. Various error analysis algorithms like R-squared value, Root Mean Square Error, Mean Absolute Error, and Mean Absolute Percentage Error were opted to validate the accuracy of the model. Keeping the error as small as possible helps the multivariate polynomial regression equation predict a less biased surface roughness value of the surface that is machined.

2 Experimental Procedure

A Mild Steel Rod of diameter 30 mm and length 220 mm was made from a raw mild steel sample of diameter 33 mm and length 260 mm from the experiment. The workpiece was held between the headstock and the tailstock of the CNC Turning lathe providing enough length for the movement of the tool over the workpiece resulting in their respective peripheral lengths providing a significant change in the surface roughness value for measurement.

Steps of diameter 25 mm and length 15 mm were made at both the ends to support for easier placement on both the live and dead centres of the headstock and the tailstock, respectively. The preparation of the workpiece was done with a different carbide-tipped tool to allow the tool to proceed for the experiment as a fresh tool. Three such specimens were formed to conduct the experiments to ensure a greater number of observations to be taken during the experiment.

The experiment was performed on a CNC Turning centre (Model: LL20TL3) (see Fig. 3) using a H-400 10% Cobalt High-Speed Steel Tool (Tool Signature: 11-11-8-8-12-35-0.086) [20] made from Miranda HSS Tool Bit Blank (20 mm × 20 mm × 4 inch). The Nose radius was observed on the Trinocular Stereo Zoom Microscope (see Fig. 1) and was measured using Caliper Pro software (see Fig. 2) which came out to be 86.678 μm. Cutting Parameters used during the project considering the operational range of HSS Tool on Mild Steel are

- Cutting speed: 20–32 m/min
- Feed: 0.05–0.45 mm/rev
- Depth of cut: 0.3–1.3 mm [5, 6]

The experiment was designed to consider as much possible data for distinct combinations of cutting parameters as possible, but it is impossible to consider each value of the cutting parameters. Therefore, five values of each cutting parameter were selected from the above-specified range covering the whole range uniformly.

The respective operating parameters selected for creating the data set are

- Cutting speeds—20, 23, 26, 29 and 32 m/min
- Feeds—0.05, 0.15, 0.25, 0.35 and 0.45 mm/rev
- Depths of cuts—0.3, 0.6, 0.9, 1.1 and 1.3 mm

Fig. 1 Trinocular stereo zoom microscope

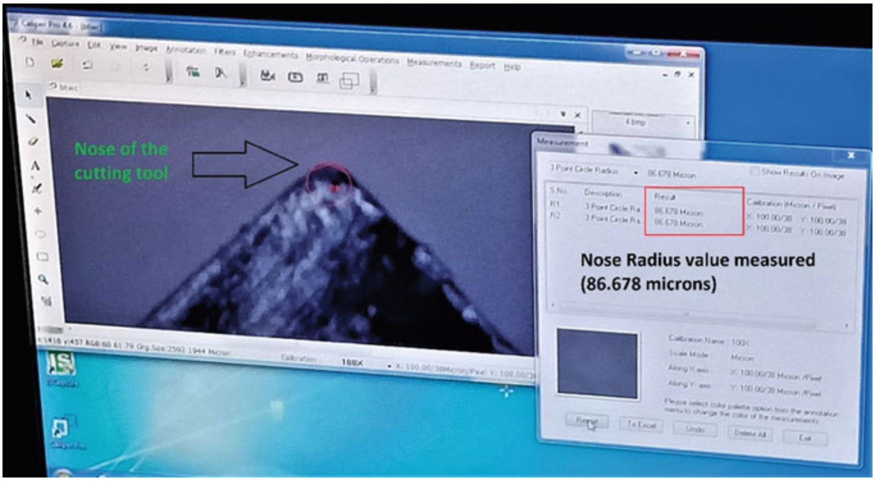


Fig. 2 Nose radius measured on stereo

Fig. 3 Operation on a CNC lathe machine (Model: LL20TL3)

A random combination of the operating conditions was made by using a random variable picker code in Python and the experiment was later conducted in the same sequence. Surface Roughness value, Ra, after each experiment was measured by a Taylor Hobson Surtronic 3+ (S-100 Series) Surface Roughness Tester [21]. Surface roughness values were measured at 4–5 different locations, avoiding any deviation and taking the average of the remaining values to determine the observed Ra value.

3 Observations

Tables 1 and 2 show the Machining Finish Method with respect to the Ra value obtained in the workpiece and accessed from Machining Surface Finish Chart [22].

Table 1 Observations

S. No.	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Cumulative peripheral length (mm)	Ra value (µm)
1	20	0.05	0.3	28,260	3.01
2	20	0.15	0.6	37,491.6	5.85
3	20	0.25	0.9	42,804.48	5.98
4	20	0.35	1.1	46,357.17	7.75
5	20	0.45	1.3	48,890.1	9.13
6	23	0.15	0.3	58,310.1	5.3
7	23	0.25	0.6	63,849.06	5.99
8	23	0.35	0.9	67,643.97	5.54
9	23	0.45	1.1	70,407.17	8.07
10	23	0.05	1.3	93,203.57	5.11
11	26	0.25	0.3	98,855.57	4.78
12	26	0.35	0.6	102,812	8.29
13	26	0.45	0.9	105,763.6	5.71
14	26	0.05	1.1	130,632.4	3.9
15	26	0.15	1.3	138,231.2	5.95
16	29	0.35	0.3	142,268.3	6.19
17	29	0.45	0.6	145,345.5	7.04
18	29	0.05	0.9	171,909.9	3.7
19	29	0.15	1.1	180,199.5	4.69
20	29	0.25	1.3	184,758.8	5.06
21	32	0.45	0.3	187,898.8	4.56
22	32	0.05	0.6	215,593.6	4.01
23	32	0.15	0.9	224,448.4	3.55
24	32	0.25	1.1	229,422.2	4.45
25	32	0.35	1.3	232,678.8	5.84
26	32	0.25	0.3	299,372.4	6.27
27	32	0.05	0.9	598,834.2	4.97
28	20	0.25	0.9	649,890.6	7.63
29	32	0.05	0.3	864,384	3.01
30	20	0.05	0.9	1,234,904	6.9
31	32	0.05	0.9	1,565,420	2.99
32	20	0.05	0.3	1,858,194	3.95
33	26	0.45	1.1	1,888,205	2.69
34	32	0.05	0.9	2,120,314	3.53
35	20	0.05	1.1	2,490,834	5.7

(continued)

Table 1 (continued)

S. No.	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Cumulative peripheral length (mm)	Ra value (μm)
36	26	0.05	1.1	2,816,578	4.59
37	26	0.25	0.9	2,872,420	5.63
38	32	0.05	0.3	3,131,281	3.07
39	32	0.25	0.3	3,181,697	5.47
40	32	0.05	0.9	3,465,427	3.89
41	26	0.25	0.9	3,516,748	6.85
42	32	0.05	0.9	3,753,001	4.56
43	26	0.25	1.1	3,796,182	5.38
44	26	0.25	0.9	3,845,242	6.57
45	20	0.25	0.9	3,890,232	6.97

Table 2 Machining surface finish chart showing finish method versus Ra value of the finished workpiece [22]

Ra value (μm)	Finish method
0.10	Surface dark gloss
0.20	Machining marks direction invisible
0.40–0.63	Machining marks direction blur
0.80–1.25	Machining marks direction blur but still visible
1.60–2.50	Machining marks blur but direction obvious
3.20–5.00	Machining marks not obvious but still visible
6.30–8.00	Machining marks visible

USA Ra value (μm) was used in the experiment as per the specifications of the surface roughness tester.

4 Results

The idea of this project was to create a prediction algorithm for surface roughness values by feeding the cutting parameters in the overall range of the operating conditions to facilitate further surface roughness values to be predicted corresponding to the net machining done with the tool without the use of a stylus and was successfully achieved in the experiment by the use of the algorithm given by Pedregosa et al. [8]. Surface Roughness was predicted at specific operating conditions: 32 m/min cutting speed, 0.05 mm/rev feed, and 0.3 mm depth of cut with an increased peripheral length to predict the change in surface roughness values and plot the same. It was observed that after around 47,00,000–48,00,000 mm peripheral length, i.e. chip

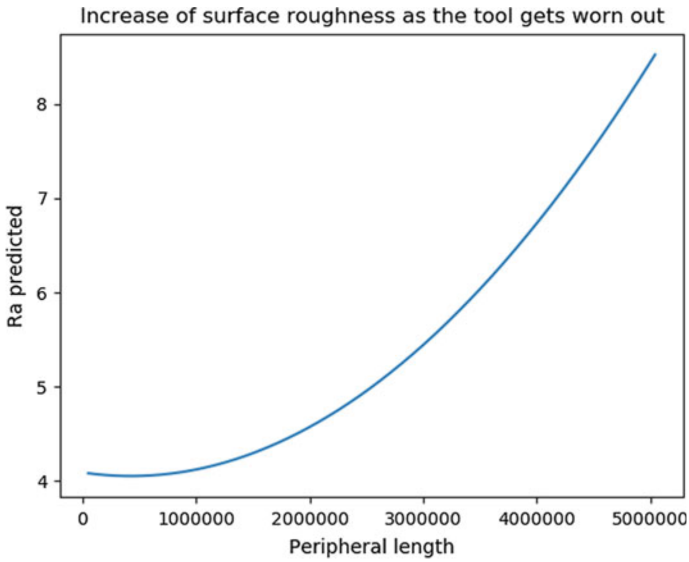


Fig. 4 Variation of predicted surface roughness, Ra value with the peripheral length [24]

length removed, the predicted Ra value was observed to exceed 8.0, i.e. machining marks become visible (see Table 1).

The error analysis has been carried out and the polynomial regression fit of degree 2 was found out to be the best fit for the above data. Prediction accuracy of surface roughness by polynomial regression-developed methods is very good both for the training and the testing data set.

R-squared value is a statistical measure representing the proportion of the variance for a dependent variable explained by an independent variable or variables in a regression model. It is the ratio of variance explained by the model to total variance [23]. *R*-Squared is represented as follows (Fig. 4):

$$R^2 = 1 - \frac{\sum_i (y - \hat{y})^2}{\sum_i (y - \hat{y})^2}$$

where

- y is observed value,
- $\hat{y}$ is predicted value, and
- $\bar{y}$ is the mean value.

It is also known as the coefficient of determination, and it has a value between 0 and 1 (0–100%). The highest possible value of the *R*-square is 1 when all the prediction errors are zero. It's important to note that the *R*-squared score does not indicate whether a model is adequate or not. A low *R*-squared value is also possible for a good model. Therefore, the *R*-square score needs to be analysed closely to determine whether it suits well for the model or not. Using the test data in our observation, the *R*-squared value, R^2 score, was observed to be **0.8763 (or 87.63%)**. The obtained *R*-square value fits well for the model.

Root Mean Squared Error is defined as the square root of the mean of the square of all the errors [23]. RSME is a widely used regression analysis technique to verify the experimental results and a standard way to measure the error of a model in predicting quantitative data. The RMSE mathematical relation is given by

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(\hat{y} - y\right)^2}{n}}$$

where

- y is observed value,
- $\hat{y}$ is predicted value, and
- n is the number of data.

The comparison of the RSME value of testing and training data is crucial to avoid overfitting of the model. When the RMSE values of testing and training data have too much difference, the case model is said to be overfitting. The RSME value of our testing data is **0.8068** and for training data, it is **0.8527** which is pretty good for our model. The ideal *R*-squared value is 1. The closer the value of *R*-square to 1, the better is the model fitted. A polynomial regression model was successfully modelled to get the desired Ra value.

Mean Absolute Error (or simply Absolute Error) is the amount of error in the obtained data measurements. It is the difference between the measured value and the actual data. Mean absolute error is obtained by doing the average of all the error terms calculated. Mean Absolute Error, MAE, of the testing set was **0.71**. Lower MAE is preferred more. For the data ranging in vast numbers, 0.71 is quite an acceptable term. Mean Absolute Percentage Error is perceived as weighted versions of MAE or the percentage equivalent of MAE. It is a measure of predictive accuracy of a forecasting method in statistics. It is widely used in machine learning algorithms as a loss function. Mean Absolute Percentage Error, MAPE, of the testing set was **14.92%**.

5 Conclusion and Future Scope

The surface roughness depends upon the three deciding factors: cutting speed, feed, and depth of cut. In order to find the real-time surface roughness of a workpiece, a parameter was needed, which depicts the tool wear, hence, the tool travel, i.e. chip length produced, or the peripheral length was selected. This parameter need not be externally measured by a device and can be simply calculated by using the dimensions and the other parameters. Thus, this additional parameter combined with the other three basic parameters plugged into the multivariate polynomial regression equation gives a much closer accurate value of the surface roughness of a workpiece produced by an old tool.

The algorithm given by Pedregosa et al. [8] used here that works under multivariate polynomial regression can also be implemented to predict the surface roughness corresponding to any other operating parameters as required and Table 1 can be used to determine the machining condition of the finished workpiece after the operation. The maximum length of working was limited to 180 mm to prevent any heating effect in the tool to avoid any error in the surface roughness value caused by creating temperature as a significant factor. The other factors (Noise) that may cause the error in the experiment are Vibration, Variation in raw metal material, CNC Machine conditions and Operator Skills.

Tool Life can be estimated depending on the surface roughness value obtained after a specific number of operations. A tool can be chosen for a specific type of operation depending on the surface roughness value it is providing as well. The tool giving higher surface roughness values can accordingly no longer be worked on to make a finished product. It can be shown in Table 1 accessed from Machining Surface Finish Chart [22] that normal turning is only operable until 8.00 Ra value, and a tool can be used for rough turning after that. No type of turning operation is possible after reaching 25.0 Ra value. Similarly, for normal controlled turning, Ra value less than 2.5 is desirable and less than 0.2 for super machining (exceptional finished product).

This equation was generated with just 45 randomly generated experiment parameters which gives a variance of 0.81, and if this idea is scaled on an industrial level with generating data of the complete wearing out of multiple turning tools, the accuracy of the prediction can be improved as increasing the sample size will increase the accuracy and, hence, it being a future scope of the project. The same process can be done for operations other than turning, and similar predictions can be made. Also, the nose radius used in the experiment was designed as per the industrial usage of the tool. The nose radius, if varied, can also cause an effect on the prediction as shown by Ozel et al. [25–27].

References

1. Bennett, J.M.: Recent developments in surface roughness characterization. Meas. Sci. Technol. **3**, 1119–1127 (1992)
2. Shaw, M.C.: Metal Cutting Principles. Oxford University Press, New York (1984)
3. Benardos, P.G., Vosniakos, G.C.: Predicting surface roughness in machining: a review. Int. J. Mach. Tools Manuf. **43**, 833–844 (2003)
4. Choudhury, I.A., Ei-Baradie, M.A.: Surface roughness prediction in the turning of high-strength steel by factorial design of experiments. J. Mater. Process. Technol. **67**, 55–61 (1997)
5. Virasak, L.: Manufacturing processes 4–5. In: Open Oregon Educational Resources, pp. 23–25, 59–62 (2019)
6. Chapin, M., Kalpakjian, S.: Machinery's Handbook, ME 3221—Design and Manufacturing I. Department of Mechanical Engineering: University of Minnesota (2012)

7. Tušek, A.J., Jurina, T., Benković, M., et al.: Application of multivariate regression and artificial neural network modelling for prediction of physical and chemical properties of medicinal plants aqueous extracts. J. Appl. Res. Med. Arom. Plants **16**, 100229 (2020)
8. Pedregosa, F., Varoquaux, G., Gramfort, A., et al.: Scikit-learn: Machine learning in Python. J. Mach. Learn. Res. **12**, 2825–2830 (2011)
9. Forouzbakhsh, F., Gatabi, J.R., Gatabi, I.R.: A new measurement method for ultrasonic surface roughness measurements. J. Int. Measur. Confederation **42**, 702–705 (2009)
10. Valicek, J., Drzik, Hryniewicz, T., et al.: Non-contact method for surface roughness measurement after machining. Measur. Sci. Rev. **12**, 184–188 (2012)
11. Brezocnik, M., Kovacic, M., Ficko, M.: Prediction of surface roughness with genetic programming. J. Mater. Process. Technol. **157**, 28–36 (2004)
12. Abu-Mahfouz, I., Rahman, A.E., Banerjee, A.: Surface roughness prediction in turning using three artificial intelligence techniques; a comparative study. Procedia Comput. Sci. **140**, 258–267 (2018)
13. Onwubolu, G.C.: Modelling and predicting surface roughness in turning operations using hybrid differential evolution and the group method of data handling networks. Proc. Inst. Mech. Eng. Part B J. Eng. Manuf. **222**, 785–795 (2008)
14. Ho, S.Y., Lee, K.C., Chen, S.S., Ho, S.J.: Accurate modelling and prediction of surface roughness by computer vision in turning operations using an adaptive neuro-fuzzy inference system. Int. J. Mach. Tools Manuf. **42**, 1441–1446 (2002)
15. Shiraishi, M.: In-process measurement of surface roughness in turning by laser beams. J. Eng. Ind. **103**, 203 (1981)
16. Shin, Y.C., Oh, S.J., Coker, S.A.: Surface roughness measurement by ultrasonic sensing for in-process monitoring. J. Eng. Ind. **117**, 439 (1995)
17. Singh, S.K., Srinivasan, K., Chakraborty, D.: Acoustic characterization and prediction of surface roughness. J. Mater. Process. Technol. **152**, 127–130 (2004)
18. Samanta, B., Erevelles, W., Omurtag, Y.: Prediction of workpiece surface roughness using soft computing. Proc. Inst. Mech. Eng. Part B J. Eng. Manuf. **222**, 1221–1232 (2008)
19. Ostertagová, E.: Modelling using polynomial regression. Procedia Eng. **48**, 500–506 (2012)
20. Sadegh, A.M., Worek, M.: Marks' Standard Handbook for Mechanical Engineers, 12th edn. In: Machining Processes and Machine Tools. McGraw-Hill Education, Table 4.14.1. Recommended Tool Geometry for Turning, deg. (2018)
21. Surtronic S-100 Series Surface Roughness Tester, AMETEK Ultra Precision Technologies. https://www.taylor-hobson.com/products/surface-profilers/handheldsurtronic/surtronic-s-100-series-surface-roughness-tester
22. Machining Surface Finish Chart, Destiny Tool. https://www.destinytool.com/surface-finish.html.
23. Dash, R., Dash, P.K..: MDHS–LPNN: a hybrid FOREX predictor model using a legendre polynomial neural network with a modified differential harmony search technique. In: Handbook of Neural Computation (pp. 459–486). Elsevier (2017)
24. Hunter, J.D.: Matplotlib: A 2D Graphics Environment. Comput. Sci. Eng. **9** 90–95 (2007)
25. Ozel, T., Karpat, Y.: Predictive modeling of surface roughness and tool wear in hard turning using regression and neural networks. Int. J. Mach. Tools Manuf **45**, 467–479 (2005)
26. Bhardwaj, B., Kumar, R., Singh, P.K.: Surface roughness (Ra) prediction model for turning of AISI 1019 steel using response surface methodology and Box-Cox transformation. Proc. Inst. Mech. Eng. Part B J. Eng. Manuf. **228**, 223–232 (2014)
27. Singh, D., Rao, P.V.: A surface roughness prediction model for hard turning process. Int. J. Adv. Manuf. Technol. **32**, 1115–1124 (2007)

Effects of Cutting Parameters and Cutting Fluids in Turning of Aluminium Alloy

Farhan Akhtar, Sakim Hasan, Shrikant Vidya, Kamlendra Kumar, and Amit Kumar

Abstract The purpose of this paper is to explore the effects of cutting parameters (feed rate, cutting speed, depth of cut, and cutting fluid) on material removal rate (MRR) and surface roughness in turning of Aluminium 6063-T6 alloy by employing the Taguchi method. Experiments have been conducted using $L16$ orthogonal array, and a new cutting tool was used for each test to maintain accurateness of the performance measures. The effects of feed rate, cutting speed, and depth of cut on surface roughness and MRR under dissimilar cutting fluids were analysed by analysing the Signal-to-Noise (S/N) ratio calculated through the Minitab software.

Keywords Taguchi method · Surface roughness · MRR · Aluminium alloy · Turning

1 Introduction

A lathe machine is the first machine which is always introduced to a mechanical engineering student, in which required size and shape is obtained by subtracting metals from a workpiece. The lathe machine is a versatile conventional machine which can perform a large number of operations like turning, facing, chamfering, grooving, knurling, forming, etc. Among various operations, turning operation is a very general and vital machining process. In turning operation, the feed is provided linearly along the rotational axis of the spindle. The performance of turning operation depends on the selection of optimized process parameters. The choice of preferred process parameters by knowledge or using a handbook does not ensure that the chosen parameters are most favourable for the exact instrument and atmosphere [1]. There is a direct reflection of process parameters on the machining performance.

The optimization techniques have been applied to find out the right level or value of the parameters that have to be maintained for obtaining quality products/services.

F. Akhtar · S. Hasan · S. Vidya (✉) · K. Kumar · A. Kumar
School of Mechanical Engineering, Galgotias University, Greater Noida, India
e-mail: skvrsm@gmail.com

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_87

The optimal selection of the process parameters can be introduced during the early stage of the product and process development to achieve the quality product with cost effectiveness. With increasing competition in the world of materials and metals, manufacturing of quality products with finer tolerances and high productivity and optimization of cost and production activities becomes a great challenge. Productivity may be measured as material removal rate and during the course of machining, quality can be interpreted in the form of surface roughness. An increase in productivity leads to a lesser time of machining which may cause loss of quality and vice versa [2].

The present study applied the Taguchi method to find out which process parameters have more influence on low surface roughness and maximum material removal rate while turning an aluminium alloy bar on CO636X1000MM conventional lathe. The paper has considered four process parameters namely feed rate, cutting speed, depth of cut, and cutting fluid to optimize the performance measures like MRR and surface roughness. Higher MRR is desired by the industry for fast production in a short time, which can be improved by increasing the cutting parameters namely feed, cutting speed, depth of cut, and cutting fluid. So, the selection of suitable process parameters plays an essential role in the effectiveness and financial system of the product to achieve low surface roughness and higher MRR. Some researchers use this method to optimize the cutting parameter. Katle et al. [3] studied the effects of process parameters and cutting fluids on MRR in turning operation and they investigate that there is no considerable effect of cutting fluid on material removal rate while the depth of cut contributes the most in material removal rate in turning operation. Deepak et al. [4] performed turning of AI6061 and optimized surface roughness considering various process parameters. They concluded that surface roughness gets influenced mostly by the feed rate. Researchers [5, 6] have tried to optimize the cutting parameters by utilizing the Taguchi method to obtain the highest surface finish in turning. Hassan et al. [7] optimized MRR by employing the Taguchi method and identified the optimized values for process variables to calculate MRR. Kishor et al. [8] tried to optimize the MRR by using *L*9 orthogonal array and they investigate that the actual and the predicted MRR values are almost the same and the deviations between the actual and predicted material removal rates is 1.82%. Singh et al. [9] tried to optimize the surface roughness by the ANOVA-based Taguchi method using Minitab 15 software, and they investigate that among chosen parameters, surface roughness gets influenced mostly by the feed rate while the depth of cut contributes to the least extent.

Most of the researchers studied the influence of parameters under different cutting fluid conditions like vegetable oil mixed with dispersions, soluble oil, etc. mainly in conventional and CNC turning of steel and different aluminium alloys [10–13], but very few or limited studies dealt with the conventional turning of Aluminium 6063-T6 and selecting castor and mustard oil as cutting fluid. So, based on the studies conducted and knowledge gained, an attempt has been made to analyse the performance of conventional turning under castor and mustard oil as cutting fluid.

1.1 Design of Experiments

The design of experiments for this study based on the Taguchi method has been used as a tool for design of experiments (DOE) in this study where the effects on output variables by input variables are investigated through an orthogonal array. Based on an orthogonal array, several experiments are performed, and optimized results are obtained by identifying influencing factors. So, it becomes easy to keep trials to improve the manufacturability, quality, reliability, and performance, once the affecting factors are identified. So, a high-quality system can be achieved through the Taguchi method [3]. Performance measures are optimized through this method by listing design parameters and lowering the sensitivity of the performance of the system towards variation. The optimization of a parameter is done in 3 steps, i.e. design of system, design of parameter, and design of tolerance.

According to Taguchi, *S*/*N* ratio has been used to assess the quality characters differing from the preferred value. Quality characters are analysed on the basis of the *S*/*N* ratio in the categories like Nominal-the-Best (NB), Lower-the-Better (LB), and Higher-the-Better (HB).

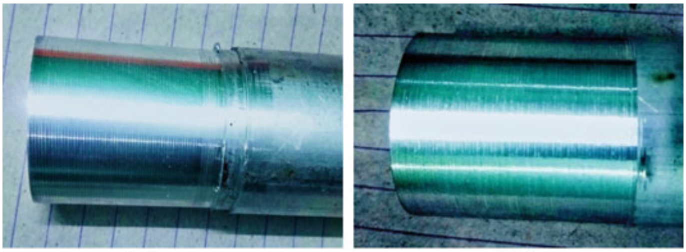
2 Experimental Setup

The experiment is conducted over Aluminium 6063-T6 Alloy as the workpiece material. This alloy has a medium strength and better resistance to corrosion. It is easily weldable and anodizable with the tool (High-speed steel-101 HSS M-2) during the machining. Different cutting fluids are used like castor oil and mustard oil which work as a coolant and reduce the power consumption. A central lathe machine (C0363X1000MM) (Fig. 1) is used for machining the workpiece and it has two

Fig. 1 Lathe machine's setup

Table 1 Cutting parameters with their levels

Process parameters	Level 1	Level 2
Cutting speed (mm/min)	75	125
Feed rate (mm/rev)	4	5
Depth of cut (mm)	0.5	1.0
Cutting fluid	Mustard oil	Castor oil



(a) (b)

Fig. 2 Machined workpiece (**a**) under mustard oil as cutting fluid (**b**) under castor oil as cutting fluid

fixed cutting speeds (75 mm/min and 125 mm/min). During the turning operation, four different factors (depth of cut, feed rate, cutting speed, and cutting fluids) have been selected and each has two Levels (Table 1). Figure 2 shows the machined workpiece under different cutting fluid conditions. For measuring surface roughness, the SURFCOM FLEX surface roughness measuring system has been utilized. It can display the measuring results numerically and graphically and these results can be printed. So, with an integrated printer unit, it becomes easy to control and analyse the measured data. It is easily transported and is used anywhere because of its portable size and durable feature. Based on the degrees of freedom, the design of the orthogonal array has been made for experiments. The experimental plan has been designed based on the Taguchi *L*16 orthogonal array as given in Table 2.

3 Results and Discussion

3.1 Surface Roughness Analysis

In the Taguchi method, the amount of deviation in the performance measures is assessed by calculating the signal-to-noise ratio (*S*/*N* ratio). Lower the value of surface roughness will be, more finished products are obtained. So, the *S*/*N* ratio values equivalent to various experiment runs are analysed on the basis of "Smaller—the Better" for surface roughness evaluation (Table 3).

Table 2 *L*16 orthogonal design matrix

Exp. No.	Cutting speed	Feed rate	Depth of cut	Cutting fluid
1	75	4	0.5	Mustard
2	75	4	0.5	Castor
3	75	4	1	Mustard
4	75	4	1	Castor
5	75	5	0.5	Mustard
6	75	5	0.5	Castor
7	75	5	1	Mustard
8	75	5	1	Castor
9	125	4	0.5	Mustard
10	125	4	0.5	Castor
11	125	4	1	Mustard
12	125	4	1	Castor
13	125	5	0.5	Mustard
14	125	5	0.5	Castor
15	125	5	1	Mustard
16	125	5	1	Castor

Table 3 Response table for *S*/*N* ratio for surface roughness

Levels	Cutting speed	Feed rate	Depth of cut	Cutting fluid
1	−12.61	−12.33	−12.59	−13.99
2	−12.70	−12.98	−12.73	−11.32
Delta	0.09	0.66	0.14	2.67
Rank	4	2	3	1

3.2 Material Removal Rate Analysis

If the material removal rate is high, the performance of the machine is better, machining time will be less, and production is more. So, the *S*/*N* ratio values equivalent to various experiment runs are analysed on the basis of "Larger—the Better" for MRR evaluation (Table 4). The experimental formula which is used for Material Removal Rate is

$$\text{Material Removal Rate} = \frac{\text{Initial Weight of workpiece} - \text{Final Weight of workpiece}}{\text{Density of material} \times \text{Machining Time}} \quad (1)$$

Table 4 Response table for *S*/*N* Ratio for MRR

Levels	Cutting speed	Feed rate	Depth of cut	Cutting fluid
1	84.60	83.38	81.24	84.86
2	85.12	86.35	88.49	84.86
Delta	0.52	2.97	7.25	0.00
Rank	3	2	1	4

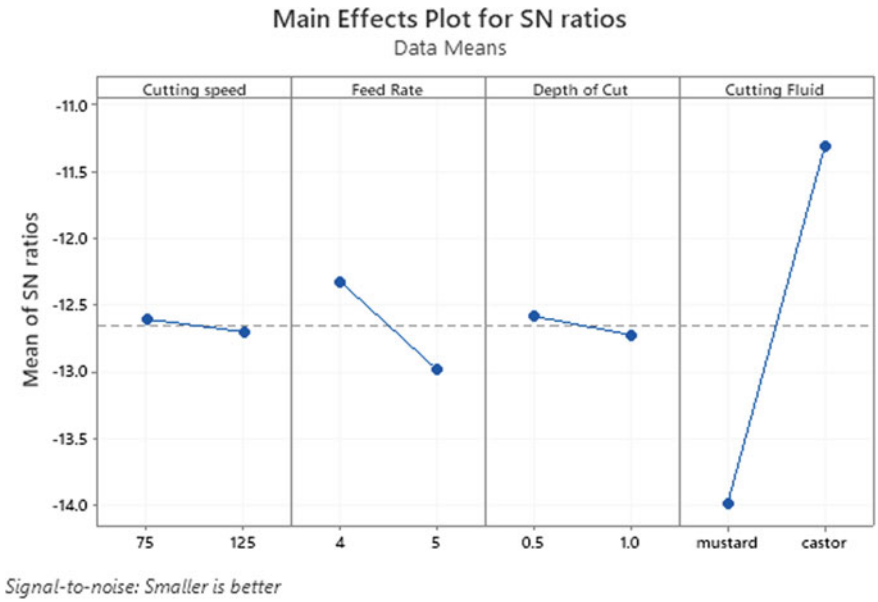


Fig. 3 *S*/*N* graph for surface roughness

From the Taguchi analysis, it can easily be observed that optimal operating conditions for surface roughness are achieved at a combination of speed of 75 mm/min, feed rate of 4 mm/rev, depth of cut of 0.5 mm, and castor oil as cutting fluid. Similarly, it can easily be observed that the optimal operating condition for MRR is achieved at a combination of speed 125 mm/min, feed rate of 5 mm/rev, depth of cut of 1.0 mm, and there is no considerable effect of cutting fluid on MRR (refer to Figs. 3 and 4).

4 Conclusion

In this study, an attempt has been made to do optimization of Cutting Fluid and Cutting Parameter for Surface Roughness and Material Removal Rate (MRR). On the basis of experimental analysis, the authors conclude the following points:

Fig. 4 *S*/*N* graph for MRR

- The Taguchi method defines a simple, systematic, simple, and competent procedure for the optimizations of the cutting fluid and cutting parameter.
- Cutting Fluid and Feed Rate are the influential factors for surface roughness. On the other hand, feed rate and depth of cut are the vital factors for MRR.
- In turning for minimum surface roughness, use of lower cutting speed (75 mm/min), lower feed rate (4 mm/rev), lower depth of cut (0.5 mm), and castor oil as a cutting fluid is recommended.
- For maximum MRR, use of higher cutting speed (125 mm/min), higher feed rate (5 mm/rev), and higher depth of cut (5 mm) are recommended.
- This experiment also reports that there is no considerable influence on the cutting fluid on MRR.
- The minimum value of surface roughness at the optimum cutting parameter and cutting fluid is 3.411 μm.
- The maximum material removal rate at the optimum cutting parameter is 32,082.9 mm^3/min.
- This research illustrates a basic procedure of designing parameters in the Taguchi method for optimizing machine performance with minimum time and cost.

In a nutshell, the outcome of this paper is that castor fluid can serve as a better option of cutting fluid as compared to mustard oil as cutting fluid as well as dry condition for improving the surface finish of the machined components and enhancing the machine performance. This paper also serves as a platform for young researchers to take initiatives in this area to conduct research and perform optimizations of the parameters to enhance the capabilities of the process.

Acknowledgements The authors are grateful to all the staff of the machining laboratory of galgotias university for supporting in the research activities.

References

1. Abhang, L.B., Hameedullah, M.: Optimization of machining parameters in steel turning operation by Taguchi method. Procedia Eng. **38**, 40–48 (2012)
2. Jha, S.K.: Optimization of process parameters for optimal MRR during turning steel bar using taguchi method and ANOVA. Int. J. Mech. Eng. Robot. Res. **3**(2), 231–243 (2014)
3. Katle, K.A., Rehpade, A., Qureshi, F.: Influence of cutting fluid condition and cutting parameter on material removal rate in straight turning process of En31 steel. Semantic Scholar, Corpus ID: 212524195 (2017)
4. Deepak, D., Rajendra, B.: Optimization of machining parameter for turning AI6061 using robust design principle to minimize the surface roughness. Procedia Technol. **24**, 372–378 (2016)
5. Nalbant, M., Gokkaya, H., Sur, G.: Application of Taguchi method in the optimization of Cutting parameter for surface roughness in turning. Mater. Des. **28**(4), 1379–1385 (2007)
6. Thamizhmanii, S., Saparudin, S., Hasan, S.: Analyses of surface roughness by turning process using Taguchi method. J. Achiev. Mater. Manuf. Eng. **20**(1–2), 503–506 (2007)
7. Hassana, K., Kumar, A., Garg, M.P.: Experimental investigation of Material removal rate in CNC turning using Taguchi method. Int. J. Eng. Res. Appl. **2**(2), 1581–1590 (2012)
8. Tupe, K., Zanje, V., Shaikh, S., Shigwan, A., Kulkarni, O., Kulkarni, S.: Optimization of cutting parameters for MRR in turning process of EN31 steel using Taguchi approach. Int. Res. J. Eng. Technol. **4**(6), 1274–1278 (2017)
9. Singh, D.P., Mall, R.N.: Optimization of surface roughness of aluminium by anova based taguchi method using Minitab 15 software. Int. J. Technol. Res. Eng. **2**(11), 2782–2787 (2015)
10. Padmini, R., Krishna, P.V., Rao, G.K.M.: Effectiveness of vegetable oil based nanofluids as potential cutting fluids in turning AISI 1040 steel. Tribol. Int. **94**, 490–501 (2016)
11. Rapetia, P., Pasam, V. K., Gurram, K.M.R., Revuru, R. S.: Performance evaluation of vegetable oil based nano cutting fluids in machining using grey relational analysis—a step towards sustainable manufacturing. J. Clean. Prod. 172:2862–2875 (2018)
12. Hegab, H., Umer, U., Soliman, M., Kishawy, H.A.: Effects of nano-cutting fluids on tool performance and chip morphology during machining Inconel 718. Int. J. Adv. Manuf. Technol. **96**, 3449–3458 (2018)
13. Katna, R., Singh, K., Agrawal, N., Jain, S.: Green manufacturing—performance of a biodegradable cutting fluid. Mater. Manuf. Processes **32**(13), 1522–1527 (2017)

Multi-objective Optimization and Modelling of AISI D2 Steel Using Grey Relational Analysis and RSM Approaches Under Nano-based MQL Hard Turning

Vaibhav Chandra, Andriya Narasimhulu, Sudarsan Ghosh, and P. Venkateswara Rao

Abstract AISI D2 is a high-carbon and high-chromium cold-work tool steel, which exhibits various properties such as high wear resistance, high hardness, high strength and rapid strain hardening. Because of such kind of properties, the AISI D2 cold work steel is considered as a difficult material to be machined. The selection of process parameters plays a very vital role in terms of output quality characteristics such as surface roughness and cutting force. The current work focuses on the application of grey relation theory combined with central composite design (CCD) for optimizing the process parameters for machining AISI D2 hardened steel (54 ± 1HRC). TiAlN PVD-coated inserts of different geometry are selected to machine the AISI D2. Surface roughness and cutting force are chosen as an output response. By executing the confirmation experiments, it is observed that grey relational analysis is a valuable methodology to find out the optimum level of parameters. The optimum parameters are cutting speed 105 m/min, feed 0.04 mm/rev, depth of cut 0.4 mm and rake angle 1°. Regression-based models are also developed for predicting the cutting force and surface roughness values using the RSM approach.

Keywords AISI D2 steel · Hard turning · Grey relational analysis · RSM · Optimization

V. Chandra (✉)
Department of Tool Engineering, Delhi Institute of Tool Engineering, New Delhi, Delhi, India
e-mail: vcdite007@gmail.com

A. Narasimhulu
Department of Manufacturing Process and Automation Engineering, Netaji Subhas University of Technology, Dwarka, Delhi, India

S. Ghosh · P. V. Rao
Department of Mechanical Engineering, Indian Institute of Technology Delhi, New Delhi, India

R. K. Phanden et al. (eds.), *Advances in Industrial and Production Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4320-7_88

1 Introduction

Nowadays, manufacturers need constant improvement in terms of manufacturing cost, environment-related issues, quality of manufactured parts, etc. Such desires influence the workpiece material development and the process of manufacturing the products. Therefore, the concept of hard turning is introduced in the metal cutting industry. Along with the industry, the research fraternity also shows a keen interest to explore the benefits of hard turning. Any turning process whose material has a hardness value more than 45 HRC is considered as hard turning [1]. Hard turning reduces the manufacturing cost and increases productivity. It is preferred over the conventional grinding process [2]. The AISI D2 steel material is frequently used in the field of the tooling industries, such as in making forging dies, dies of pressure, die casting, and cutting dies. The typical composition of AISI D2. is Carbon 1.4%, Chromium 12%, Silicon 0.6%, Manganese 0.6%, Molybdenum 0.7%, Nickel 0.6% by weight and the rest is Iron [3]. In current research work GRA technique is implemented to find out muti-objective optimum parameters during the hard turning of AISI D2 steel. In today's scenario, the optimum use of resources is desired to have maximum level of profit. Optimization models have been developed for performance measures that will give the best optimal setting of the process parameters to have a low level of cutting force and surface quality. The GRA technique is quite suitable for performing optimization nowadays. It can be applied when we have multi-objective output parameters, and it gives the weightage and ranking of every experimental run and the parameter which affects the output responses; this makes this technique very special. Therefore, GRA is applied to optimize the cutting parameters.

2 Literature Review

Hard turning is usually performed at a lower feed rate and depth of cut. It is one of the most appropriate alternatives for grinding operations for achieving a good surface finish than grinding. In most of the research papers, the range of cutting speed is between 100 and 250 m/min. Feed is selected in the range 0.05–0.2 mm/rev, and the depth of cut is not more than 0.2 mm [4]. The most recent techniques used for optimization are fuzzy logic, grey relational analysis, scatter search technique, genetic algorithm, Taguchi technique and response surface methodology. In machining, the surface quality of the workpiece is directly influenced by the selection of cutting speed, depth of cut, feed rate, cutting tool and cutting environment. Shihab et al. [5] explored the optimization of turning process parameters of AISI 52100 by using the ANOVA and RSM methodologies. Sahoo and Ashok [6] presented the experimental study and have done the parametric optimization for surface roughness in turning D2 steel using TiN-coated carbide insert. Das et al. [7] optimized the process parameters by using the grey-based Taguchi approach and predicted the models which have been developed using regression analysis for surface roughness. It was found that the optimum values for feed and depth of cut are 0.04 mm/rev and 0.4 mm, respectively. The most dominant factor which affects the surface roughness (Ra and Rz) value is the feed. Ilhan and Harun [8] selected the AISI 4140 steel (51 HRC) and a coated carbide tool for optimizing surface roughness with the help of the Taguchi method. They found feed is the most significant factor in the surface roughness value. De Paiva et al. [9] implement the optimization theory based on the multi-objective hybrid approach combining response surface methodology (RSM) with principal component analysis (PCA) using AISI 52100 hardened steel. To turn their material, they used wiper mixed ceramic tools. M.K. Pradhan found the optimum machining parameters for the EDM process on the AISI D2 tool steel. He implemented the combination of response surface methodology (RSM) and grey relational analysis coupled with principal component analysis (PCA) to find out the effects of machining parameters on output responses [10]. Tzeng et al. [11] performed the turning operation on a CNC machine using SKD11 (high carbon, high chromium steel) material and a TiN-coated carbide insert. From the study, they found that the depth of cut is the most dominant parameter on the average roughness, and the cutting speed was the most significant parameter on the maximum roughness and the roundness.

3 Grey Relational Methodology

The implemented procedures to optimize the cutting parameters by using the GRA-based methodology are described as follows:

1. Selection of input process and output responses.
2. Determination of different levels and plan of experiments.
3. Perform the experiments as per the DOE.
4. Normalize the data. Generally, there are three types of data normalization which can be carried out, the lower the better (LB), the higher the better (HB) or the nominal the best (NB). In our study, cutting force and surface roughness are chosen as output responses. The cutting force and surface roughness values can be normalized on the basis of the lower the better (LB) criteria.

$$X_i^*(k) = \frac{\min X_i(k)}{X_i(k)} \tag{1}$$

   Here, $X_i^*(k)$ = is the normalized data of the kth element in the ith sequence, where $i = 1, 2, 3\ldots, m$ and $k = 1, 2, \ldots, n$. In this paper, $m = 31$ and $n = 2$.
5. Calculate the grey relational coefficients (GC) for normalized response values:

$$\mathrm{GC}_{ik} = \frac{\Delta_{\min} + \zeta\,\Delta_{\max}}{\Delta_{\mathrm{ij}} + \zeta\,\Delta_{\max}}$$
$$\left[i = 1, 2, 3\ldots m\text{---Experiment and } k = 1, 2, n\text{---Response}\right] \tag{2}$$

Table 1 Overall machining condition of the experiments

Machine tool	CNC T-6 (Leadwell, Taiwan) Turning centre
Cutting insert	TiAlN PVD-coated inserts, Kennametal make VNMG 160408(SM1105), CNMG 120408(MM1115, KC5025, KC5510, KC5010)
Tool holder specification	PCLNL2020K12, MVTNL 12 3B
Cutting condition	MQL: Mist Flow rate 200 ml/h, Compressed Air Pressure 4 Bar, Twin Fluid Siphon Nozzle, Distance between Nozzle and rake face is 50 mm, Nozzle Angle 45°, Solution in the ratio of 1:10 cutting oil to water added with Nano Particales ($Al_2O_{3)}$ Having fluid concentration of 0.3% by volume
Cutting parameters	Cutting speed (m/min): 65, 85, 105, 125, 145 Feed rate (mm/rev/): 0.04, 0.08, 0.12, 0.16, 0.20 Depth of cut (mm): 0.4, 0.6, 0.8, 1.0, 1.2 Rake angle (degree): −10, −6, 1, 7, 14

where GC_{ij} = Grey relational coefficient for *i*th experiment and *k*th dependent response.

Δ = absolute difference between Y_{oj} and Y_{ij} which is a deviation from the target value and called quality loss. ζ is the distinguishing coefficient, which is defined in the range 0–1. Here, its value is taken as 0.5.

6. Determine the grey relational grade (G_i)

$$G_i \frac{1}{m} \Sigma GC_{ij} \tag{3}$$

where m is the number of responses.

4 Experimental Details and Data Analysis

4.1 Cutting Tool and Cutting Conditions

The complete details of all the experimental runs which are conducted in this research work can be see Table 1.

4.2 Data Analysis

The experiment results observed while machining AISI D2 steel under nano-based MQL conditions are listed in Table 2. Normalized data, quality loss, grey relation coefficient and grey relational grade are also shown in the same table.

Table 2 Overall experimental results and optimization data

S. No.	Cutting speed (V)	Feed rate (F)	Depth of cut (t)	Rake angle	Cutting force (N)	Surface roughness (Ra)	Normalize data (CF)	Normalize data (Ra)	Quality loss (CF)	Quality loss (Ra)	Grey coefficient (CF)	Grey coefficient (Ra)	GR grade
1	105	0.12	0.8	1	210	0.26	0.54	0.84	0.46	0.16	0.52	0.76	0.64
2	85	0.16	1	7	280	0.58	0.21	0.27	0.79	0.73	0.39	0.41	0.40
3	125	0.08	1	7	180	0.57	0.68	0.29	0.32	0.71	0.61	0.41	0.51
4	125	0.16	0.6	−6	225	0.25	0.47	0.86	0.53	0.14	0.49	0.78	0.63
5	105	0.12	0.8	1	220	0.25	0.50	0.86	0.50	0.14	0.50	0.78	0.64
6	125	0.16	0.6	7	207	0.22	0.56	0.91	0.44	0.09	0.53	0.85	0.69
7	85	0.16	0.6	−6	258	0.4	0.32	0.59	0.68	0.41	0.42	0.55	0.49
8	85	0.16	1	−6	314	0.66	0.06	0.13	0.94	0.88	0.35	0.36	0.35
9	105	0.12	0.8	1	219	0.28	0.50	0.80	0.50	0.20	0.50	0.72	0.61
10	125	0.16	1	7	287	0.61	0.18	0.21	0.82	0.79	0.38	0.39	0.38
11	85	0.08	1	7	182	0.42	0.67	0.55	0.33	0.45	0.60	0.53	0.57
12	125	0.08	1	−6	187	0.28	0.65	0.80	0.35	0.20	0.59	0.72	0.65
13	125	0.16	1	−6	319	0.65	0.03	0.14	0.97	0.86	0.34	0.37	0.35
14	105	0.12	1.2	1	318	0.73	0.04	0.00	0.96	1.00	0.34	0.33	0.34
15	105	0.12	0.8	1	210	0.25	0.54	0.86	0.46	0.14	0.52	0.78	0.65
16	105	0.12	0.8	1	231	0.27	0.44	0.82	0.56	0.18	0.47	0.74	0.61
17	145	0.12	0.8	1	254	0.34	0.34	0.70	0.66	0.30	0.43	0.62	0.53
18	65	0.12	0.8	1	222	0.43	0.49	0.54	0.51	0.46	0.49	0.52	0.51
19	85	0.16	0.6	7	187	0.33	0.65	0.71	0.35	0.29	0.59	0.64	0.61
20	105	0.12	0.8	1	224	0.28	0.48	0.80	0.52	0.20	0.49	0.72	0.60

(continued)

Table 2 (continued)

S. No.	Cutting speed (V)	Feed rate (F)	Depth of cut (t)	Rake angle	Cutting force (N)	Surface roughness (Ra)	Normalize data (CF)	Normalize data (Ra)	Quality loss (CF)	Quality loss (Ra)	Grey coefficient (CF)	Grey coefficient (Ra)	GR grade
21	105	0.2	0.8	1	326	0.32	0.00	0.73	1.00	0.27	0.33	0.65	0.49
22	125	0.08	0.6	−6	172	0.17	0.72	1.00	0.28	0.00	0.64	1.00	0.82
23	105	0.04	0.8	1	112	0.18	1.00	0.98	0.00	0.02	1.00	0.97	0.98
24	85	0.08	0.6	−6	162	0.42	0.77	0.55	0.23	0.45	0.68	0.53	0.60
25	105	0.12	0.8	14	197	0.6	0.60	0.23	0.40	0.77	0.56	0.39	0.48
26	105	0.12	0.8	−10	234	0.28	0.43	0.80	0.57	0.20	0.47	0.72	0.59
27	85	0.08	0.6	7	120	0.5	0.96	0.41	0.04	0.59	03	0.46	0.69
28	105	0.12	0.8	1	230	0.25	0.45	0.86	0.55	0.14	0.48	0.78	0.63
29	105	0.12	0.4	1	157	0.34	0.79	0.70	0.21	0.30	0.70	0.62	0.66
30	125	0.08	0.6	7	118	0.5	0.97	0.41	0.03	0.59	0.95	0.46	0.70
31	85	0.08	1	−6	207	0.35	0.56	0.68	0.44	0.32	0.53	0.61	0.57

Table 3 Mean table for the grey relational grade

Process parameters	Mean grey relational grade						Rank
	Level-2	Level-1	Level 0	Level 1	Level 2	Max–Min	
Cutting Speed	0.5058	0.5357	**0.6086**	0.5934	0.526	0.1028	4
Feed	**0.9828**	0.5647	0.5747	0.4407	0.4922	0.5421	1
Depth of cut	**0.6652**	0.6631	0.5722	0.47391	0.3376	0.3255	2
Rake Angle	0.5926	0.5593	**0.606**	0.5696	0.4758	0.1302	3

Table 4 Results of confirmation experiments for multi-response

Process parameters	Optimal prediction	Confirmatory
Cutting forces F_c	120	107
Surface roughness, Ra	0.20	0.16
GR grade	0.920	1.043

The higher value of GRA is taken into consideration for finding out the optimal conditions. In the last step of GRA, Table 3 identified the mean value for the grey relational grade.

Table 3 shows the optimal parameters. Thus, the optimal parametric combination is found to be: cutting speed (105 m/min), feed (0.04 mm/rev), depth of cut (0.4 mm) and effective rake angle 1degree. The two output characteristics, i.e. cutting force and surface roughness at the optimum level, are found to be 107 N and 0.16μ. Feed was found to be the most dominating parameter among all, followed by depth of cut, rake angle and cutting speed. The confirmation results are shown in Table 4; it shows the improvement in GRG of about 0.123.

Here, the GRG grade is obtained by the following steps of Sect. 3, and it is used to plot the 2D contour graphs. These graphs are utilized to assess the optimum value of machining parameters. Figure 1 shows the 2D contour plots for GRG with respect to the process parameters.

4.3 Mathematical Modelling of Output Responses Using RSM

To obtain applicable and predictive relationships, it is necessary to model the AISI D2 steel machining responses and process variables.

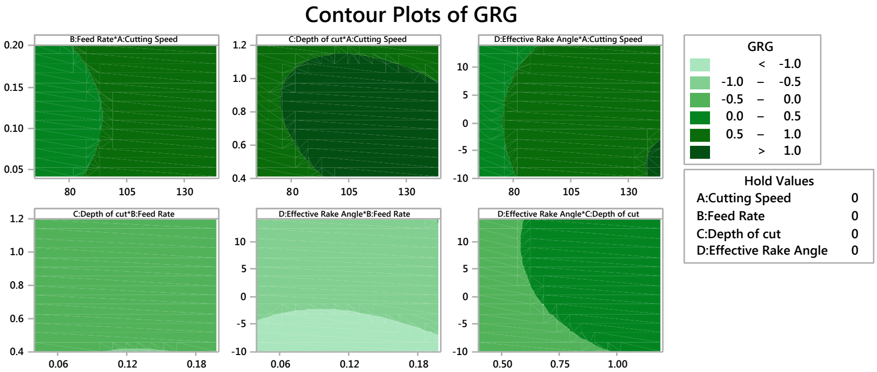


Fig. 1 2D graph between GR grade and process parameters

4.3.1 Cutting Force Model

Cutting forces are one of the most important criteria by which the performance of any machining process can be evaluated. Cutting forces also help in understanding the machinability of the material. The quadratic model developed for the cutting force using the response surface methodology on the basis of experimental results for nano-based MQL cutting environment of AISI D2 machining is as follows:

$$\begin{aligned}\text{Cutting Force (Fy)} = {} & 219.03 + 2.13 \times A + 48.32 \times B \\ & + 35.34 \times C - 15.09 \times D + 0.81 \times AB - 0.31 \times AC \\ & + 3.57 \times AD + 8.68 \times BC - 1.80 \times BD + 5.15 \times CD \\ & + 2.00 \times A^2 - 3.74 \times B^2 + 2.87 \times C^2 - 2.45 \times D^2 \end{aligned} \quad (4)$$

where A = cutting speed, B = feed rate, C = depth of cut and D = effective rake angle.

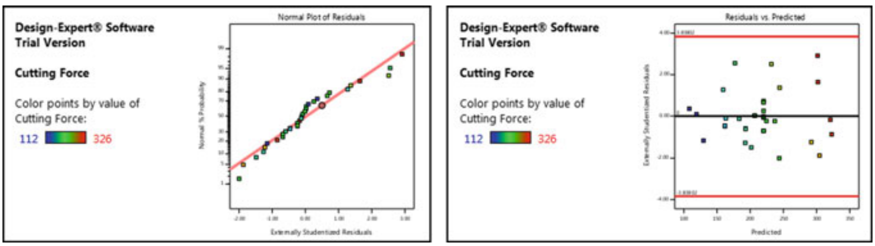


Fig. 2 Normal probability of residuals and plot of residuals versus predicted for quadratic cutting force model

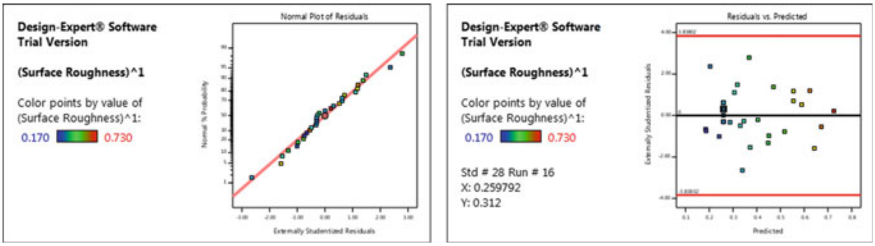


Fig. 3 Normal probability of residuals and plot of residuals versus predicted for quadratic Surface roughness model

The multiple regression coefficient, R^2, of the second-order model is estimated at 0.95. Figure 2 shows that all the points are close to the regression line and within the control limits of the process.

4.3.2 Surface Roughness Model

The good surface finish of a machined product is always desirable for any manufacturing industry. It also indicates the effectiveness of the machining process. The quadratic model developed for surface roughness using the response surface methodology on the basis of experimental results for nano-based MQL cutting environment of AISI D2 machining is as follows.

$$\begin{aligned} \text{Surface Roughness(Ra)} = {} & 0.262 - 0.023 \times A + 0.031 \times B + 0.087 \times C \\ & + 0.042 \times D - 0.00 \times AB + 0.038 \times AC + 0.034 \times AD \\ & + 0.079 \times BC - 0.061 \times BD - 0.0047 \times CD + 0.034 \times A^2 \\ & - 0.0002 \times B^2 + 0.072 \times C^2 + 0.055 \times D^2 \ldots \qquad (5) \end{aligned}$$

where A = cutting speed, B = feed rate, C = depth of cut, D = effective rake angle.

The multiple regression coefficient, R^2, of the second-order model is estimated at 0.97. Figure 3 shows that all the points are close to the regression line and within the control limits of the process.

5 Conclusion

The current study examines comprehensively the aspects connected to cutting forces, surface roughness and their optimization by implementing the grey relational optimization technique and RSM. Based on the investigation, it is concluded that

1. GRA has turned out to be a good promising tool for the conversion of multiple objective problems into a single objective problem. So both optimization techniques are suitable to optimize the multi-objective function.
2. The optimal parametric combinations are found to be cutting speed (105 m/min), feed rate (0.04 mm/rev), depth of cut (0.4 mm) and effective rake angle (1°) by using the grey relational optimization technique.
2. Feed and depth of cut were found to be the most dominating input parameters.
3. Further, the RSM technique also confirms the optimum levels of parameters through 2D graphs developed with respect to GRG and input process parameters.
4. Regression-based models for cutting forces and surface roughness under nano-based MQL conditions are found to be significant in nature.

References

1. Dogra, M., Sharma, V.S., Sachdeva, A., Suri, N.M., Dureja, J.S.: Tool wear, chip formation and workpiece surface issues in CBN hard turning: a review. Int. J. Prcis. Eng. Manuf. **11**(2), 341–358 (2010)
2. Alok, A., Das, M.: Multi-objective optimization of cutting parameters during sustainable dry hard turning of AISI 52100 steel with newly develop HSN2-coated carbide insert. Measurement **133**, 288–302 (2019)
3. Mukhtar, F., et al.: Effect of chrome plating and varying hardness on the fretting fatigue life of AISI D2 components. Wear 418, 215–225 (2019)
4. de Diniz, O.A.J., Eduardo, A.: Hard turning of interrupted surfaces using CBN tools. J. Mater. Process. Technol. 275–281 (2007)
5. Siddiquee N.A., Shihab, S.K., Khan, Z.A., Mohammad, A.: Cryogenic hard turning of alloy steel with multilayer hard surface coatings (TiN/TiCN/Al_2O_3/TiN) insert using RSM. Int. J. Curr. Eng. Technol. 2 (2014)
6. Sahoo B.S., Ashok, K.: Int. Jounal Ind. Eng. Comput. **2**, 819–830 (2011)
7. Das, D.K., Sahoo, A.K., Das, R., Routara, B.C.: Investigations on hard turning using coated carbide insert: Grey based Taguchi and regression methodology. In: Procedia Mater. Sci. **6**, no. Icmpc, 1351–1358
8. Ilhan, A., Harun, A.: Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method. Measurement **44**, 1697–1704 (2011)
9. De Paiva, P., Gomes, J.H.F., Peruchi, R.S., Leme, R.C., Balestrassi, P.P.: A multivariate robust parameter optimization approach based on principal component analysis with combined arrays. Comput. Ind. Eng. **74**, 186–198 (2014)
10. Pradhan, M.K.: Estimating the effect of process parameters on MRR, TWR and radial overcut of EDMed AISI D2 tool steel by RSM and GRA coupled with PCA. Int. J. Manuf. **68**, 591–605 (2013)
11. Tzeng, C., Lin, Y., Yang, Y., Jeng, M.: Optimization of turning operations with multiple performance characteristics using the Taguchi method and Grey relational analysis. J. Mater. Process. Technol. **209**, 2753–2759 (2008)