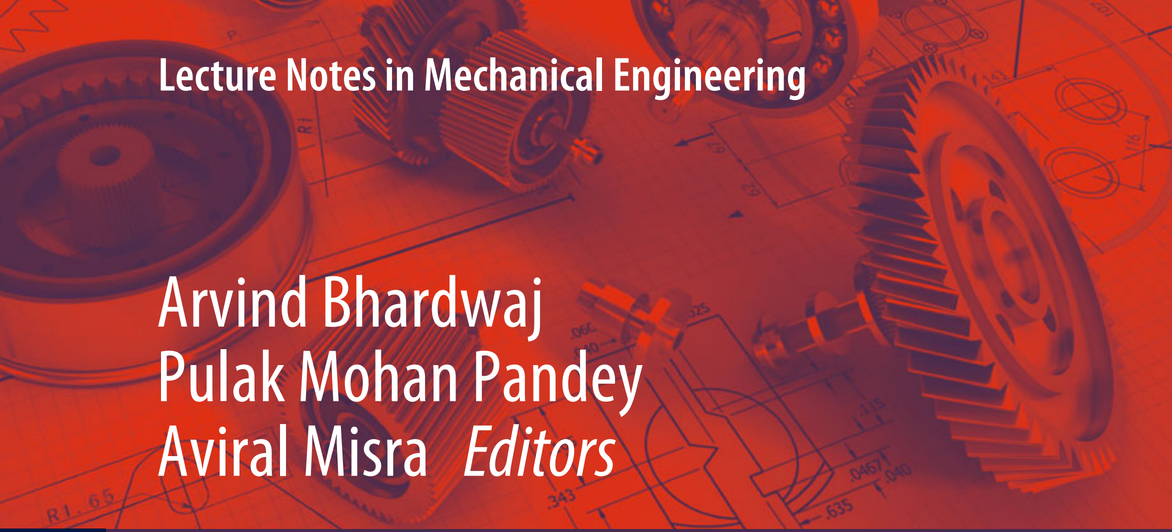

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Arvind Bhardwaj
Pulak Mohan Pandey
Aviral Misra *Editors*

Optimization of Production and Industrial Systems

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Editors
Arvind Bhardwaj
Department of Industrial and Production Engineering
Dr. B. R. Ambedkar National Institute of Technology Jalandhar
Jalandhar, Punjab, India

Pulak Mohan Pandey
Department of Mechanical Engineering
Indian Institute of Technology Delhi
New Delhi, India

Aviral Misra
Department of Industrial and Production Engineering
Dr. B. R. Ambedkar National Institute of Technology Jalandhar
Jalandhar, Punjab, India

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Preface

It is with great pleasure that we present this collection of conference papers, carefully curated under the title *Optimization of Production and Industrial Systems, select proceedings from CPIE-2023*. This book contains a collection of conference papers highlighting recent advancements for enhancing productivity and reshaping the contours of manufacturing and industrial practices. This collection provides a comprehensive overview of the current trends, challenges, and solutions to improve the industrial systems that underpin our industrial processes to optimize their performance.

The papers in this volume cover a wide range of topics, encompassing the design of industrial systems and optimization techniques to enhance productivity. Many important subjects are being discussed, from the human–human interface to the human–machine interface. The collection contains a few innovative design concepts to improve the performance of the existing systems. It also encompasses the application of advanced optimization techniques to the industrial and production engineering elements for productivity improvement. The papers offer a wealth of insights into the ever-evolving landscape of the field of production and industrial systems.

Furthermore, this collection showcases the interdisciplinary nature, highlighting the integration of engineering principles to inspire the reader's curiosity, ignite creativity, and provide avenues for future research. The research presented here explores the symbiotic relationship between different engineering domains, fostering collaboration and cross-pollination of ideas to drive innovations.

We want to express our gratitude to all the authors who have contributed valuable research to this volume. Their expertise, dedication, and intellectual curiosity have made this collection a testament to the remarkable progress being made in the design and optimization of production and industrial systems.

We also thank the reviewers and editors who have diligently worked to ensure the quality and rigor of the papers included in this volume. Their expertise and commitment to scholarly excellence have played a vital role in shaping this collection.

At last, we express our profound gratitude to Springer for providing the platform to disseminate this knowledge to a broader audience. As you navigate the pages of the book *Optimization of Production and Industrial Systems*, consider yourselves integral

participants in a discourse that aims to shape the contours of industrial excellence. We hope the research presented in this book will inspire further exploration, spark new collaborations, and contribute to advancing the production and industrial systems.

Jalandhar, India — Dr. Prof. Arvind Bhardwaj
New Delhi, India — Dr. Prof. Pulak Mohan Pandey
Jalandhar, India — Dr. Asst. Prof. Aviral Misra

Contents

About the Editors

Dr. Arvind Bhardwaj received his Bachelor in Mechanical Engineering from the Punjab University, India, in 1988, and Ph.D. from the Kurukshetra University, India, in 2006. He is working as Professor in the Department of Industrial and Production Engineering at Dr. B. R. Ambedkar National Institute of Technology, Jalandhar (An Institute of National Repute established by Government of India), Punjab, India. He is also looking after the responsibility of Dean Research and Consultancy. He has one years of industrial and more than 27 years of teaching experience. His areas of research are supply chain management, operations management, and optimization of production systems and ergonomics. He has published more than 100 articles in various international journals and conferences.

Prof. Pulak Mohan Pandey is working as Professor in the Department of Mechanical Engineering, Indian Institute of Technology (IIT) Delhi. He on deputation also served as Director, BIET Jhansi. His area of research includes rapid prototyping, unconventional machining, CAD/CAM, biomedical applications, micromachining, nano-finishing, and finite elements applications to manufacturing. He has guided 40 Ph.D. and 35 master's dissertations at IIT Delhi. He has published more than 200 hundred research papers in the journals of high repute and also published books and magazines with reputed international publishers. He has also published more than 20 patents in the field of the manufacturing process.

Dr. Aviral Misra is working as Assistant Professor in the Department of Industrial and Production Engineering, at Dr. B. R. Ambedkar National Institute of Technology, Jalandhar (An Institute of National Repute established by Government of India), Punjab, India. He earned his Ph.D. in Mechanical Engineering from IIT Delhi and completed his M.Tech. degree in Production Engineering from IIT-BHU, Varanasi, India. He has more than six years of the teaching experience. His area of research includes unconventional machining, CAD/CAM, additive manufacturing, micromachining, nano-finishing, finite element method, optimization, and application of machine learning. His commitment to academic and research awarded him funded research project from SERB-DST, New Delhi. He has more than 15 research publications in international publications of repute. Dr. Misra is serving as Reviewer in several international journals and Lifetime Member of Institute of Engineers (India) [IEI].

Productivity Improvement by Upgrading Skills Using TWI–JI in Special Purpose Machine Manufacturing Company

Gajanan Gambhire, Anand Umrani, Hritikesh Nilawar, Atharwa Kharkar, and Himanshu Patil

Nomenclature

TWI	Training Within Industry
JI	Job Instruction
JBS	Job Breakdown Sheet

1 Introduction

Training within Industry (TWI) is a systematic approach to employee training that was developed in the United States during World War II to help address labor shortages and increase productivity in manufacturing plants [1]. However, in this fast-moving world of industrialization and technological advancement, many MNCs are moving toward automation and relying more on technologies like Artificial Intelligence (AI) and Robotics under the revolution of Industry 4.0 [2]. But for medium and small-scale industries capital investment or affordability, skilled manpower, and infrastructure development in these technologies are major challenges [3]. Hence, their dependency is majorly on the manpower available within their hands. It is prominently observed in developing countries like India and China, labor turnover is higher specifically in medium and small-scale industries [4]. The main reasons behind this were first the opportunities in the industry and second, the availability of

G. Gambhire (✉) · A. Umrani · H. Nilawar · A. Kharkar
Vishwakarma Institute of Technology, Pune 411037, India
e-mail: gajanan.gambhire@vit.edu

H. Patil
Executive, Industrial Engineer, Tata Boeing Aerospace, Hyderabad, India

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resources, i.e., operators and employees in huge numbers, resulting in constant job switching by operators and employees.

Most industries find better ways to tackle this type of situation without compromising their brand identity and the quality of the product. However, certain industries face some challenges to overcome loss due to labor turnover and have two options—either to spend more on trained, experienced, and skilled operators or to compromise on quality in order to save cost by executing the work with an untrained workforce. The majority of the time industries opt for the former option to save time but eventually end up paying more to their operators. To train industry operators, they assign an experienced specialist to work with trainees for hands-on learning, which is time intensive. The implementation of TWI training resulted in favorable and enduring outcomes for company performance and the adoption of advantageous managerial approaches [5]. Hence, there is a concept in the industry named Training Within Industry, which is not only limited to training freshers, but the main aim of it is to upgrade operator or employee in terms of skill, knowledge, relation, practical approach, personal development, etc.

2 Experimentation

2.1 Background

This study is performed at a medium-scale special purpose machine manufacturing enterprise, which manufactures machines for the paper and pulp industry. This enterprise operates in a very high product variety and low volume manufacturing environment, i.e., like a job shop production system. As variation is high, the ground-level challenges are different from batch or mass production systems. In MSMEs, operators need to be trained in multiple skills to fulfill the timely deliveries and quality products to the customers. To make operators multi-skilled, enterprises need to spend many resources like time on training and development.

Single skilled and less-skilled operators may produce low-quality products and will consume more time to complete the job. At the chosen enterprise, it is observed that more customer complaints were received, and more resources need to be deployed on rework or correction. One of the major root causes identified which affects operators' performance is lack of skill apart from the physical and mental health of the operator. The TWI program has the potential to address the underlying causes of human errors, leading to their elimination [6, 7]. To overcome this challenge, industry can work on upgrading the operator's skills through training. To get positive results by upgrading the operator's skills, other attributes like technical concepts should be introduced to fulfill the lack of knowledge with their morale and responsibility [8].

2.2 Problem Statement

Variation in production processes is a hindrance to achieving higher productivity. In the welding section of the production department, operators were observed performing tasks differently due to differences in skill level. This affects the total output of the production line, leading to delays or stoppages in production and resulting in losses due to penalties. Skilled operators are especially valuable, as their absence can be costly if other operators lack the necessary skills. However, some skilled operators may not be able to train others due to a lack of experience.

2.3 Methodology

Making the operators up-skill may be a viable option for increasing the output and enhancing productivity while minimizing the expenditure. Mastering the skills acquired through TWI can enable an organization to establish a sustainable culture of continuous improvement and the job instruction training approach instructs operators on how to efficiently train other operators to perform their job duties with accuracy, safety, and diligence [9]. Thus, the TWI-JI approach is implemented to assist the operators in upgrading skills and reducing rework or corrections [10]. As the production system is like a job shop, timely delivery of the product is important, and hence, it is difficult to tackle the irregularities in such scenarios. Even a change in the skill level of the operator could hamper the production output. Thus, the enterprise should plan to set a standard skill level for operators to maintain uninterrupted production output. To eliminate these difficulties, it is required to select a methodology or technique that will make the operators able to train effectively, to breakdown job methods easily explicable, and also to manage the workforce without affecting the production. Hence, the TWI concept was selected to overcome these challenges simultaneously to maintain the above attributes regarding operators.

To implement the TWI-JI at the welding section, the data was collected in the form of a skill matrix through the observations on the shop floor. Analysis carried out from pre-post TWI-JI implementation for the calculations of the result including skill-wise and operator-wise improvements. For maintaining the standardization of the process analysis, the implementation was supported with the well-defined JBS and hence eliminated the irregularities. Standardized work is one of the key principles of TWI [11].

2.4 Data Collection and Data Analysis

The operations having the same Key Performance Indicators (KPI), the same set of instructions, and work procedures were chosen to form a natural team in the

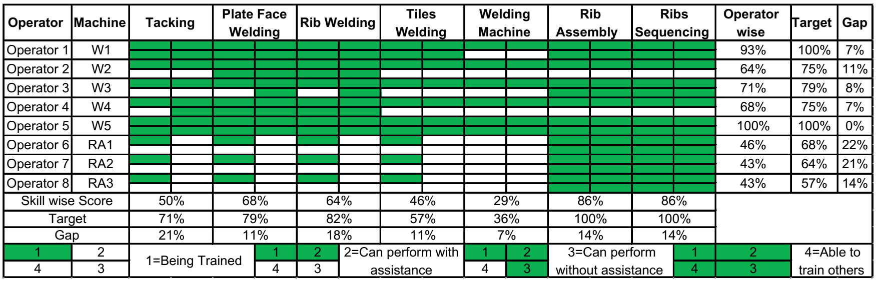


Fig. 1 Skill matrix of welding section before start of TWI-JI

welding section. A standard matrix format has been developed for the skill matrix including various welding operations and their proficiency based on rating parameters for the TWI-JI. The matrix format also included the operator-wise and skill-wise scores. The welding parameters consisted of tacking, plate face welding, ribs welding, tiles welding, welding machine setup, rib assembly, and ribs sequencing. The rating parameters were defined as 1-being trained, 2-can performing with assistance, 3-can performing without assistance, and 4-able to train others required. The first skill matrix was plotted for the welding section from the observations and inputs from the supervisors as given below in Fig. 1.

After mapping the initial skill levels of the operators, the trainers have been identified. The TWI-JI concept has been explained to the selected trainers and asked to start the process of training the operators. A Job Instruction Card, as shown in Fig. 2, was introduced to help the trainers to trail the procedure. The Job Instruction Card is a compact version of the Job Instruction program, presented on a small card outlining the program's main features [12]. Trainers were instructed to teach operators according to TWI-JI terminology with the help of a Job Instruction Card, which included the sequence of procedures to up-skill them.

Later, the trainers were introduced to Job Breakdown Sheet (JBS) as given in Table 1, and have been instructed on its use and importance. The format of the JBS is divided into three sections 'Important Step, Key Points, and Reasons', it delivered necessary information to the trainee, i.e., the key points given in the sheet will help the process easier to understand, and other safety measures were included. This was modified in the TWI-JI technique to enhance its impact on productivity.

The previous skill matrix in Fig. 1 was updated after the training session, wherein the improvements were recorded. The upgraded skills were marked with orange color as shown in Fig. 3. Similarly, further training sessions were conducted to achieve the upskilling of operators and the results are marked with blue color as shown in Fig. 3. Hence, by using the same procedure and the same JBS, those operators are trained and now they can operate independently.

Before moving to the next phase, analysis was made from the updated matrix and concluded to go for rib welding skill with the same trainee as in phase 1, i.e., Operators 6, 7, and 8, and the same trainer as Operator 5. The difference between actual and target scores was much more comparatively for these operators and skill

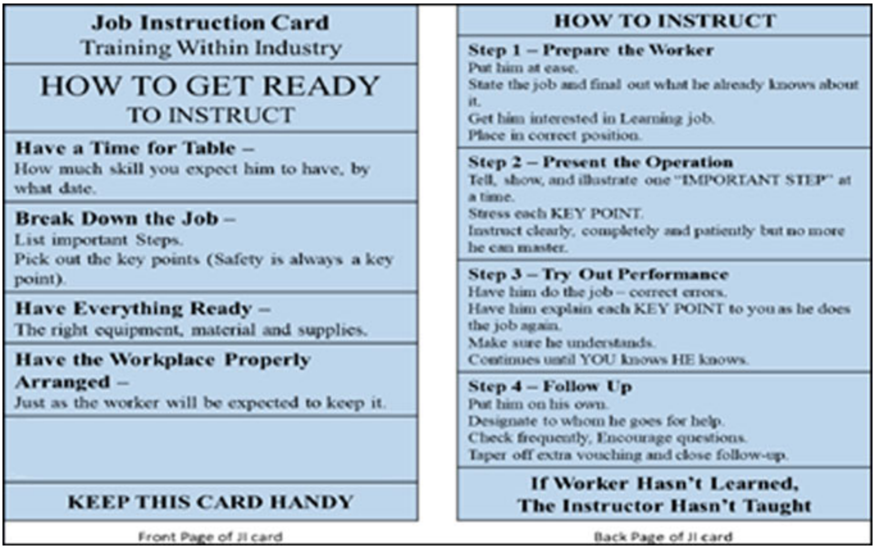


Fig. 2 Job instruction card

demand up-gradation in it. Again, following the same methodology and procedure, first, all setup was made available as expected from the trainee afterward. Then conduct a meeting with the respective supervisor and trainer and prepared a JBS for the rib welding procedure and finalized it with the manager of the plant as given in Table 2. Same as earlier, the training sessions were conducted with them and the skill matrix was updated after the session. The updated skill matrix shows team was close to achieving the decided targets provided by managers. In the updated matrix, purple color as shown in Fig. 4 indicates improvement in the skill of the respective operators in rib welding skill, and 3rd phase is completed here.

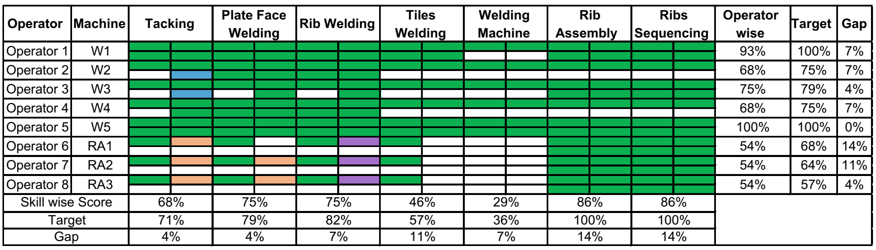
Similarly, move forward with this methodology and continuously upgrade the skill set of all sections. It became an internal part of the production department and nowadays all mapping and conducting training sessions were organized by a supervisor under the guidance of the operational excellence department and managers.

3 Results and Discussions

As mentioned above labor turnover create the scope for industry training and which leads us to utilize this old but more beneficial terminology. As shown in Fig. 4, targets were successfully achieved for four operators and four skills (the yellow color represents targets achieved). The overall improvement in the skill of operators from the welding section was approximately 15%. As given in Table 3, the improvement

Table 1 JBS for tacking of tiles skill

Description	Tacking of tiles	
Parts	Ribs assembly	
Tools and materials	Welding machine, fixture, hammer, safety equipment	
Important step (what)	Key points (how)	Reasons (why)
A. Set welding parameters	(i) It should be 170–190 Amps. Or refer welding manual	(i) To avoid burnout condition
		(ii) To avoid improper welding
B. Inspect torch	(i) Check the coolant inside it	(i) If coolant is absent, machine gets burned
	(ii) Check sharpness, if not sharpen, make it by buffing	(i) To get a steady arc/flame
	(iii) Release saturated shield gas	(i) To avoid overheating and unstable arc
		(ii) To avoid an accident
C. Start welding from the (outer) bigger curve	(i) Tacking should start from the corner side	(i) To avoid any gap between the base of the groove and the ribs
	(ii) Full-length tacking for longer ribs and dot tacking for small ribs	(i) To avoid distortion
	(iii) Weld throughout ribs	(i) Ribs get rigidly fit into grooves
D. Hammer the tile	(iv) With soft hands	(i) Just to repair the bend that occurred during welding



Operator	Machine	Tacking	Plate Face Welding	Rib Welding	Tiles Welding	Welding Machine	Rib Assembly	Ribs Sequencing	Operator wise	Target	Gap
Operator 1	W1								93%	100%	7%
Operator 2	W2								68%	75%	7%
Operator 3	W3								75%	79%	4%
Operator 4	W4								68%	75%	7%
Operator 5	W5								100%	100%	0%
Operator 6	RA1								54%	68%	14%
Operator 7	RA2								54%	64%	11%
Operator 8	RA3								54%	57%	4%
Skill wise Score		68%	75%	75%	46%	29%	86%	86%			
Target		71%	79%	82%	57%	36%	100%	100%			
Gap		4%	4%	7%	11%	7%	14%	14%			

Fig. 3 Skill matrix after stage 3 implementation

for skill was 14.92% and in the case of the operator, the improvement was 14.96% as given in Table 4.

As an earlier calculation indicates the score of individual skills and operators, the target plays an important role. Hence given in Table 5, the percentage target gain was 67.26% in the case of skills and 44.25% in the case of an operator.

Table 2 JBS for rib welding operation

Description	Rib welding operation	
Parts	Outer base, ribs, dome	
Tools and materials	Welding machine, filler rod, hammer, safety equipment	
Important step (what)	Key points (how)	Reasons (why)
A. Set welding parameters	(i) Current 190–230 Amp or refer to welding manual	(i) To avoid burnout condition
		(ii) To avoid improper welding
B. Inspect torch	(i) Check the flow of coolant	(i) In the absence of coolant, machine gets burned
	(ii) Check the sharpness of the tip	(i) To get a steady arc/flame
	(iii) Release saturated shield gas	(i) To avoid overheating and unstable arc
C. Perform Welding	(i) Fix rib inside groove with a hammer	(i) To avoid any gap between the base of the groove and the ribs
	(ii) Tack at 3 points on ribs	i. To avoid distortion
	(iii) Hammer ribs gently	(i) To get the correct alignment of ribs
	(iv) Weld dome at one point of the rib	(i) To maintain the gap between two consecutive ribs
	(v) Weld throughout ribs	(i) Ribs get rigidly fit into grooves
D. Hammer ribs	(i) Gently hammer a rib	(i) To get proper alignment

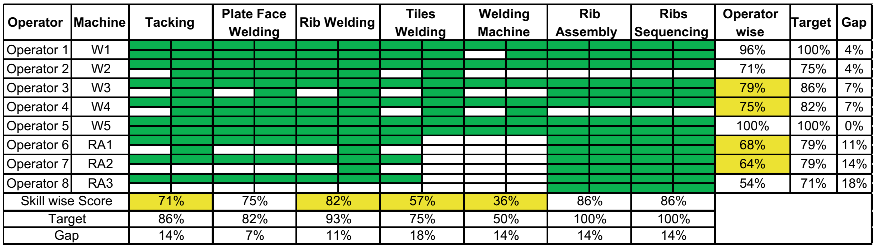


Fig. 4 Final updated skill matrix for welding section

Table 3 Skill-wise percentage improvement in welding section

	Tacking	Plate face welding	Ribs welding	Tiles welding	Welding machine setup	Ribs assembly	Ribs sequencing	Average
Score before	50	68	64	46	29	86	86	61.29
Score after	71	75	82	57	36	86	86	70.43
Improvement (in %)	21	7	18	11	7	0	0	14.92

Table 4 Operator-wise percentage improvement in welding section

	OP 1	OP 2	OP 3	OP 4	OP 5	OP 6	OP 7	OP 8	Average
Score before	93	64	71	68	100	46	43	43	66.00
Score after	96	71	79	75	100	68	64	54	75.88
Improvement (in %)	3	7	8	7	0	22	21	11	14.96

Table 5 Percentage target achieved

Parameters	Avg. score before implementation (in %)	Avg. target before implementation (in %)	Avg. score after latest update (in %)	Target Achieved (in %)
Skill-wise score	61.22	75	70.49	67.26
Operator wise score	66.07	88.27	75.89	44.25

The statistics show the production rate of the welding section as 84.5 tons before implementation. After the initiation of this technique, a slight increase in production was observed, and afterward, as training session frequency increases, that resulted in an increase in production. After the complete implementation, average tonnage production closed at 101.5 tons which exhibited an average monthly increase of 20.12%, given in Table 6. The management started with the implementation of this technique as they were able to make profits and were able to save on costs by reducing penalties.

It was observed that the average monthly improvement in production after TWI-JI was 20.12%. And the average increase in monthly revenue is $17 \times 1000 \times 440 =$ 74,80,000, where Rs. 440 is the rate per kilogram of production.

Table 6 Percentage increase in production for welding section

Month	Monthly production (in tons)	Monthly avg. production (in tons)
Jul	82	84.5
Aug	85	
Sep	84	
Oct	87	
Nov	95	101.5
Dec	98	
Jan	103	
Feb	110	
% Increase in Production		20.12

4 Conclusions

The TWI-JI approach boosted a medium-scale special purpose machine manufacturing enterprise's productivity. The improvement for skill was 14.92% and in the case of the operator, the improvement was 14.96%. Operator training with specific procedures and plans led to improved skills and a 20.12% increase in welding output. Multiple factors affect productivity, such as operator skills, equipment, and manpower availability. Learning technical details helped operators understand the importance of following guidelines.

Furthermore, the implementation of TWI-JI created a positive impact on the workers, as they have developed a genuine interest in their work. This newfound interest can be attributed to their increased understanding of the technical aspects of their job, making them feel more competent and certified in their roles. As a result, their profiles have gained value within the organization.

The workers' morale has improved because they have witnessed the company's commitment to their growth through the implementation of a simple yet effective methodology. This has fostered a sense of appreciation and support among the workers, leading to a mutually beneficial relationship. The company's efforts to invest in their improvement have contributed to the maxim, "A satisfied worker is key to company success," becoming a reality within the organization.

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Implementing Solar PV System in DC Microgrid for Electric Vehicle Charging

Abhishek Yadav, Narendra Kumar, and Kusum Tharani

1 Introduction

Electric vehicle (EV) charging refers to the process of charging an electric vehicle's battery using electricity from the grid. The primary goal of EV charging is to extend the driving range of electric vehicles and to provide a convenient and accessible way for drivers to recharge their vehicles. Integration of PV and EV charging: Integrating a PV system with an EV charging station can help to reduce the carbon footprint of EV charging by using clean, renewable energy from the sun. This also helps to reduce dependence on fossil fuels and promotes the use of clean energy. Energy Management Systems (EMS): Many studies have proposed the use of Energy Management Systems (EMS) to control the power flow between the PV system, the grid, and the EV charger. This helps optimize the use of available renewable energy, reduce peak power demand from the grid, and improve the system's overall efficiency [1, 2]. Smart charging: Smart charging strategies are essential for the effective integration of PV and EV charging. By adjusting the charging power and duration of EV charging, the system can avoid grid overloading, minimize energy losses, and improve the overall efficiency of the system [3, 4]. Economic analysis: Several studies have conducted an economic analysis of grid-connected PV systems for EV charging. These studies have shown that the investment in a PV system can pay 24 39 for itself in a few years, through the savings in electricity costs, and the additional income from selling excess solar energy back to the grid [5, 6]. Technical challenges: Several technical challenges are associated with the integration of PV and EV charging. These include

A. Yadav (✉) · N. Kumar
Department of Electrical Engineering, Delhi Technological University, Delhi 110042, India
e-mail: abhi.niv@gmail.com

K. Tharani
Department of Electrical Engineering, Bharati Vidyapeeth College of Engineering, Delhi 110063, India

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the management of variable renewable energy sources. Solar energy is a renewable energy source, which means it is sustainable and will not run out. This reduces dependence on finite fossil fuels and helps mitigate the effects of climate change. Cost savings: Solar panels can be installed on-site at homes and businesses, allowing for the generation of electricity from the sun to charge EVs. This can result in substantial cost savings, especially over the long term, compared to buying electricity from the grid [7, 8]. Reduced grid strain: With more EVs on the road, the demand for electricity to charge them is increasing. By generating electricity from the sun, solar-powered EV charging can help reduce strain on the grid, particularly during peak usage times. Increased energy independence: Installing solar panels on-site for EV charging can increase energy independence and reduce reliance on the grid, which can be particularly beneficial in areas with unreliable or expensive electricity. However, there are also some limitations to using solar energy for EV charging, including: Weather dependence: Solar energy generation is dependent on weather conditions, and in some regions, there may be a lack of sunlight for long periods of time, which can impact the ability to generate electricity. Initial cost: Installing a solar energy system can be expensive, particularly for larger systems that can generate enough energy to fully charge an EV. This can be a barrier for some individuals and businesses who may not have the financial resources to invest in a solar system. Maintenance and upkeep: Solar panels and other components of a solar energy system require maintenance and upkeep, which can add to the cost of using solar energy for EV charging. Grid connectivity: To be used in the majority of homes and businesses, the direct current (DC) power that solar panels produce must be converted to alternating current (AC). An inverter must be used for this, which can be costly and raise the price of a solar energy system [9, 10].

2 Methodology

Installation of a grid-connected PV system: A grid-connected PV system is installed on the roof of a building or any other suitable location. The system generates electricity from solar radiation and feeds it back into the grid when there is an excess of generated electricity.

Connection of the EV charging station to the grid-connected PV system: The EV charging station is connected to the grid-connected PV system. This allows the charging station to draw electricity from the PV system when it is available. We are getting a voltage of around 248 volts at the EV charging station.

When the EV owner wants to charge the vehicle, they plug it into the charging station. The charging station then draws electricity from the PV system and charges the EV battery. Monitoring and control of the charging process: The charging process can be monitored and controlled using a smart energy management system. This system can be used to control the charging speed, set charging schedules, and monitor electricity usage and costs.

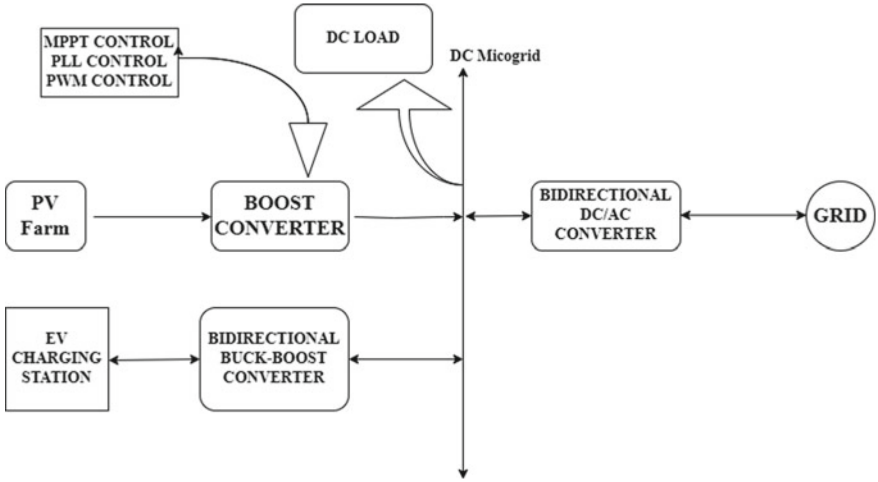

Fig. 1 Block diagram of grid-connected PV system for EV charging

Grid supply: If the PV system does not produce enough electricity to charge the EV, the charging station can draw electricity from the grid. In this case, the grid acts as a backup power source for the charging station. So, we have connected a bidirectional DC/AC converter from the DC microgrid bus and grid to convert power as per the requirement.

The performance and behavior of a grid-connected PV system for EV charging, including its energy generation, energy demand, energy management, and grid integration, may be better understood via the use of this simulation environment.

Figure 1 shows the schematic diagram of a grid-connected PV system for charging electric vehicles.

Using an EMS, which takes into account the batteries' current state of charge, the PV system's power output, and the energy requirements of the EVs being charged, it is possible so that we can maintain a better balance of the power among the solar cell, the grid, and the EV charging station.

A model of the loads linked to the grid might be used to simulate the system's overall energy consumption. We used a load of 160 ohms for our experiment.

3 Simulation Environment

To create the simulation setup, the simulation software MATLAB/Simulink is used.

4 Result and Discussion

The configuration, placement, and operational circumstances of a PV system that is grid-connected and used to charge electric cars, i.e., EVs may affect the system's output. However, the following are some typical results and notions:

A grid-connected PV system can be used to capture and supply solar energy to the grid. The amount of power the system generates depends on the size of the PV array, the tilt and orientation of the panels, and the weather. The output voltage from the PV system is 240 volts and with the use of a boost converter, we are getting a voltage of around 400 volts at the DC bus.

Also, the inverter and grid currents are found to be sinusoidal in the running condition as shown in Fig. 2.

In grid-connected PV systems, it is important to maintain a constant DC voltage in order to ensure optimal performance and prevent damage to the system components. This can be achieved through the use of voltage regulation techniques.

One common method of maintaining a constant DC voltage is through the use MPPT algorithms. These algorithms continuously monitor the voltage and current of the PV panels and adjust the operating voltage of the system to ensure that the panels are operating at their maximum power point. By doing so, the MPPT algorithm can help to optimize the energy output of the PV system and improve its overall efficiency.

By lowering the quantity of greenhouse gas emissions linked to the production of energy from fossil fuels, a grid-connected PV system can have a favorable effect on the environment. Additionally, the technology can aid in lowering the overall carbon footprint of transportation by recharging EVs using clean, renewable energy.

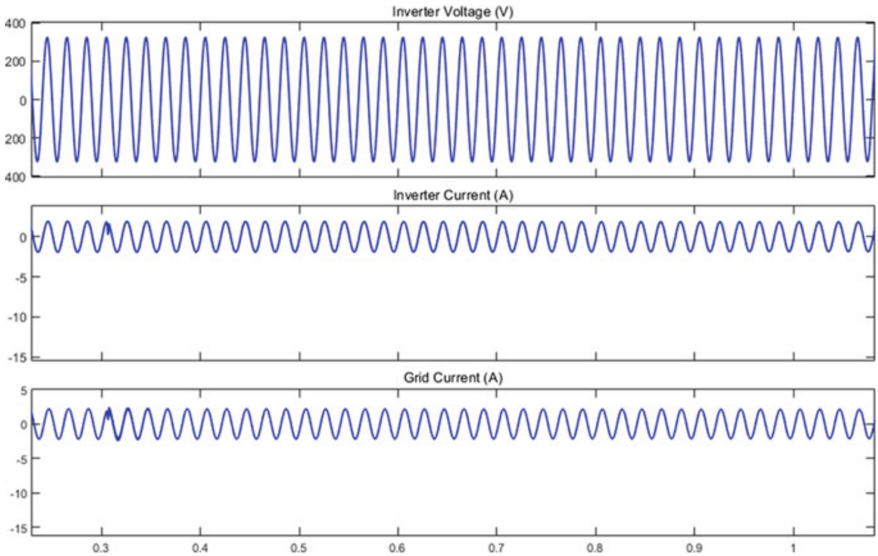

Fig. 2 Inverter and grid currents

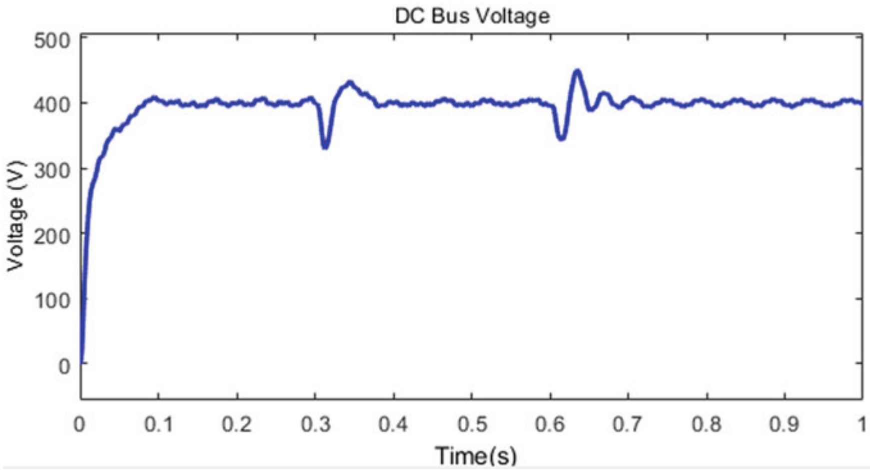

Fig. 3 DC bus voltage

An electric vehicle's battery capacity, charging duration, and charging rate all affect how much energy an EV charging system uses. The PV system should be able to provide enough electricity to satisfy the EV charging system's energy requirements. An essential issue to consider when choosing a grid-connected PV system for EV charging is system efficiency. The inverter efficiency, charging station efficiency, and energy losses within the system are only a few examples of the variables that affect the system's efficiency. The DC bus voltage is kept constant at 400 Volts so as to meet the load demands at the DC microgrid side with minor fluctuations because of variations in irradiance thereby getting fluctuations in PV output voltage as shown in Fig. 3.

The grid currents and voltages are also sinusoidal, and we were able to achieve a constant voltage of 248 volts at the charging station's output in the design simulation as shown in Fig. 4. In addition, 400 Volts of the output voltage at the load are maintained despite variations in solar radiation and PV system power production. The performance, efficacy, and cost-effectiveness of such a system may be enhanced.

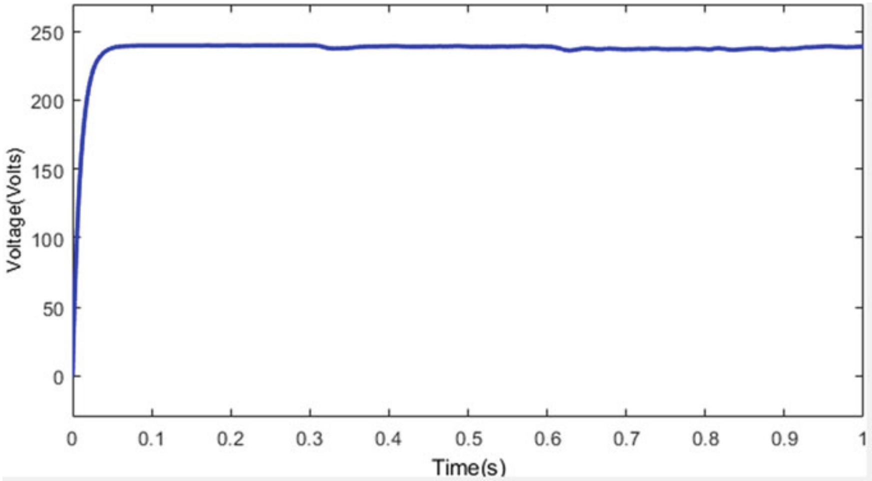

Fig. 4. Voltage output at EV charging station

5 Conclusion

1. The use of grid-connected inverters in photovoltaic-powered electric vehicle charging stations can enhance the stability of microgrids.
2. System planning and key technologies are crucial for the successful implementation of grid-connected electric vehicle charging stations.
3. Multiple-integrated converters and pseudo-DC-link inverters can be used to analyze and design grid-connected photovoltaic systems.
4. There are various methods of controlling the rate of flow of current in power grids and are critical issues that need to be addressed.
5. To analyze and provide accurate solutions both for the economical as well as the technical issues in the use of this grid-connected system considering varying values of all possible parameters.

Additionally, a grid-connected PV system can help to ensure that EVs are charged even during power outages or grid disruptions, providing owners with a reliable source of energy. The combination of PV and EV technologies can also help to manage the variability of renewable energy generation and provide a more stable and balanced energy grid.

Overall, the use of grid-connected PV systems for EV charging can provide a suitable and environment friendly solution for powering EVs, helping to reduce dependence on fossil fuels and promote a cleaner, greener energy future.

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Modelling and Analysing the Structural Relationship Among Industry 4.0 Dimensions

Love Kumar and Rajiv Kumar Sharma

1 Introduction

I4.0 was first given by Kagermann [1] to address the digitalization of the German industries towards managing a better future. It was the starting of 4th Industrial Revolution that is I4.0, as it was challenging the current manufacturing practices in the era of competition and globalization. The 1st Industrial Revolution was observed in the eighteenth century with the invention of steam engine. It was the era of development of mainly the textile and steel industries. The 2nd Industrial Revolution was observed in the nineteenth century when the invention of electricity was done. It was the era of electrification of the manufacturing industries. The 3rd Industrial Revolution was observed in the twentieth century when computers and robots were part of the manufacturing processes. The chemical and automobile industries made significant progress in the era [2]. I4.0 is the era of digital transformation of industries with the integration of the CPS, industrial IoT, 3D printing, simulation, cloud computing, cyber-security, etc.

It is required to transform the Indian manufacturing industry into smart factories because the manufacturing sector shares about 18% to India's GDP, which is one of the key factors for the developed countries. The government of India is taking steps forward to boost its manufacturing sector through the programmes like "Make in India." In support of this factor, I4.0 aims to digitalize the current production practices, which according to the study, may lead to boost the manufacturing sector to contribute 25% of the GDP. Therefore, it becomes essential to boost the manufacturing industry. For instance, I4.0 implementation in Indian SMEs will increase their productivity and flexibility in producing smart products [3]. The Indian manufacturing industries, especially those that come under the category of SMEs, are mostly struggling for I4.0 implementation to get the competitive edge in manufacturing and

L. Kumar (✉) · R. K. Sharma
National Institute of Technology, Hamirpur, Himachal Pradesh 177005, India
e-mail: lovegola1@gmail.com

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productivity [4]. Also, SMEs are more prone to changes in the process, and organizational structure than those of large-scale industries as large-scale industries are more rigid to their organizational structure and process changes [5]. Moreover, manufacturing SMEs contribute about 7% to the GDP. The Confederation of Indian Industry (CII) started a programme that is "Digital Saksham" to help strengthen three lakh small businesses to adopt digital manufacturing practice. SMEs who have adopted the digital practices in their firm increased the value and productivity by 25 and 16%, respectively [6]. In a study, small businesses in 2017 and 2018 spent 574 and 602 billion US dollars, respectively, on their IT infrastructure. In 2021, it is expected to be 684 billion US dollars. The statics shows that small businesses are getting benefitted from the digital transformation. Therefore, I4.0 has its benefits and can revolutionize the manufacturing sector [7]. The pace of I4.0 adoption is such that Japan started talking about the I5.0 [8]. But SMEs still struggle to implement I4.0 in terms of the high initial investment, government protocols, and lack of specific knowledge/skill. The concern is to find out enablers that influence the adoption of I4.0 [3, 4, 9, 10].

Competition among industries to adopt I4.0 is worth focusing on retaining in the business. Most developed countries have already started practices to adopt I4.0. The transformation of industries has great opportunities and challenges [11]. Moreover, very little literature is available to address the issue. In view of the present situation, our study aims to: Explore/model enablers that help SMEs to check the readiness index towards Industry 4.0. Evaluate structural relationship among enablers. Evaluate driving and dependence power.

The above-said objectives have been achieved by applying interpretive structural modelling followed by MICMAC analysis on the inputs given by experts from industries and academia. A structural model has been proposed for understanding I4.0 implementation. The work has shown challenges in I4.0 adoption and presented a model to eradicate the challenges. Our study contributes to modelling and analysing variables of I4.0 dimensions. The structural model derives the contextual relationship among variables and helps decision-makers smooth the I4.0 implementation process in SMEs.

Other sections contain literature review, research questions and methodology, and conclusion, respectively.

2 Literature Review

The I4.0 emerged as a leading manufacturing concept for the industrial giants and is yet to be in its initial phase. Researchers are still exploring the aspects of I4.0. Therefore, various researchers have expressed the definition of I4.0. Pagliosa et al. [12] expressed the I4.0 as the integration of CPS, ICT, and cloud computing through exchanging data. Thereby making the conventional factory into a smart factory where each component of the manufacturing unit interacts with each other by exchanging data and respond to data and improve the quality of products. The upcoming trend in industries is due to the integration of the CPS, cloud computing, IoT, and cognitive computing [13].

One of the recent studies by Culot et al. [23] presented an analysis of I4.0 definitions. Authors expressed the I4.0 as a witnessed revolution to conventional manufacturing practices, and it is a concept of integrating new technologies to boost production capacity. Therefore, it is essential to have an extensive study about the adoption and implementation criteria of I4.0. About I4.0 implementation, researchers have explored enablers/variables which affect the I4.0 adoption. In a similar study, Cunha et al. [24] identified variables: IoT, CPS, Cloud computing, Cybernetic Security and Cobots, and M2M interactions, that influence the I4.0 implementation. The study was limited to the Brazilian IT companies and included only the technological aspects. Dhamija and Bag [15] reviewed work that influences I4.0 implementation and identified 6 clusters, namely AI, R&D, machine learning, supply chain, technology, and IoT. Queiroz et al. [16] proposed guidelines for supply chain operations I4.0 and identified enabler technologies: IT, supplier, customer, policy for workers, warehouse, transportation, and smart production. Pirola et al. [17] suggested the variables such as people, strategy, customer, and technology integration. Ganzarain and Errasti [18] considered market, product, process, and value chain. O'Donovan et al. [19] developed a I4.0 assessment maturity model and considered operation technology, embedded analytics, IT, data analytics, and open standards. Gill and VanBoskirk [20] developed a maturity model considering technology, culture, organization, and insights. Another model was developed considering dimensions such as customers, products, technology, strategy, operations, governance, culture, leadership, and people [25]. It was found that the Indian SMEs are the most promised field, where the I4.0 concept is not implemented due to a lack of literature focusing on SMEs. Therefore, it is essential to investigate critical enablers for I4.0 adoption in Indian SMEs. It becomes critical to find a good relationship among the enablers that ease the process of I4.0 implementation. A systematic and structural analysis is the need of the hour. Table 1 presents the literature study.

3 Research Questions and Methodology

Figure 1 presents the methodology adopted in the study to achieve the mentioned objectives. It starts with the literature survey for the identification of variables to address an issue. The issue for the current study is to find essential enablers for I4.0 adoption in Indian SMEs. Research questions and the methodology have been discussed in this section.

Table 1 Literature study

S. No.	Authors	Issue	Remark
1	Kumar and Sharma [14]	The authors investigated several dimensions for I4.0 implementation	The work may be extended to have insights of the dimensions. The authors have explored the dimensions having read the 68 selected scientific articles
2	Dhamija and Bag [15]	The authors reviewed AI in industrial operations	Exploring key risks involved in the adoption of new technology in various sectors. Privacy and security-related issues must be explored. A case study should be done to understand the in-depth knowledge in the concern
3	Queiroz et al. [16]	Presented a digital the supply chain model	The authors identified capabilities such as IT, supplier, customer, policy for workers, warehouse, transportation, and smart production. Future work may be discussed about the barriers in adopting the enabler technologies
4	Pirola et al. [17]	The authors created a comprehensive evaluation model for SMEs	The paper identified four dimensions, namely strategy, people, process, and technology integration, among various levels of maturity for I4.0 adoption. Potential future research could concentrate on grouping similar SMEs together to gain a deeper insight into the connections between variables and dimensions
5	Ganzarain and Errasti [18]	The study created a three-stage maturity model to assess the preparedness of SMEs for Industry 4.0	The authors of the paper considered four dimensions, namely market, product, process, and value network, while evaluating SMEs in the Basque region. Potential future research could examine SMEs in other countries

(continued)

Table 1 (continued)

S. No.	Authors	Issue	Remark
6	O'Donovan et al. [19]	The study described in the paper introduced maturity model for industrial analytics for evaluating the capability of industrial analytics	The paper considered five dimensions, including IT, data, and embedded analytics, in the evaluation of industrial analytics capabilities. A potential area for future research could be the creation of maturity models that also incorporate factors such as government policies and financial resources. The current analysis did not consider SMEs
7	Gill and VanBoskirk [20]	The article introduced a maturity model for evaluation of capability assessment	It considered four broad criteria in its evaluation, including technology, culture, organization, and insights
10	Sriram and Vinodh [21]	The authors analysed readiness factors with the help of an MCDM tool that is COPRAS	Readiness factors identified are customer-focused innovativeness, comfortability with technology, and Internet set-up. Experts' opinions are specific to Tamil Nadu state only. More variables may be explored
11	Bosman et al. [22]	The authors proposed investment guidelines to digitalize industries	Identified variables to invest in I4.0 are "size of the firm," "financial aid," and "industry types." The research was region-specific, and there could be other variables that were not taken into consideration

3.1 Research Questions

Research questions have been identified in connection with the I4.0 implementation in SMEs.

1. *What are the enablers that help SMEs in I4.0 implementation?*
2. *What relationship exists among enablers for I4.0 implementation?*

Therefore, our study aims to:

1. Explore/model enablers that help SMEs in industry 4.0 implementation.

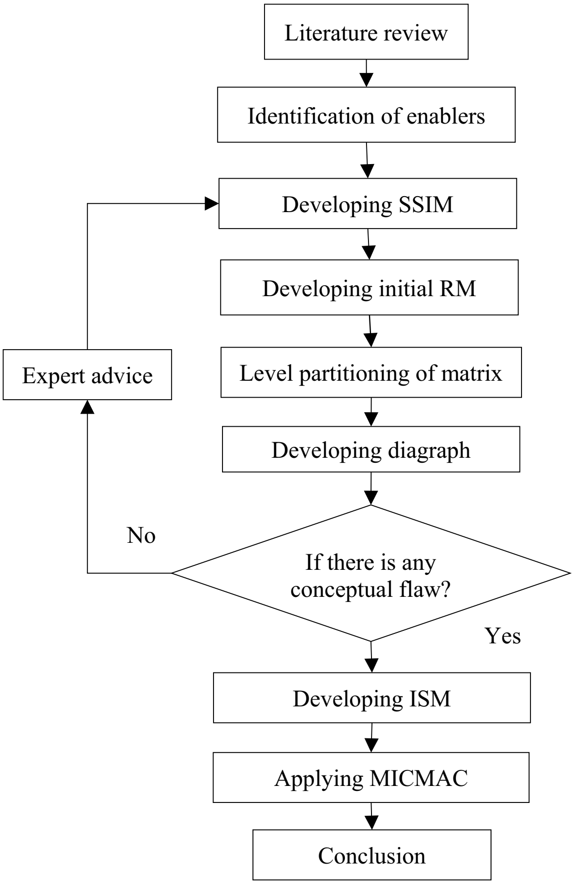


Fig. 1 Methodology

2. Evaluate the structural relationship among enablers.
3. Evaluate driving and dependence power of enablers.

3.2 Modelling the Dimensions

Table 2 gives the description of enablers. Enablers to I4.0 were explored through the rigorous study of the literature and followed by suggestions and recommendations from experts. After identifying the variable from the literature, the ISM method is applied.

Table 2 Enablers description

S. No.	Enablers	Description	Supported by
E_1	Government support	The government may support I4.0 adoption in SMEs by creating favourable policies and regulations, providing financial incentives, investing in infrastructure, offering training and education, and funding R&D initiatives. This can drive transformation and help SMEs implement advanced technologies and smart manufacturing practices	[28]
E_2	Information technology infrastructure	IT infrastructure is critical to I4.0 adoption in SMEs as it enables real-time data collection, storage, and analysis, and supports the deployment of I4.0 technologies like IoT, cloud computing, and AI. A robust IT infrastructure is necessary for secure data exchange, remote monitoring, and control of manufacturing processes, and provides the foundation for smart manufacturing practices and optimized production processes	[14, 29]
E_3	Compatibility of hardware and software	When hardware and software are compatible, it is possible to integrate various systems and technologies, such as sensors, control systems, and cloud platforms, into a cohesive and interconnected system. This enables real-time data analytics and decision-making, which is essential for the implementation of smart manufacturing practices and the optimization of production processes	[11]
E_4	Data security	Data security measures should include the implementation of strong encryption algorithms, secure data transfer protocols, and access controls to restrict unauthorized access to sensitive information. It is also important to have regular security audits to minimize potential security incidents	[11, 14]
E_5	Implementation cost	The cost of implementation is a key consideration in I4.0 adoption by SMEs. The implementation of advanced technologies and smart manufacturing practices often requires significant capital investment, and SMEs may face challenges in securing the necessary funding to support these investments	[11]

(continued)

Table 2 (continued)

S. No.	Enablers	Description	Supported by
E_6	Well-defined standards	Well-defined standards facilitate a common language and framework for the integration of different technologies and systems, and ensuring interoperability, compatibility, and security. The Industrial Internet Consortium, International Organization for Standardization, and European Telecommunications Standards Institute are among the organizations that have established standards for Industry 4.0	[3]
E_7	Top management commitment	Top management commitment in Industry 4.0 refers to active support from senior leaders in implementing the advanced technology and smart manufacturing practices. This includes providing resources, creating a strategy, and promoting a culture of innovation. It is crucial for success and helps secure resources, foster a sense of urgency, and drive the organization towards digital transformation	[2, 14]
E_8	Research and development (R&D)	R&D involves creating new technologies, products, and services through innovation. It focuses on integrating advanced technologies such as AI, IoT, and big data analytics into manufacturing processes. R&D is crucial for the development of Industry 4.0 and helps organizations stay ahead of competition by optimizing production processes, creating new solutions, and improving efficiency, quality, and sustainability	[2, 3]
E_9	Project management experience	It involves using knowledge, tools, and techniques to plan and execute Industry 4.0 projects effectively. Project management helps organizations to define goals, plan and execute projects, manage risks, and ensure quality and timely delivery	[2]
E_{10}	Employees training/ skilled staff	Employee training and skilled staff are crucial for Industry 4.0 adoption. Employee training helps build a skilled workforce and foster a culture of innovation. Skilled staff are necessary to effectively operate and maintain I4.0 technologies, leading to efficient production	[11, 14, 21]

(continued)

Table 2 (continued)

S. No.	Enablers	Description	Supported by
E_{11}	Customer-centric innovativeness	It involves using advanced technologies to understand customer needs, improve customer experience, increase customer loyalty, and gain a competitive edge. This leads to better customer-focused solutions and helps organizations stand out in the market	[16, 21]
E_{12}	Risk monitoring and control tool	The tools help organizations identify and assess potential risks, implement mitigation measures, monitor risk management, and improve decision-making. This leads to a more secure and successful implementation of I4.0	[2, 14]

3.3 Interpretive Structural Modelling (ISM)

The ISM technique was first given by Warfield and Member [26], which aimed to organize a set of variables into a structural form. The implementation of the ISM technique involves the following six steps:

Structural Self-Interaction Matrix (SSIM): After identifying the variable from the literature, the relationship between any two variables (E_i and E_j) and their directional relationship is explored, taking help from the experts working in the same field. This relationship is represented in terms of O, X, A, and V, where O: No relationship between variables E_i and E_j. X: Variables E_i and E_j are influencing each other. A: Denotes that variable E_j is influencing variable E_i. V: Shows the variable E_i is influencing variable E_j. Table 3 gives the SSIM.

Initial RM: The matrix is deducted from SSIM by using substitution conditions. Table 4 describes the substitution conditions, where '1' depicts that variable E_i influences the variable E_j and '0' depicts that variable E_i does not influence variable E_j. Table 5 gives the initials RM. The next step is to develop the final RM.

Final RM: The matrix is deducted from initial RM after a transitivity check. The transitivity condition says if variable *i, j,* and *k* if *i affects j* and *j* affects *k* then *i affects k*. In this matrix, "1*" represents the transitive relation. And the sum of row elements shows the driving rank of that variable, and similarly, the sum of column element shows the dependence rank of that variable. Table 6 gives the final RM.

Level partitioning of matrix: In this step, antecedent and reachability groups of variables are prepared for each variable [27]. The reachability group for a variable E_1 includes variables that have $E_{(1, k)} = 1$, where *k* ranges from 1 to 12 and $E_{(1, k)}$ represents an entry in the matrix. Similarly, reachability groups for other variables that is E_2–E_{12}, are prepared. After that, the antecedent groups are formed for each variable. The antecedent group for a variable E_1 includes variables that have $E_{(k, 1)}$

Table 3 SSIM

Enabler	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	E_{11}	E_{12}
E_1	X	O	O	O	O	V	X	X	V	O	O	O
E_2		X	V	V	A	O	O	O	O	O	V	O
E_3			X	O	A	O	O	O	O	O	O	O
E_4				X	V	A	O	A	O	A	O	A
E_5					X	O	A	A	A	A	A	A
E_6						X	A	X	X	A	O	O
E_7							X	O	V	V	V	O
E_8								X	V	O	V	V
E_9									X	A	O	X
E_{10}										X	V	O
E_{11}											X	O
E_{12}												X

Table 4 Substitution condition

Symbol/variable pair	*Entry* $E_{(i,\ j)}$ *in the matrix*	*Entry* $E_{(j,\ i)}$ *in the matrix*
O	0	0
X	1	1
A	0	1
V	1	0

Table 5 Initial RM

Enabler	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	E_{11}	E_{12}
E_1	1	0	0	0	0	1	1	1	1	0	0	0
E_2	0	1	1	1	0	0	0	0	0	0	1	0
E_3	0	0	1	0	0	0	0	0	0	0	0	0
E_4	0	0	0	1	1	0	0	0	0	0	0	0
E_5	0	1	1	0	1	0	0	0	0	0	0	0
E_6	0	0	0	1	0	1	0	1	1	0	0	0
E_7	1	0	0	0	1	1	1	0	1	1	1	0
E_8	1	0	0	1	1	1	0	1	1	0	1	1
E_9	0	0	0	0	1	1	0	0	1	0	0	1
E_{10}	0	0	0	1	1	1	0	0	1	1	1	0
E_{11}	0	0	0	0	1	0	0	0	0	0	1	0
E_{12}	0	0	0	1	1	0	0	0	1	0	0	1

Table 6 Final RM

Enabler	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	E_{11}	E_{12}	Dr
E_1	1	0	0	1*	1*	1	1	1	1	1*	1*	1*	10
E_2	0	1	1	1	1*	0	0	0	0	0	1	0	5
E_3	0	0	1	0	0	0	0	0	0	0	0	0	1
E_4	0	1*	1*	1	1	0	0	0	0	0	0	0	4
E_5	0	1	1	1*	1	0	0	0	0	0	1*	0	5
E_6	1*	0	0	1	1*	1	0	1	1	0	0	1*	7
E_7	1	1*	1*	1*	1	1	1	1*	1	1	1	1*	12
E_8	1	1*	1*	1	1	1	1*	1	1	0	1	1	11
E_9	0	1*	1*	1*	1	1	0	1*	1	0	0	1	8
E_{10}	0	1*	1*	1	1	1	0	1*	1	1	1	1*	10
E_{11}	0	1*	1*	0	1	0	0	0	0	0	1	0	4
E_{12}	0	1*	1*	1	1	1*	0	0	1	0	0	1	7
De	4	9	10	10	11	7	3	6	7	3	7	7	

*Dr- Driver power, De-dependence power

= 1, where *k* ranges from 1 to 12 and $E_{(k, 1)}$ represents an entry in the matrix. Table 7 presents the partitioning levels.

Developing digraph: Soon as the levels are determined, the relationship among variables is shown by drawing a directional arrow between any two variables. This is known as a directed graph or digraph. Figure 2 shows the digraph representing the relationships among enablers.

Developing interpretive structural model: The digraph is transformed into ISM by removing the transitive links. Figure 3 shows an interpretive structural model to I4.0 implementation and adoption in Indian SMEs. There are five levels.

Level V consists of "government support (E1)," and "top management commitment (E7)" comes out to be the most critical variables that drive I4.0 implementation in Indian SMEs supported by Jain and Ajmera [3] and Majumdar et al. [2]. Governments of other countries are taking steps to boost the manufacturing sector. Germany, France, and China started programmes like "Industrie 4.0", "Industrie du Futur," and "Made in China," respectively. Likewise, the Indian government is also taking its steps to boost the manufacturing sector to an I4.0 environment and already started programmes such as "Make in India" and "Skill India".

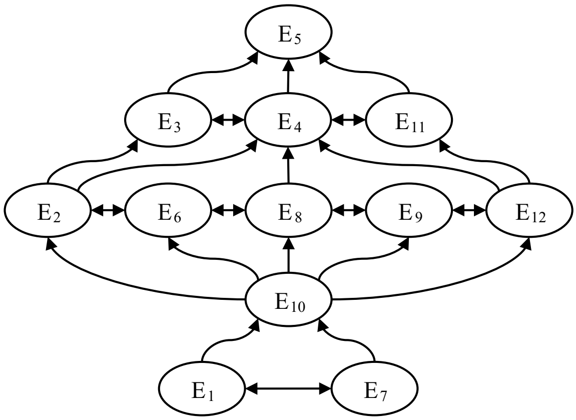
Top managers respond to the hiring skilled workforce, defining rules and regulations, training the employees, and any significant changes which benefit the company [30].

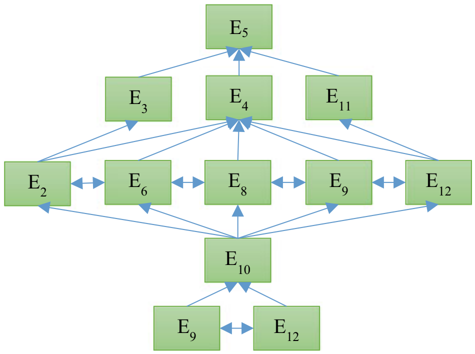
Level IV of the ISM consists of "skilled/trained staff (E_{10})" which comes out to be the second most important variable supported by [2]. It is driven by the enablers placed at the level I that is "government support (E_1)" and "top management commitment (E_7)". The government helps managers avoid the redundant implementation of an idea by issuing standard guidelines. Therefore, top management commitment to

Table 7 Level partitioning

Enabler	Reachability group	Antecedent group	Intersection group	Level
E_1	E_1 E_4 E_5 E_6 E_7 E_8 E_9 E_{10} E_{11} E_{12}	E_1 E_6 E_7 E_8 E_{12}	E_1 E_6 E_7 E_8 E_{12}	V
E_2	E_2 E_3 E_4 E_5 E_{11}	E_2	E_2	III
E_3	E_3 E_5	E_2 E_3	E_3	II
E_4	E_4 E_5	E_1 E_2 E_4 E_6 E_7 E_8 E_9 E_{10} E_{12}	E_4	II
E_5	E_5	E_1 E_2 E_3 E_4 E_5 E_6 E_7 E_8 E_9 E_{10} E_{11} E_{12}	E_5	I
E_6	E_1 E_4 E_5 E_6 E_8 E_9 E_{11} E_{12}	E_1 E_6 E_7 E_8 E_9 E_{10} E_{12}	E_1 E_6 E_8 E_9 E_{12}	III
E_7	E_1 E_4 E_5 E_6 E_7 E_8 E_9 E_{10} E_{11} E_{12}	E_1 E_7 E_8	E_1 E_7 E_8	V
E_8	E_1 E_4 E_5 E_6 E_7 E_8 E_9 E_{11} E_{12}	E_1 E_6 E_7 E_8 E_9 E_{10} E_{12}	E_1 E_6 E_7 E_8 E_9 E_{12}	III
E_9	E_4 E_5 E_6 E_8 E_9 E_{12}	E_1 E_6 E_7 E_8 E_9 E_{10} E_{12}	E_6 E_8 E_9 E_{12}	III
E_{10}	E_4 E_5 E_6 E_8 E_9 E_{10} E_{11} E_{12}	E_1 E_7 E_9 E_{10}	E_9 E_{10}	IV
E_{11}	E_5 E_{11}	E_1 E_2 E_6 E_7 E_8 E_{10} E_{11} E_{12}	E_{11}	II
E_{12}	E_1 E_4 E_5 E_6 E_8 E_9 E_{11} E_{12}	E_1 E_6 E_7 E_8 E_9 E_{10} E_{12}	E_1 E_6 E_8 E_9 E_{12}	III

Fig. 2 Digraph





E1 Government support
E2 Information technology infrastructure
E3 Compatibility of hardware and software
E4 Data Security
E5 Implementation cost
E6 Well-defined standards
E7 Top management commitment
E8 Research and development in the industry
E9 Project management experience
E10 Employees training/ skilled staff
E11 Customer-centric innovativeness
E12 Risk monitoring and control tool

Fig. 3 Interpretive structural model

decision-making related to implementation and financial risk is greatly influenced by the government guidelines and schemes. As the I4.0 concept is new for the existing employees, it is not easy for the top managers to find the workforce compatible with the current technology. They lack the competency in the skilled employee. Therefore, it becomes necessary to work on this parameter. Top managers are directly responsible for training drives for the employees.

Level III of digraph consists of "research and development (E_8)," "well-defined standards (E_6)," "information technology infrastructure (E_2)," "project management experience (E_9)," and "risk monitoring and control tool (E_{12})", which according to our study are driven by "skilled/employee training (E_{10})".

Research and development (E_8) in this area is still in the initial phase. A lot more gap is to be filled between theory and practice. Today advanced manufacturing practices are becoming complex due to the integration of cyber-physical systems, intelligent manufacturing systems, IIoT, cloud computing, machine-to-machine interactions, additive manufacturing, big data, product-driven systems, etc. [31].

Due to the lack of well-defined standards (E_6), necessary changes in the process, organizational architecture, etc., become difficult to implement. Moreover, risk of failure, risk of financial loss, risk of project failure always comes into existence; therefore, risk monitoring and control tools (E_{12}) have equal significance in I4.0 implementation in Indian SMEs. The lack of these tools demoralizes the top managers to discontinue adopting and implementing the I4.0 environment [2]. Moreover, they have all the time pressure of benefitting the firm at all costs, failing which they always have a risk of losing the job. In such a scenario, they do not step forward in transforming the existing firm into the digital one.

Because of this, project management experience (E_9) becomes the essential factor in eradicating the risk involved in implementation. Project managers always struggle with the permits required to share investments, integrating technologies protocol and standards driven by government support (E_1). In addition to this, research, and development (E_8) play a supporting role in framing the well-defined standards (E_6). Information technology infrastructure (E_2) includes hardware, software, networking devices, data storage devices, cyber-physical systems, IIoT, internet, cloud computing, complex operating systems, and edge computing. These components are lacking in our existing SMEs, due to which it becomes a hurdle in the I4.0 implementation. However, the enablers at level III are driven by skill development/ employee training (E_{10}).

Level II of the digraph consists of "compatibility of hardware and software (E_3)," "data security (E_4)" and "customer-centric innovativeness (E_{11})," which, according to our findings, are driven by the level III enablers. A better information technology infrastructure (E_2) leads to data security (E_4) which is crucial for I4.0 implementation [3]. Therefore, it would not be wrong to say that data security (E_4) is driven by information technology infrastructure (E_2). Moreover, data security earns the confidence of the customer in sharing information with the manufacturer. Similarly, if the information technology infrastructure (E_2) is adequate, then there is no such issue as compatibility of hardware and software (E_3). SMEs struggle to procure information technology-related hardware and software from different suppliers over a period, leading to compatibility issues. Therefore, managers must face difficulties in finding solutions [3].

Level I consist of "implementation cost (E_5)," which, according to our study, is the most deciding factor for the I4.0 concept implementation in Indian SMEs. Effective study at all the driving levels will be the deciding factor for the I4.0 concept implementation. Cost-effective analysis at all levels will act as a driving force (Kumar et al., 2020). Crucial study at each level will help decision-makers in I4.0 implementation.

MICMAC: MICMAC analysis groups the enablers into linkage, autonomous, dependent, and driver clusters depending upon the enablers' dependence and driver powers. The power is derived from the final RM. Figure 4 shows the cluster diagram of enablers. Compatibility of hardware and software (E_3) and information technology

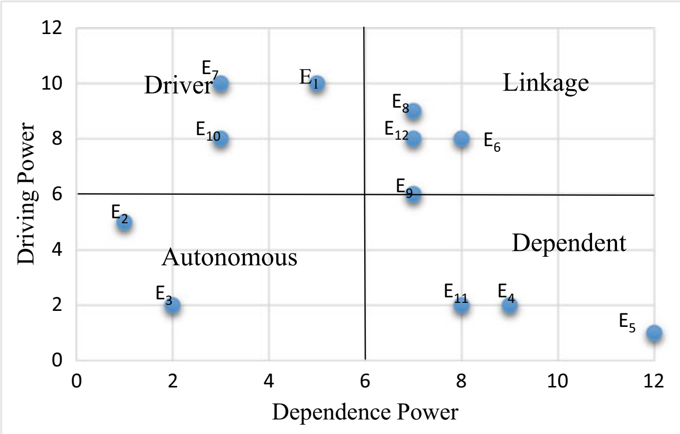


Fig. 4 MICMAC diagram

infrastructure (E_2) is the autonomous variables. Implementation cost (E_5), customer-centric innovativeness (E_{11}), and data security (E_4) are dependant variables and have very low driving power and are powered by the driver variables. Linkage variables from MICMAC analysis are research and development (E_8), well-defined standards (E_6), and risk monitoring and control tool (E_{12}). High dependence and high driving power are shown by linkage variables. Finally, government support (E_1) and top management commitment (E_7), and skilled/employee training (E_{10}) are the driver variables that are responsible for successfully driving the implementation process. One variable is also at the boundary line of the driven cluster. This variable needs to be eliminated for the I4.0 implementation.

4 Conclusion

The current study aimed to investigate and analyse the key variables for I4.0 implementation by utilizing interpretive structural modelling (ISM) and MICMAC.

This study evaluated and analysed the important factors using ISM and MICMAC after first identifying them through a comprehensive literature review. Based on the findings, a framework for analysing Industry 4.0's adoption was proposed. These findings exposed difficulties encountered during Industry 4.0's adoption and execution and provided a thorough approach to addressing them. The study's findings pointed to three key factors: Government support (E1), management commitment (E7), and well-employee training (E10). The report emphasizes the need for government and industry leadership to work together to overcome barriers to the adoption and implementation of I4.0.

The Indian government has launched programmes like “Make in India” and “Skill India” and enacted regulations like the “National policy for advanced manufacturing” to aid the manufacturing sector’s transition to an Industry 4.0 environment. A new initiative dubbed “Digital Saksham” has been launched by the Confederation of Indian Industry (CII) to encourage and facilitate the use of digital manufacturing techniques in SMEs. The government’s dedication to fostering the expansion and improvement of Industry 4.0 in the country is on full display in these initiatives.

Taking steps like employing a qualified workforce, establishing regulations, training employees, and adopting changes that benefit the SMEs are all examples of how top management can promote and facilitate I4.0 adoption [30]. It is important for top managers to initiate the process of developing a skilled workforce, keeping in mind the requirements of I4.0 implementation. Skill programmes should be aligned with I4.0 enablers, and employees should be trained and motivated to adopt the new work culture, gaining expertise in areas such as data analytics, information technology, machine-human interaction, and computerized machine knowledge [29].

The cost of implementation (E5), customer-centric innovativeness (E11), and data security (E4) emerge as dependent variables in I4.0 adoption. Conducting cost-effective analysis at all levels can act as a driving force [11]. Research and development should be carried out to reduce the overall cost of I4.0 implementation, and data security should be reinforced through advanced information technology infrastructure. Industries should allocate teams to gather insights for each enabler, which will be beneficial in understanding the challenges and opportunities in I4.0 implementation. The achievement of the goal of I4.0 adoption and implementation in Indian SMEs requires collaboration between three key entities, namely the government (represented by the variable “government support” or E1), the industry (represented by the variable “top management commitment” or E7), and academic institutions (represented by the variable “research and development” or E8). The government and industry should work together to establish clear standards and policies that support each other, while the industry and academic institutions should collaborate to gain insight into the specific aspects of I4.0 implementation on a case-by-case basis. Additionally, educational institutions and the government should collaborate to promote and establish labs for the advancement of the implementation of I4.0 aspects.

Limitations: The results obtained from the ISM model are based on the subjective inputs of experts in the relevant field for the formation of the SSIM. This method may result in potential biases in the results. To further validate the findings, it is recommended to perform a more thorough examination of each variable related to I4.0, and to apply structural equation modelling. The study may be quantified using various statistical tools to enhance its validity.

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Strategic Integration of Lean and Six Sigma in Era of Industry 4.0: Navigating the Confluence of Barriers and Enablers

Ashwani Sharma, Bikram Jit Singh, and Rippin Sehgal

1 Introduction

Industry 4.0, also referred to as the Fourth Industrial Revolution, signifies the ongoing digital transformation of the manufacturing and industrial sectors [1]. It represents the convergence of technologies, including artificial intelligence, big data analytics, the Internet of Things (IoT), robotics, and cloud computing, which are reshaping organizational operations and interactions [2]. The evolution of Industry 4.0 can be traced back to previous industrial revolutions, such as the First Industrial Revolution introducing steam power mechanization and the Second Industrial Revolution marking the era of mass production and electricity [3, 4]. The Third Industrial Revolution brought automation and computerization, while Industry 4.0 builds upon these advancements by integrating physical and digital systems, facilitating real-time connectivity, automation, and data-driven decision-making [5]. The benefits of Industry 4.0 are extensive and impact various facets of business operations [2–6]. Enhanced operational efficiency is one of the notable advantages, achieved through the integration of intelligent machines and systems, allowing organizations to optimize production processes, minimize downtime, and reduce waste [7]. Automation and robotics further enable tasks to be executed with heightened speed, accuracy, and consistency [8].

Industry 4.0 also enhances product quality and customization [9]. With the aid of data analytics and IoT, manufacturers can monitor and analyze real-time production data, identify quality issues, and make timely adjustments. This leads to improved

A. Sharma · B. Jit Singh (✉)
Department of Mechanical Engineering, MM Engineering College, Maharishi Markandeshwar Deemed to Be University, Mullana, Haryana, India
e-mail: Chann461@gmail.com

R. Sehgal
Department of Biotechnology, Ambala College of Engineering and Applied Research, Devsthali, Ambala, Haryana, India

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product quality, reduced defects, and the ability to tailor products to individual customer needs. Additionally, Industry 4.0 facilitates predictive maintenance [10]. By leveraging data from sensors and equipment, organizations can proactively identify maintenance needs, schedule repairs, and prevent costly breakdowns. This approach reduces downtime, extends the lifespan of equipment, and optimizes maintenance costs. Furthermore, Industry 4.0 enables supply chain optimization [11]. Through interconnected systems and real-time data exchange, organizations can achieve end-to-end visibility, track inventory levels, streamline logistics, and improve demand forecasting. This results in reduced lead times, better inventory management, and enhanced customer satisfaction. Industry 4.0 also opens up new business models and opportunities [12]. With increased connectivity and digitalization, organizations can offer value-added services, such as remote monitoring, predictive analytics, and software upgrades [13]. This shift from selling products to providing solutions creates new revenue streams and strengthens customer relationships. In nutshell, Industry 4.0 represents a transformative era in manufacturing and industrial sectors, bringing about increased operational efficiency, improved product quality, predictive maintenance, supply chain optimization, and new business models. Embracing these advancements can lead to competitive advantages and sustainable growth for organizations in the digital age.

2 Need of Integration of Lean and Six Sigma (LSS) in Industry 4.0 Period

The integration of Lean and Six Sigma techniques in the Industry 4.0 era is crucial for organizations to fully leverage the benefits and overcome the challenges presented by this digital transformation [14]. Here are the key reasons why the integration of Lean and Six Sigma is necessary:

Operational Excellence: Lean and Six Sigma methodologies have long been recognized as effective approaches for driving operational excellence and process improvement. By integrating these techniques with Industry 4.0 technologies, organizations can optimize their operations, eliminate waste, reduce variability, and enhance overall efficiency. This integration ensures that the advancements brought by Industry 4.0 are effectively utilized to achieve operational excellence goals [15].

Quality Improvement: Lean and Six Sigma have a strong focus on quality improvement. Industry 4.0 technologies provide valuable data and real-time insights that can be utilized to identify and address quality issues more effectively. The integration of Lean and Six Sigma with Industry 4.0 enables organizations to leverage data analytics, IoT, and automation to proactively detect and prevent defects, resulting in higher product quality and customer satisfaction [16].

Data-Driven Decision-Making: Industry 4.0 generates vast amounts of data from various sources across the value chain. Lean and Six Sigma methodologies emphasize the importance of data-driven decision-making. By integrating Lean and Six Sigma with Industry 4.0, organizations can harness the power of data analytics to gain actionable insights, make informed decisions, and drive continuous improvement. This integration allows for more accurate problem-solving and enables organizations to identify patterns, trends, and improvement opportunities [17].

Agility and Adaptability: Industry 4.0 is characterized by its dynamic and rapidly evolving nature. Lean and Six Sigma provide organizations with the tools and mindset to adapt to changes and continuously improve their processes. By integrating these methodologies with Industry 4.0, organizations can foster a culture of agility, embrace innovation, and effectively respond to the changing demands of the market [18].

Employee Engagement and Empowerment: Lean and Six Sigma methodologies emphasize the importance of engaging and empowering employees in the improvement process. In the Industry 4.0 era, where human–machine collaboration is becoming increasingly prevalent, the integration of Lean and Six Sigma ensures that employees are actively involved in utilizing technology, analyzing data, and driving improvement initiatives [19]. This integration enhances employee skills, fosters a culture of innovation, and promotes a sense of ownership and accountability.

In summary, the integration of Lean and Six Sigma (LSS) in the Industry 4.0 era is essential for organizations to optimize operations, improve quality, make data-driven decisions, adapt to changes, and empower employees. This integration allows organizations to effectively harness the power of Industry 4.0 technologies and methodologies to drive continuous improvement and achieve sustainable success in the digital age.

3 Barriers Before LSS in Industry 4.0 Environments

Implementing Lean and Six Sigma (LSS) quality techniques in the Industry 4.0 era comes with its own set of challenges and barriers. Here are some specific challenges organizations may face when integrating LSS in the context of Industry 4.0:

Technological Complexity: Industry 4.0 technologies, such as IoT, big data analytics, and automation, can be complex to implement and integrate with LSS methodologies. Organizations may struggle with selecting and implementing the right technologies, ensuring compatibility and data interoperability, and managing the complexity of interconnected systems [20]. This challenge requires a thorough understanding of both LSS principles and Industry 4.0 technologies, as well as effective project management and technical expertise.

Skill Gaps and Talent Acquisition: Industry 4.0 demands a new skill set, including expertise in data analytics, IoT, and emerging technologies [21]. Organizations may face challenges in acquiring and developing the necessary skills within their workforce to effectively apply LSS techniques in an Industry 4.0 environment. Upskilling and reskilling initiatives, partnerships with educational institutions, and attracting talent with relevant expertise can help address this barrier.

Data Quality and Availability: Industry 4.0 generates massive amounts of data from various sources, but ensuring data quality and availability can be a challenge

[18]. Organizations may encounter issues with data accuracy, completeness, and reliability, as well as data accessibility across different systems and platforms. Robust data governance processes, data cleansing and validation techniques, and investments in data infrastructure are necessary to overcome this barrier [22].

Security and Privacy Concerns: With the increased connectivity and data exchange in Industry 4.0, organizations face heightened concerns regarding cybersecurity and data privacy. Protecting sensitive data, preventing unauthorized access, and ensuring compliance with data protection regulations can be challenging [23]. Implementing robust security measures, conducting regular risk assessments, and establishing clear data governance and privacy policies are essential to address these concerns.

Organizational Alignment and Change Management: Integrating LSS in the Industry 4.0 era requires organizational alignment and effective change management [24]. The convergence of Lean and Six Sigma with digital technologies may require significant shifts in processes, roles, and responsibilities. Resistance to change, cultural barriers, and lack of clarity about the value and benefits of LSS in the Industry 4.0 context can hinder implementation efforts [20]. Effective change management strategies, stakeholder engagement, and a clear communication plan can help overcome these challenges.

Data Overload and Analysis Paralysis: Industry 4.0 generates vast amounts of data, and organizations may struggle with effectively analyzing and utilizing this data for LSS purposes [25]. The sheer volume and complexity of data can lead to analysis paralysis, where organizations struggle to extract meaningful insights. Developing data analytics capabilities, utilizing advanced analytics tools, and focusing on relevant and actionable data are key to addressing this challenge.

Integration of Digital and Physical Systems: Integrating LSS in the Industry 4.0 era requires effectively merging digital and physical systems. This can pose challenges in terms of interoperability, system integration, and ensuring seamless communication between different technologies and processes [26]. Organizations need to develop a clear integration strategy, define data exchange protocols, and establish robust interfaces to enable the smooth flow of information across systems.

Scalability and Flexibility: Industry 4.0 is characterized by its scalability and flexibility, allowing organizations to adapt to changing demands and customize products. However, integrating LSS in this context can be challenging due to the need to balance standardization and customization [27]. Organizations must find ways to incorporate LSS techniques in a flexible and scalable manner, ensuring that processes are optimized while maintaining the ability to quickly respond to customer requirements.

Redefining Roles and Responsibilities: Industry 4.0 introduces new roles and responsibilities, such as data analysts, IoT specialists, and system integrators. Integrating LSS in this context requires redefining roles and responsibilities, aligning them with the evolving technological landscape [28]. Organizations need to assess the skills and competencies required for LSS implementation in the Industry 4.0 era and provide training and development opportunities to bridge any gaps.

Cost and Return on Investment: Industry 4.0 technologies often require significant upfront investments, and organizations may face challenges in justifying these costs and demonstrating a return on investment (ROI) for LSS implementation. It is essential to develop a comprehensive business case that highlights the potential benefits, cost savings, and improved performance resulting from the integration of LSS in the Industry 4.0 environment [11]. Organizations should also establish metrics and monitoring mechanisms to track the progress and measure the impact of LSS initiatives [19].

Regulatory and Compliance Considerations*:* With the integration of Industry 4.0 technologies, organizations need to navigate the regulatory and compliance landscape. Compliance requirements regarding data privacy, intellectual property, and cybersecurity need to be addressed to ensure that LSS implementation aligns with legal and regulatory obligations [15–18]. Organizations should stay updated on relevant regulations and establish appropriate controls and safeguards to mitigate risks.

Overcoming these challenges requires a comprehensive approach that combines expertise in Lean and Six Sigma methodologies with a deep understanding of Industry 4.0 technologies. Organizations should prioritize collaboration, invest in training and development, foster a culture of innovation and adaptability, and continuously monitor and assess the progress of LSS implementation. By addressing these challenges, organizations can effectively integrate LSS in the Industry 4.0 era and achieve sustainable improvements in quality, efficiency, and competitiveness. It involves developing a clear roadmap, investing in technology and skill development, fostering a culture of continuous improvement, and effectively managing change throughout the organization. By overcoming these barriers, organizations can harness the full potential of LSS in the Industry 4.0 era and drive significant improvements in quality, efficiency, and competitiveness.

4 Key Drivers to Implement LSS in Industry 4.0 Epoch

Implementing Lean and Six Sigma (LSS) quality techniques in the Industry 4.0 era is driven by several factors that are specific to this technological landscape. Here are some key drivers for implementing LSS in the context of Industry 4.0:

Technological Advancements*:* Industry 4.0 is characterized by advanced digital technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, and automation. These technologies provide organizations with unprecedented access to real-time data, enabling more accurate process monitoring, predictive maintenance, and data-driven decision-making [29]. Implementing LSS in the Industry 4.0 era leverages these technological advancements to drive continuous improvement and optimize processes.

Enhanced Data Visibility and Analysis*:* Industry 4.0 technologies generate vast amounts of data from various sources, allowing organizations to have greater visibility into their processes. By integrating LSS with Industry 4.0, organizations can leverage advanced data analytics tools and techniques to identify patterns, uncover root causes, and drive targeted improvements [30]. The availability of real-time and historical data facilitates more precise process control and the ability to proactively address quality issues.

Increased Process Automation: Industry 4.0 technologies enable increased process automation, reducing manual intervention and human error [2–5]. By integrating LSS with automation systems, organizations can standardize processes, eliminate variation, and reduce defects. Automation also enables the collection of accurate and reliable data, enables organizations to make data-driven decisions, and implements effective process improvements.

Agile and Flexible Manufacturing: Industry 4.0 promotes agile and flexible manufacturing, allowing organizations to quickly adapt to changing market demands and customer requirements. LSS techniques complement this agile approach by providing a structured methodology to continuously identify and eliminate waste, improve efficiency, and optimize processes [4–9]. Implementing LSS in the Industry 4.0 era enables organizations to achieve both flexibility and operational excellence.

Improved Customer Experience: Industry 4.0 facilitates personalized and customized products and services. By integrating LSS in this context, organizations can ensure consistent quality, reduce defects, and meet customer expectations more effectively [1–3]. LSS techniques such as Design for Six Sigma (DFSS) can help organizations optimize product design and development processes, resulting in products that align with customer needs and preferences.

Scalability and Global Operations: Industry 4.0 enables organizations to scale their operations globally and integrate supply chains seamlessly [17]. Implementing LSS in this era allows organizations to standardize processes across different locations, monitor performance consistently, and drive improvements on a global scale. LSS methodologies provide a common language and approach for process optimization, fostering alignment and consistency in operations [19–25].

Competitive Advantage: Integrating LSS in the Industry 4.0 era provides organizations with a competitive advantage in the market. By leveraging advanced technologies and data analytics, organizations can achieve superior quality, reduced costs, and shorter cycle times [22]. The ability to deliver products and services with speed, precision, and customization gives organizations an edge over competitors.

Risk Mitigation: Industry 4.0 introduces new risks and challenges, such as cybersecurity threats, data privacy concerns, and system integration issues. Implementing LSS in the Industry 4.0 context allows organizations to proactively identify and address potential risks through robust process controls, data security measures, and risk management strategies. LSS methodologies provide a structured approach to risk mitigation and ensure that quality and reliability are embedded in the organization's processes [20–28].

By integrating LSS techniques in the Industry 4.0 era, organizations can harness the power of advanced technologies, data analytics, automation, and agility to achieve operational excellence, deliver superior quality, and drive innovation. The drivers of LSS implementation in the Industry 4.0 era enable organizations to stay ahead in a rapidly evolving digital landscape and gain a competitive edge in the market. This integration allows organizations to optimize their processes, improve product quality, enhance customer satisfaction, and achieve cost savings through increased efficiency and reduced waste [25]. Furthermore, implementing LSS in the Industry 4.0 era helps organizations navigate the complexities and challenges posed by digital transformation. LSS methodologies provide a structured and systematic approach to process improvement, ensuring that organizations can effectively leverage technology while maintaining a focus on quality and efficiency. By integrating LSS with Industry 4.0 technologies, organizations can overcome barriers such as technological complexity, data overload, and security concerns [18, 24, 29].

The combination of LSS and Industry 4.0 also supports the development of a culture of continuous improvement and innovation. The dynamic and interconnected nature of Industry 4.0 necessitates organizations to continuously adapt and optimize their processes to stay competitive. LSS provides the tools and mindset needed to drive continuous improvement initiatives, empower employees, and foster a culture of collaboration and problem-solving. Moreover, the integration of LSS in the Industry 4.0 era facilitates the achievement of broader organizational goals and objectives. It aligns with strategic initiatives such as digital transformation, operational excellence, and customer-centricity. By implementing LSS in conjunction with Industry 4.0, organizations can realize the full potential of their digital investments, maximize operational performance, and drive sustainable business growth. In brief, the drivers to implement LSS in the Industry 4.0 era are rooted in the opportunities and benefits that arise from the convergence of advanced technologies, data analytics, automation and agile manufacturing. By leveraging LSS techniques within this context, organizations can achieve operational excellence, enhance customer satisfaction, gain a competitive edge, mitigate risks and foster a culture of continuous improvement. Integrating LSS in the Industry 4.0 era is essential for organizations seeking to thrive in the digital age and capitalize on the transformative potential of Industry 4.0.

5 Convergence of Barriers and Drivers

The convergence of barriers and drivers in implementing Lean and Six Sigma (LSS) quality techniques in the context of Industry 4.0 represents a complex landscape that organizations must navigate. Understanding the interplay between these barriers and drivers is crucial for successful implementation. Industry 4.0 introduces advanced technologies, such as IoT, AI, and big data analytics, which offer immense potential but also pose challenges. The complexity of implementing and integrating these technologies can be a significant barrier. However, organizations can leverage these same technologies as drivers to support LSS implementation. For example, data analytics can provide insights for process improvement, while automation can enhance efficiency and quality. The abundance of data generated by Industry 4.0 technologies can overwhelm organizations, making data management and integration a barrier. However, by effectively harnessing this data through LSS methodologies, organizations can extract valuable insights to identify improvement opportunities, monitor performance, and make data-driven decisions. The convergence of data overload and LSS-driven data analysis becomes a driver for process optimization.

Implementing LSS in the Industry 4.0 era necessitates organizational change and workforce adaptation. Resistance to change, lack of employee buy-in, and skills gaps can be significant barriers. However, by actively addressing change management and investing in employee training and development, organizations can turn these barriers into drivers. Engaged and skilled employees can embrace LSS methodologies and leverage Industry 4.0 technologies to drive continuous improvement and innovation. The integration of digital and physical systems in Industry 4.0 presents challenges in terms of interoperability, system integration, and communication. This convergence of barriers can impede LSS implementation. However, organizations that prioritize seamless integration and develop strategies to overcome these challenges can leverage the integration of digital and physical systems as a driver for optimizing processes, improving quality, and achieving operational excellence. The upfront costs associated with implementing Industry 4.0 technologies and LSS methodologies can be a barrier for some organizations. However, by demonstrating a clear business case, highlighting potential cost savings, improved quality, and competitive advantages, organizations can turn this barrier into a driver. The potential return on investment, coupled with the long-term benefits of LSS-driven process improvements and Industry 4.0 technologies, can justify the initial investment.

Industry 4.0 introduces new regulatory and cybersecurity challenges, which can act as barriers to LSS implementation. Organizations must navigate compliance requirements, protect data privacy, and ensure robust cybersecurity measures. However, by proactively addressing these challenges, organizations can transform regulatory compliance and cybersecurity considerations into drivers for quality assurance, risk mitigation, and customer trust. The convergence of barriers and drivers in implementing LSS in the Industry 4.0 era requires organizations to approach challenges strategically. By addressing barriers through effective change management, investing in workforce development, leveraging technology integration, and demonstrating the value of LSS and Industry 4.0, organizations can transform these barriers into drivers for sustainable improvements, enhanced competitiveness, and successful implementation of LSS in the context of Industry 4.0.

6 Strategic Frame Work to Formulate LSS 4.0

The integration of Lean, Six Sigma, and Industry 4.0 tools, commonly referred to as LSS 4.0, can provide a strategic framework for effective quality control during the upcoming 4th Industrial Revolution. This strategic framework combines the principles of Lean and Six Sigma with the advanced technologies and capabilities of Industry 4.0. Here are the key components of the 10 step LSS 4.0 framework:

Define the Quality Objectives: Clearly define the quality objectives that align with the organization's overall strategic goals. This includes identifying critical quality parameters, customer requirements, and performance metrics that will guide the quality control efforts.

Identify Improvement Opportunities: Utilize Lean techniques, such as value stream mapping and waste identification, to identify improvement opportunities within the processes. This involves analyzing the current state, identifying bottlenecks, and areas for waste reduction or process optimization.

Implement Lean Principles: Apply Lean principles, such as just-in-time (JIT), continuous flow, and standardized work, to streamline processes and eliminate waste. This involves optimizing workflows, reducing cycle times, and improving overall process efficiency.

Apply Six Sigma Methodologies: Leverage Six Sigma methodologies, such as DMAIC (Define, Measure, Analyze, Improve, Control), to identify and minimize process variations, enhance process capability, and strengthen quality control. This involves statistical analysis, root cause analysis, and the implementation of data-driven improvement initiatives.

Leverage Industry 4.0 Technologies: Integrate advanced technologies from Industry 4.0, such as IoT, AI, big data analytics, and automation, to enhance quality control capabilities. This includes real-time data collection, predictive analytics, remote monitoring, and automated quality control systems.

Data-Driven Decision-Making: Utilize data analytics and visualization tools to collect, analyze, and interpret data in real time. This enables data-driven decision-making, proactive quality control, and the identification of patterns, trends, and anomalies that can impact product quality.

Implement Digital Quality Control Systems: Utilize digital quality control systems, such as digital twin technology, to create virtual representations of products, processes, and quality control systems. This enables simulations, testing, and optimization of quality control strategies before implementation.

Continuous Improvement and Innovation: Promote a culture of continuous improvement and innovation throughout the organization, encouraging active employee participation in problem-solving, idea contribution for process enhancement, and fostering a mindset of lifelong learning.

Collaboration and Cross-Functional Integration: Foster collaboration and cross-functional integration among different departments, such as manufacturing, engineering, quality control, and IT. This ensures alignment, knowledge sharing, and effective implementation of LSS 4.0 initiatives.

Training and Skill Development: Allocate resources toward training and skill development initiatives aimed at equipping employees with the requisite knowledge and skills to effectively utilize LSS 4.0 tools. This includes providing training on Lean, Six Sigma, Industry 4.0 technologies, data analytics, and quality control methodologies.

By integrating Lean, Six Sigma, and Industry 4.0 tools in a strategic framework, organizations can achieve effective quality control, enhance process efficiency, reduce waste, and drive continuous improvement during the upcoming 4th industrial revolution. The LSS 4.0 framework enables organizations to leverage the power of advanced technologies, data analytics, and process optimization methodologies to deliver superior product quality, meet customer expectations, and gain a competitive edge in the rapidly evolving digital landscape.

7 Discussion

The integration of Lean, Six Sigma, and Industry 4.0 tools within the LSS 4.0 framework presents several advantages over traditional quality control approaches. By combining the principles and methodologies of Lean and Six Sigma with the advanced technologies of Industry 4.0, organizations can achieve a more comprehensive and effective approach to quality control in the 4th Industrial Revolution. The utilization of Industry 4.0 technologies such as IoT, AI, big data analytics, and automation enables real-time data collection, analysis, and visualization, providing organizations with valuable insights into their processes. This facilitates proactive quality control, early issue detection, and data-driven decision-making.

Moreover, the LSS 4.0 framework fosters a culture of continuous improvement and innovation by integrating Lean and Six Sigma methodologies with Industry 4.0 technologies. It emphasizes cross-functional collaboration, employee training, and skill development to empower individuals to actively contribute to problem-solving and process improvement initiatives. This inclusive approach enhances employee engagement and ownership, leading to more effective and sustainable quality control practices. In nutshell, the LSS 4.0 framework offers a robust and adaptive approach to quality control in the 4th Industrial Revolution. By leveraging advanced technologies, data analytics, and continuous improvement methodologies, organizations can drive efficiency, improve product quality and gain a competitive edge in the dynamic digital landscape. These facts are well supported by various researchers in their respective studies describe as below:

Enhanced Real-time Monitoring and Control: The integration of Industry 4.0 technologies in the LSS 4.0 framework enables organizations to monitor and control quality-related processes in real-time [30–32]. This real-time visibility allows for proactive identification of quality issues, rapid response to deviations, and immediate corrective actions, leading to improved quality control and reduced defects [33–35].

Predictive Analytics for Quality Improvement: By leveraging advanced analytics and machine learning algorithms within the LSS 4.0 framework, organizations can move from reactive to proactive quality control. Predictive analytics can anticipate potential quality issues, identify critical factors affecting quality, and optimize process parameters to prevent defects and improve overall product quality [36, 37].

Integration of Digital Twin Technology: Digital twin technology, an essential component of Industry 4.0, creates virtual replicas of physical processes and systems. Within the LSS 4.0 framework, digital twin technology allows organizations to simulate and optimize quality control strategies, identify bottlenecks, and test alternative scenarios before implementation, leading to more effective and efficient quality control [38].

Scalability and Flexibility: The LSS 4.0 framework addresses the need for scalability and flexibility in quality control. With the integration of Industry 4.0 technologies, organizations can easily scale quality control practices across different manufacturing sites, adapt to changing market demands, and customize quality control approaches for different products or customer requirements [34].

Enhanced Collaboration and Communication: The LSS 4.0 framework facilitates improved collaboration and communication among various stakeholders engaged in quality control processes. With the use of digital platforms, cloud-based systems, and real-time data sharing, teams can collaborate seamlessly, share insights, and make informed decisions, leading to improved quality outcomes [29].

Integration of Quality Control with Supply Chain Management: Industry 4.0 emphasizes the integration and connectivity of supply chains [39]. By integrating quality control practices within the LSS 4.0 framework, organizations can ensure end-to-end quality management across the entire supply chain, enhance traceability, and minimize quality-related disruptions [40].

By harnessing the benefits of the LSS 4.0 framework, organizations can attain elevated levels of quality control, efficiency, and customer satisfaction within the context of the 4th Industrial Revolution. The integration of Lean and Six Sigma principles with Industry 4.0 technologies offers a comprehensive and data-driven approach to quality control, empowering organizations to excel amidst the dynamic and digitized manufacturing landscape.

8 Conclusions

In conclusion, the manuscript "Strategic Integration of Lean and Six Sigma Quality Techniques in the Era of Industry 4.0: Navigating the Confluence of Barriers and Enablers" highlights the importance of integrating Lean and Six Sigma methodologies with Industry 4.0 technologies for effective quality control in the 4th Industrial Revolution. It explores the challenges, drivers, and the convergence of barriers and enablers in implementing these quality techniques in the context of Industry 4.0. The review emphasizes that organizations need to adopt a strategic approach to overcome the barriers associated with technological complexity, data overload, change management, integration of digital and physical systems, cost, regulatory compliance, and cybersecurity. By addressing these barriers, organizations can harness the drivers offered by Industry 4.0, such as advanced analytics, automation, real-time data collection, and digital twin technology. The proposed framework, LSS 4.0, offers a comprehensive strategy for organizations to navigate the complexities of the 4th industrial revolution. By combining the principles of Lean and Six Sigma with Industry 4.0 technologies, organizations can achieve improved quality control, enhanced process efficiency, and sustainable competitive advantages. The LSS 4.0 framework enables organizations to leverage real-time monitoring, predictive analytics, digital twin technology, scalability, flexibility, collaboration, and supply chain integration. It fosters a culture of continuous improvement and innovation, empowers employees, and enables data-driven decision-making for quality control.

By embracing the strategic integration of Lean and Six Sigma with Industry 4.0, organizations can unlock new opportunities for process optimization, cost reduction, and customer satisfaction. The effective implementation of LSS 4.0 paves the way for organizations to thrive in the era of Industry 4.0 by embracing digital transformation, leveraging advanced technologies, and delivering superior product quality in a rapidly evolving manufacturing landscape. In conclusion, the manuscript underscores the importance of integrating Lean and Six Sigma quality techniques with Industry 4.0 tools and offers valuable guidance for organizations in navigating the challenges and opportunities. It serves as a valuable resource for practitioners, researchers, and decision-makers looking to implement effective quality control strategies in the era of Industry 4.0.

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Enabling a Green Supply Chain with Machine Learning and Industry 4.0: Certain Investigations for Research and Applications

Muskaan Aggarwal, Alok Yadav, and Rajiv Kumar Garg

1 Introduction

A green supply chain is a comprehensive and integrated approach to managing the flow of goods and services that incorporates environmentally responsible and sustainable practices throughout all stages of the supply chain [1]. It is a response to the growing awareness of the impact that business activities have on the environment and the need for businesses to reduce their carbon footprint and minimize waste. The goal of a green supply chain is to minimize the environmental impact of production and distribution, while also improving the efficiency and profitability of the supply chain (SC) as a whole [2]. The implementation of a green supply chain requires a deep understanding of the entire SC, from the sourcing of raw materials to the end-of-life disposal of products. This includes the selection of environmentally friendly suppliers, the use of environmentally friendly production processes, the optimization of transportation and logistics to reduce emissions, and the design of products for end-of-life recycling or disposal [3]. The benefits of a green supply chain go beyond environmental sustainability and can include cost savings, improved brand reputation, increased customer loyalty, and a competitive advantage in the market [4]. By taking a proactive approach to reducing the environmental impact of their operations, companies can also demonstrate their commitment to social responsibility and contribute to the creation of a more sustainable future for the planet [5]. A green supply chain is an essential component of a sustainable business model that seeks to balance economic, social, and environmental considerations in the production and distribution of goods and services. By integrating sustainable practices throughout the entire supply chain, businesses can minimize their impact on the environment, increase efficiency, and contribute to a more sustainable future for all

M. Aggarwal (✉) · A. Yadav · R. K. Garg
Department of Industrial and Production Engineering, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar 144027, India
e-mail: muskaana.ip.20@nitj.ac.in

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[6]. The integration of ML and I4.0 technologies is enabling the creation of a more sustainable and environmentally responsible supply chain [7]. A green supply chain aims to minimize the environmental impact of production and distribution while also improving efficiency and profitability [8]. The implementation of ML and I4.0 technologies can help companies achieve this by providing new and innovative solutions for reducing waste, conserving energy, and reducing the carbon footprint of the products and services we consume. ML algorithms can analyse large amounts of data from various sources to identify trends and patterns, allowing companies to make more informed decisions about the environmental impact of their operations. For example, ML algorithms can be used to optimize transportation and logistics, reducing emissions and fuel consumption. Additionally, ML algorithms can be used to identify waste in production processes, enabling companies to reduce the amount of resources they consume and the waste they generate [7]. The integration of ML and I4.0 technologies has the potential to transform the supply chain into a more sustainable and environmentally responsible system. By leveraging these technologies, companies can reduce their carbon footprint, minimize waste, and conserve energy, contributing to the creation of a more sustainable future for both the planet and future generations [9]. There is a growing trend towards integrating machine learning and I4.0 technologies into GSC management. These technologies are being used to automate supply chain operations, reduce waste and carbon emissions, optimize production processes, and improve the overall sustainability of supply chain operations [10]. Machine learning algorithms are being used to predict supply chain disruptions and optimize routes, while I4.0 technologies are providing real-time data and insights to help companies make more informed decisions about their supply chain operations [11]. The trend towards green supply chain management is driven by a growing awareness of the importance of sustainability and the need to reduce the environmental impact of SC operations. Companies are investing in these technologies to improve the efficiency and resilience of their SC operations while also reducing their carbon footprint and contributing to a more sustainable future. India is at the forefront of the global movement towards a more sustainable and green future, and there have been several recent developments related to enabling a GSC with machine learning and I4.0. Here are some of the key trends and initiatives in India.

Government Support: The Indian government is supportive of the adoption of Industry 4.0 and sustainable technologies and has introduced several initiatives to promote green manufacturing and supply chain practices [12].

Adoption of Machine Learning: Indian companies are increasingly using machine learning and artificial intelligence to optimize their supply chains and reduce their environmental impact. For example, machine learning algorithms can help to optimize transportation routes and reduce the carbon footprint of supply chain operations [7].

Focus on Sustainable Manufacturing: Companies in India are placing a greater emphasis on sustainable manufacturing practices, such as reducing waste, conserving energy, and minimizing their carbon footprint [13].

Increase in Eco-friendly Logistics: Companies are investing in eco-friendly logistics solutions, such as electric vehicles and sustainable transportation methods, to reduce the environmental impact of their supply chain operations [14].

Partnerships with Sustainable Suppliers: Indian companies are partnering with sustainable suppliers to ensure that the products and materials used in their supply chains are produced in an environmentally responsible manner [5].

Investment in Clean Energy: Companies are investing in clean energy solutions, such as renewable energy and energy-efficient technologies, to power their operations and reduce their carbon footprint [15].

India is taking significant steps towards enabling a green supply chain with machine learning and Industry 4.0, with companies and the government working together to create a more sustainable and environmentally responsible future. With continued investment and innovation, India has the potential to become a leader in sustainable SC management. The aim of this review is to investigate the research trends and patterns in the area of Industry 4.0 and machine learning, with a focus on their application to green supply chains. The review will explore how these technologies interact to create a more sustainable and efficient supply chain. The present study has formulated the following research question (RQ), taking into account the factors mentioned above.

RQ1. What are the trends of publications in the research related to machine learning and I4.0 in the context of the GSC?

RQ2. What are the challenges and limitations in this area?

The remaining study is structured as follows: Sect. 2 presents the literature review, Sect. 3 outlines the methodology used in the study, Sect. 4 presents the study's results and discussions, and lastly, Sect. 5 presents the conclusion.

2 Literature Review

The integration of machine learning and I4.0 technologies into GSC management has received significant attention in the academic literature. In recent years, there has been a growing body of research examining the role of these technologies in improving the sustainability of supply chain operations [16]. A study focused on the use of machine learning algorithms to optimize supply chain operations, such as reducing waste and carbon emissions. For example, researchers have explored the use of predictive analytics to identify and mitigate supply chain risks, such as disruptions and inefficiencies [17]. Other studies have focused on the use of I4.0 technologies, such as "smart manufacturing" and the "Internet of Things", to optimize production processes and reduce environmental impact. A study exploring the benefits of green supply chain management, such as improved efficiency, increased competitiveness, and enhanced reputation [12]. Researchers have investigated the impact of these benefits on a variety of stakeholders, including companies, consumers, and the environment. According to a study, the integration of machine learning and I4.0 technologies into GSC management can have significant positive impacts, including reduced waste and carbon emissions, improved efficiency, and enhanced sustainability. However, there are also challenges associated with the adoption of these technologies, such as the need for investment, the risk of data breaches, and the potential for increased complexity. The existing literature highlights the potential benefits of integrating machine learning and I4.0 technologies into green supply chain management, while also acknowledging the challenges that must be overcome. Further research is needed to fully understand the impact of these technologies on the sustainability of SC operations and to identify best practices for their implementation.

There have been several studies that explore the relationship between machine learning and I4.0 technologies and green supply chain management. These studies have found that the use of these technologies can lead to improved supply chain performance and increased sustainability by reducing waste, improving resource utilization, and reducing carbon emissions. For example, machine learning algorithms can be used to optimize supply chain routes, reducing transportation costs and emissions, while Industry 4.0 technologies can provide real-time data and insights that can be used to improve production processes and reduce waste. The finding of the study explains that collaboration and partnerships in enabling a green supply chain with machine learning and Industry 4.0. Research has found that companies that collaborate with suppliers and customers can improve supply chain performance and sustainability by sharing data and resources, reducing waste, and promoting sustainable practices. For example, companies can collaborate to improve logistics and transportation, reducing emissions and improving supply chain resilience.

Table 1 shows the existing study represented by different authors with their area of focus and findings. The literature highlights the potential benefits of integrating machine learning and Industry 4.0 technologies into green supply chain management, as well as the importance of collaboration and the use of digital technologies in enabling this integration. These technologies have the potential to improve SC performance and sustainability, but there are also challenges that must be overcome, such as the need for investment, the risk of data breaches, and the potential for increased complexity. Further research is needed to fully understand the impact of these technologies on the sustainability of SC operations and to identify best practices for their implementation.

Table 1 Existing study with a focus area and findings [12, 18–22]

Authors	Focus area	Findings
[18]	Logistics industry	It has been found that predictive analytics can help improve the sustainability of supply chains in the logistics industry, by predicting demand and reducing waste
[19]	Construction industry	The investigation found that I4.0 technologies can help improve the sustainability of SC in the construction industry, by improving supply chain visibility and reducing waste
[20]	Agricultural industry	The study found that integrating I4.0 technologies and GSC management practices can help improve the sustainability of supply chains in the agricultural industry, by reducing waste and improving the use of sustainable energy sources
[12]	Food and beverage industry	The study builds that integrating Industry 4.0 technologies into logistics operations can help improve the sustainability and efficiency of supply chains in the food and beverage industry, by reducing waste and improving supply chain visibility
[21]	Automotive industry	The study found that the use of machine learning algorithms could help improve the efficiency and sustainability of supply chains in the automotive industry, by optimizing supply chain operations and reducing waste
[22]	Consumer goods industry	The study found that I4.0 technologies can have a significant impact on the sustainability of SC in the consumer goods industry, by improving supply chain visibility, reducing waste, and increasing the use of renewable energy sources

3 Methodology

A bibliometric analysis is a statistical approach to analysing scientific publications, like articles, conference papers, journal articles, and book chapters, of a specific author [3]. The most commonly used databases for this purpose are "Web of Science", "Scopus", and "Google Scholar", with Scopus being the most popular. This study uses the Scopus database. In this analysis, a search was performed using the terms "Industry 4.0", "machine learning", "supply chain", and "sustainable supply chain", resulting in 113 items. To refine the results, certain inclusion criteria were applied, such as limiting the language to English and choosing a journal or conference papers from all years. The types of documents considered were articles, conference papers, and reviews. After applying the inclusion criteria, 80 results were obtained, most of which were articles.

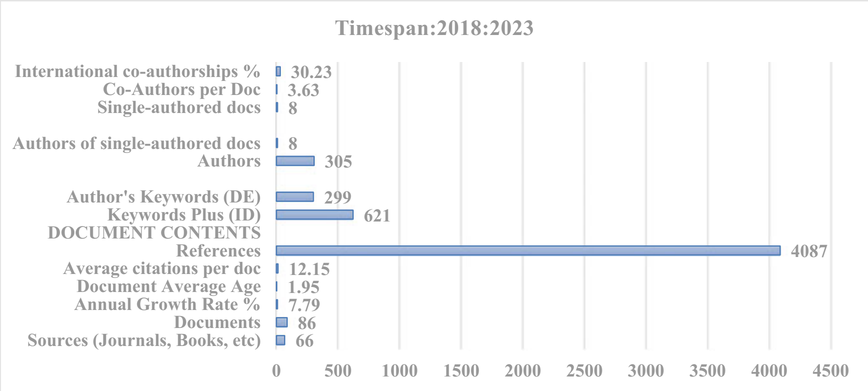

Fig. 1 Main information of studies

4 Result and Discussion

4.1 Main Information

Figure 1 depicts the basic statistics of the study.

4.2 Annual Publication Trends

In Fig. 2, the graph represents the annual trend in the publication of research papers on Machine learning from 2018 to February 11, 2023. The graph depicts an upward trend in the number of research papers published each year. It can be seen that there is a gradual increase in the number of publications on this in recent years. It is noteworthy that the year 2021 has seen a significant surge in the number of published papers, which is more than twice the number of papers published in the preceding years of 2019 and 2020. This trend indicates that the research interest in machine learning is on the rise and is becoming an increasingly relevant field for researchers to explore. This is likely due to the growing demand for machine learning applications in various industries such as health care, finance, and transportation, among others. The graph in Fig. 1 demonstrates the increasing importance of machine learning as a field of study and research, and it highlights the growth in the number of publications related to this topic.

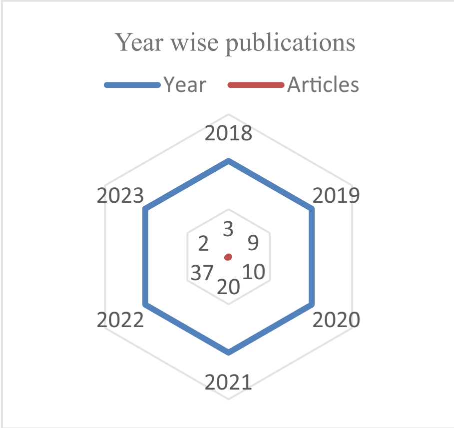

Fig. 2 Annual publication trends

4.3 *Most Productive Author*

Table 2 provides information about the most productive authors in the research area of Machine learning and sustainable supply chain. Table 2 displays the names of these authors and the number of research papers they have published in this field. The analysis of the data indicates that the top six most productive authors in this field are “Caiado, R.G.G.”, “Garza-Reyes, J.A.”, “Scavarda, L.F.”, Stal-Le Cardinal, J., Zhou, R., and de Paula Vidal, G.H. Each of these authors has published two papers in this area. These authors may have achieved high productivity due to their expertise, research experience, or resources available to them. Their research could have made significant contributions to the advancement of machine learning and sustainable supply chain studies and may have helped to identify new trends, challenges, and opportunities in this field.

Table 2 Most productive authors

Serial No.	Author name	No. of publications
1	Caiado, R.G.G	2
2	Garza-Reyes, J.A	2
3	Scavarda, L.F	2
4	Stal-Le Cardinal, J	2
5	Zhou, R	2
6	de Paula Vidal, G.H	2
7	Abbas, Q	1
8	Abd Elghany, M	1
9	Abouloifa, H	1
10	Ada, N	1

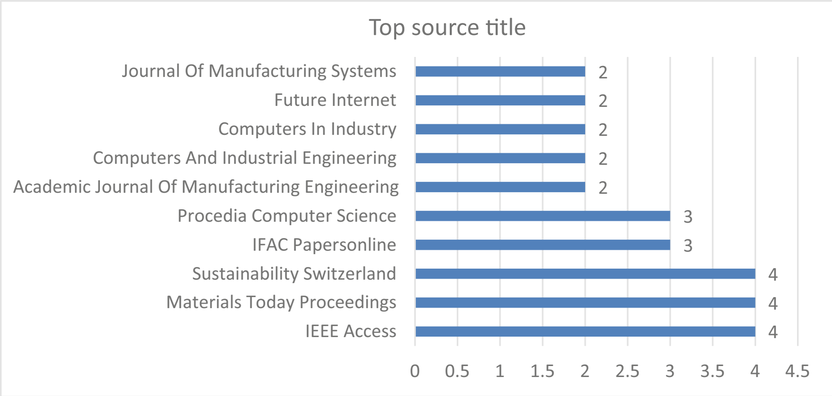

Fig. 3 Top ten source titles

4.4 Top Ten Sources of Publications

Figure 3 illustrates the statistics of the most productive sources in the world. The graph represents the top sources and the number of published documents by each source. The sources with the highest number of publications have been identified and ranked according to their productivity. The data reveals that IEEE Access, Materials Today Proceedings, and Sustainability Switzerland are the top sources with four published documents in their particular research areas. These sources stand out from others in terms of their high productivity and are therefore considered to be the most prolific in the world. IEEE Access is a peer-reviewed, open-access scientific journal that covers a wide range of research areas, including engineering, technology, and computer science. Materials Today Proceedings is an online platform that provides a comprehensive overview of the latest scientific research in the field of materials science. Sustainability Switzerland is a journal that aims to publish original research in the area of sustainable development and sustainability science. The productivity of these sources can be attributed to the quality of their editorial processes, the high impact of their publications, and the support provided to authors by these sources. The number of documents published by these sources indicates their dedication and commitment to advancing research in their respective fields.

4.5 Top Affiliations

Table 3 displays the top affiliations in terms of their research productivity. It indicates that despite being developing countries, Morocco and India have produced research of considerable quality. In particular, Hassan II University of Casablanca from Morocco has published the highest number of papers, with three, while "Dr. B.R. Ambedkar

Table 3 Top affiliations of their respective country

Serial No.	Affiliation	Publications	Country	Developed/ Developing
1	Hassan II University of Casablanca	3	Morocco	Developing
2	"Dr. B.R. Ambedkar National Institute of Technology"	2	India	Developing
3	Jamia Millia Islamia	2	India	Developing
4	Universidade de Aveiro	2	Portugal	Developed
5	Pontifícia Universidade Católica do Rio de Janeiro	2	Brazil	Developing
6	Université Paris-Saclay	2	France	Developed
7	Vellore Institute of Technology, Chennai	2	India	Developing
8	CentraleSupélec—Paris-Saclay	2	France	Developed
9	The Institute of Technology and Business in Ceske Budejovice	1	Czechia	Developed
10	Nelcast Ltd	1	India	Developing

National Institute of Technology in India" comes in second with two publications. This reveals the significant contributions of these affiliations toward the advancement of knowledge in their respective fields. The inclusion of two more Indian affiliations on the list further highlights the country's commitment to research and its capacity to produce high-quality research. The table underlines the crucial role of affiliations in developing countries in advancing research and contributing to the global knowledge base.

4.6 Top 10 Keywords

Figure 4 displays the most frequently used keywords in publications related to sustainable SC in I4.0. The analysis reveals that the most commonly used keyword is "Industry 4.0," appearing 55 times in the documents. The next most frequently used keyword is "machine learning," with a frequency of 44, followed by "supply chain." In contrast, keywords such as "engineering education," "forecasting," and "decision-making" have lower frequencies in the documents.

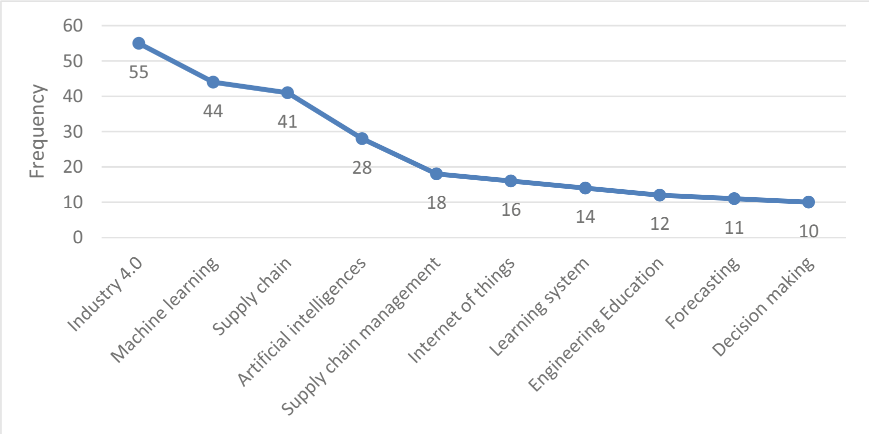

Fig. 4 Topmost used keywords

4.7 Three-Field Plot

A three-field plot shown in Fig. 5, also known as a ternary plot, is a graph used to display the relative proportions of three variables. In this study, a three-field plot can be used to visualize the relative proportions of publications in terms of author, keyword, and country. In such a plot, each axis represents one of the variables being compared, and the points on the plot represent the relative proportions of each variable for each publication. The location of a point on the plot indicates the proportional contribution of the corresponding author, keyword, and country to the overall publications in the field. For example, the location of a point on the plot might indicate that a particular publication was authored by an author from India, with a focus on sustainable supply chain and using the keyword "machine learning." The locations of multiple points on the plot, trends, and patterns can be identified in terms of the most active authors, commonly used keywords, and influential countries in a particular field of research.

4.8 Top Ten Countries' Production

Table 4 provides a breakdown of the number of publications on Industry 4.0 by country. The table highlights that India has the highest number of publications in the field, with 19 results, indicating the country's significant contribution to research in this area. The United States follows closely behind with 15 results, suggesting a strong research presence in the field. Notably, the table reveals that both developed and developing countries are actively publishing research on Industry 4.0, suggesting a global interest in this area. The table underlines the importance of cross-national

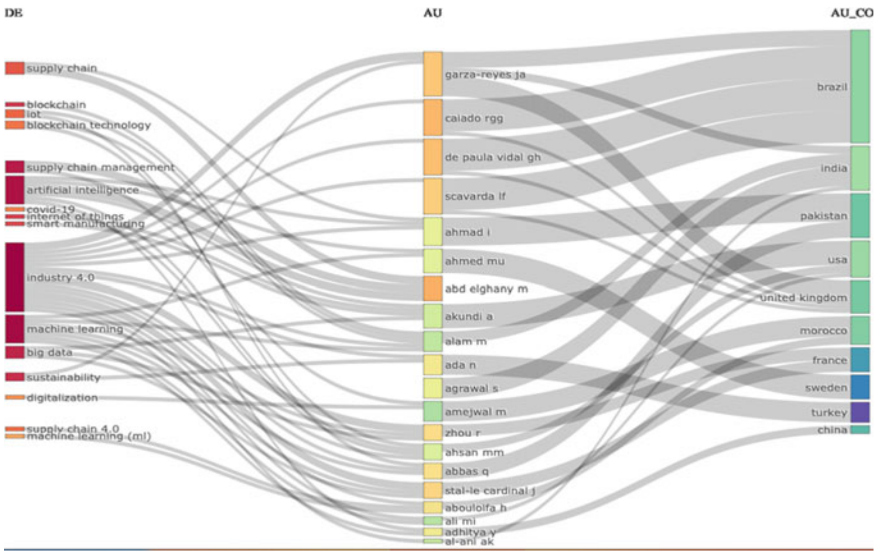

Fig. 5 Relation between three different variables

collaborations and exchange of knowledge to advance research and contribute to the global knowledge base.

RQ2*. What are the challenges and research gaps in this field?*

The field of enabling a green supply chain with machine learning and Industry 4.0 technologies faces several environmental challenges that need to be addressed. Some of the major environmental challenges include:

- *Climate Change*: Climate change is a major challenge that affects the entire planet, including supply chains. There is a need to develop machine learning algorithms

Table 4 Top countries with publications

Serial No.	Country	Results	Developed/Developing
1	India	19	Developing
2	United States	15	Developed
3	Brazil	6	Developing
4	Morocco	5	Developing
5	United kingdom	5	Developed
6	France	4	Developed
7	Iran	4	Developing
8	Australia	3	Developed
9	Canada	3	Developed
10	China	3	Developed

that can help companies to reduce their carbon footprint and to transition to more sustainable practices.

- *Resource Depletion*: Many of the raw materials and resources used in the production of goods are becoming increasingly scarce. There is a need to use machine learning to better manage and optimize the use of these resources, as well as to reduce waste and increase efficiency.
- *Biodiversity Loss*: The loss of biodiversity is a major environmental challenge that affects ecosystems, species, and the services they provide. There is a need to use machine learning to better understand the impact of supply chains on biodiversity and to develop strategies to mitigate these impacts.
- *Environmental Degradation*: Supply chains often involve activities that result in environmental degradation, such as deforestation, soil erosion, and air and water pollution. There is a need to use machine learning to better understand the environmental impact of supply chains and to develop strategies to mitigate these impacts.
- *Waste Management*: Supply chains generate large amounts of waste, including packaging materials, paper, and electronic waste. There is a need to use machine learning to better manage and reduce waste in supply chains, as well as to increase recycling and reduce the environmental impact of waste.

There are several environmental challenges related to the field of enabling a green supply chain with machine learning and Industry 4.0 technologies that need to be addressed. By using machine learning and Industry 4.0 technologies to better understand and mitigate these challenges, it will be possible to create a more sustainable and environmentally responsible supply chain that benefits both businesses and the environment. The following are some of the research gaps in the field of enabling a green supply chain with machine learning and I4.0:

- *Integration of I4.0 Technologies with Existing SC Systems*: There is a need for research to develop strategies for the seamless integration of Industry 4.0 technologies with existing supply chain systems, to ensure that companies can adopt these technologies more easily and effectively.
- *Development of Effective Machine Learning Algorithms*: There is a need for research to develop machine learning algorithms that can effectively analyse and optimize supply chain operations, taking into account the complex and dynamic nature of SC.
- *Education and Training of Supply Chain Professionals*: There is a need for ongoing education and training programs to help supply chain professionals understand and effectively implement I4.0 technologies and ML in their operations.
- *Assessment of the Environmental Impact of I4.0 Technologies*: While I4.0 technologies have the potential to improve the sustainability of supply chains, there is a need for research to assess their environmental impact and to ensure that they are being implemented in a sustainable manner.
- *Evaluation of the Economic Benefits of I4.0 Technologies*: There is a need for research to evaluate the economic benefits of I4.0 technologies and ML, to help companies make informed decisions about their adoption and implementation.

- *Integration of I4.0 Technologies Across the Entire SC*: There is a need for research to develop strategies for the integration of I4.0 technologies across the entire SC, including "suppliers", "manufacturers", "distributors", and "customers".

These research gaps highlight the need for ongoing research and development in this field, to help create a more sustainable and environmentally responsible future for supply chains.

5 Conclusions

This study delves into the trends in research related to machine learning in Industry 4.0 and identifies numerous opportunities for authors in this field. Over the years, there has been a substantial increase in the number of published articles, with a marked rise in 2022 in comparison with the previous years. This suggests a growing interest in the area of sustainable machine learning. In total, 81 documents were analysed, and it was found that there was a higher proportion of journal articles compared to conference papers. The field of developing a GSC with the help of I4.0 technologies and machine learning is a critical and rapidly evolving area of research and development. By leveraging the power of these technologies, it is possible to create a more sustainable and environmentally responsible supply chain that benefits both businesses and the environment. However, there are several challenges that need to be addressed, including the integration of I4.0 technologies with existing systems, the development of machine learning algorithms that can effectively analyse and optimize supply chain operations, and the need to educate and train supply chain professionals on the use of these technologies. To overcome these challenges and create a more sustainable future for supply chains, ongoing research, and development, as well as investment in education and training, will be necessary. Future research in this field should focus on developing strategies to address the challenges, such as the development of new machine learning algorithms that can effectively analyse and optimize supply chain operations and the integration of I4.0 technologies with existing systems in an efficient and effective manner. It is also recommended that future research should emphasize the education and training of supply chain professionals to promote the widespread adoption and effective utilization of these technologies.

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Enhancing Supply Chain Sustainability Through Industry 4.0 and Additive Manufacturing Technologies: A Bibliometric-Based Review

Amisha Attri, Alok Yadav, and Rajiv Kumar Garg

1 Introduction

AM, also "known as 3D printing", "refers to the process of creating three-dimensional objects by building up layers of material" [1, 2]. Unlike traditional manufacturing processes such as injection molding or machining, which involve cutting or shaping material to create a final product, additive manufacturing builds objects by adding material layer by layer [3]. This allows for the creation of complex and customized objects, without the need for extensive tooling or setup. AM can be used to produce a wide range of products, including prototypes, end-use parts, and finished products [4]. It is used in a variety of industries, including aerospace, medical, and automotive, among others [5]. The key benefits of additive manufacturing include reduced lead times, increased design flexibility, improved product performance, and reduced waste. Additionally, additive manufacturing can reduce the need for excessive production runs, reducing the waste of raw materials and energy [6]. With the continuous advancements in technology, additive manufacturing is becoming increasingly accessible and is poised to play an important role in the future of manufacturing and product development. The role of additive manufacturing and I4.0 in a sustainable supply chain (SSC) is to reduce waste, increase efficiency, and improve sustainability performance [7]. These technologies can help organizations to create a more sustainable supply chain by reducing waste through just-in-time production, reducing transportation costs through localized production, and improving the use of materials through advanced production techniques [8]. Industry 4.0 technologies can provide organizations with real-time data and insights into their supply chain operations, enabling them to make informed decisions and optimize their processes [9]. By providing greater visibility and control over supply chain operations, Industry

A. Attri (✉) · A. Yadav · R. K. Garg
Department of Industrial and Production Engineering, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar 144027, India
e-mail: amishaa.ip.20@nitj.ac.in

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4.0 technologies can help organizations to reduce waste and improve sustainability performance. Additive manufacturing, through its ability to produce only what is needed and its ability to produce complex and customized products, can help organizations to reduce waste and improve sustainability performance [10]. By reducing the need for excessive production runs, additive manufacturing can help organizations to reduce the waste of raw materials and energy [11]. The role of additive manufacturing and I4.0 in a SSC is to provide organizations with the tools and technologies needed to create a more sustainable, efficient, and flexible supply chain [5]. These technologies have the potential to reduce waste, increase efficiency, and improve sustainability performance, helping organizations to meet the increasing demands for sustainable supply chain practices [12]. The modern business environment is characterized by increasing pressure to enhance sustainability in supply chain operations [13]. The implementation of I4.0 technologies and the growing prominence of additive manufacturing has provided organizations with new opportunities to reduce waste and increase efficiency. In this context, it is important to examine the role that these technological advancements play in promoting sustainability in supply chain management [14]. This bibliometric-based review aims to provide a comprehensive overview of the current state of research in the area of enhancing SC sustainability through I4.0 and additive manufacturing technologies. The review will explore the current literature, identify the most frequently cited authors, organizations, and journals, and discuss the key findings and recommendations for future research. The objective of this review is to provide valuable insights for organizations and researchers looking to understand the impact of I4.0 and additive manufacturing on SC sustainability.

By keeping the above things in mind, the following research question has been defined for the present study.

RQ1. What are the trends of publications in the research related to I4.0 and additive manufacturing technologies in the context of SC sustainability?

RQ2. What are the challenges and limitations in this field of research?

The findings of this review will provide valuable insights for organizations looking to enhance their supply chain sustainability performance. This review will serve as a valuable resource for academics, practitioners, and policy-makers interested in understanding the impact of I4.0 and additive manufacturing technologies on SC sustainability. By providing a comprehensive overview of the current state of research in this field, this review will contribute to the development of a more sustainable and efficient supply chain sector.

The remainder of the research is organized in the following way: Sect. 2 provides an overview of the pertinent literature; Sect. 3 outlines the approach used in the study; Sect. 4 offers an analysis of the study's discoveries and subsequent discussion; and Sect. 5 offers a synopsis and conclusive remarks on the study's results and implications.

Table 1 Existing literature on AM and I4.0 in SCM

Authors	Type of study	Findings
[15]	A systematic review	This study found that I4.0 technologies such as the “Internet of Things (IoT)”, “Big Data analytics”, and “cloud computing” have a significant positive impact on supply chain sustainability by reducing waste, improving efficiency, and enhancing transparency
[16]	A literature review	This review found that additive manufacturing can contribute to sustainability in supply chains by reducing lead times, reducing waste, and enabling local production
[17]	A review	The study found that I4.0 technologies can support the integration of sustainability considerations into SC management processes
[18]	A literature review	This review found that AM has the potential to reduce waste and energy consumption, and improve product performance. However, the authors also noted that further research is needed to fully understand the sustainability implications of AM
[19]	A comprehensive review	This study found that I4.0 technologies have the potential to contribute to SSC management by improving visibility, reducing waste, and enabling more efficient use of resources

2 Existing Review

There has been a significant amount of study in the field of enhancing SC sustainability through the use of I4.0 and additive manufacturing technologies. A number of studies have investigated the potential benefits and challenges of these technologies in the context of SSC management. In terms of AM, a study has found that 3D printing has the potential to reduce waste and improve product performance, while also enabling local production [2]. Collaboration and partnerships have been identified as key factors in enhancing supply chain sustainability in the context of I4.0 and additive manufacturing technologies [14]. Table 1 represents the existing studies related to this area.

3 Methodology

Bibliometric analysis is a method that helps in evaluating the statistical impact of scientific documents such as books, articles, conference papers, or chapters [20]. It is a tool used by researchers to assess how much a scientific document has influenced the scientific community.

To perform bibliometric analysis, researchers typically utilize databases like “Scopus”, “Web of Science”, and “Google Scholar”. Out of these databases, Scopus and Web of Science are considered to be of higher quality and more widely used [21]. The authors of this study used the Scopus database for their analysis. When conducting the bibliometric analysis, the authors used search terms such as “Industry 4.0,” AND “Additive manufacturing,” AND “Supply chain,” OR “Sustainable supply chain OR Green supply chain” to search for articles, keywords, and titles. These search terms were chosen because they are related to the study’s topic, and the authors wanted to find documents that match their research interests. The search using the Scopus database resulted in 82 documents being found, which met the criteria set by the authors. These documents could then be further evaluated and analyzed to determine their impact on the scientific community.

4 Result and Discussions

4.1 Discussion on Current Developments in Publications

RQ1. What are the trends of publications in the research related to I4.0 and additive manufacturing technologies in the context of SC sustainability?

4.1.1 The Yearly Increase in the Publications works/The Yearly Expansion in the Publication Output

Figure 1 displays the trends over the years in terms of the number of published research papers. The data shown in Fig. 1 covers the period from 2008 to 2022. The first research paper was published in 2008, and the number of publications remained relatively low until 2019 when there was a sudden increase with the publication of 8 papers. This trend continued in 2020. The growth in publications can be attributed to the increased interest and investment in advanced data on the supply chain as a part of Industry 4.0, with industrialists incorporating advanced digital technologies such as cognitive planning and AI-based systems. The number of published research papers continued to increase in 2021, with a jump to 19 and reached a peak of 22 in 2022.

4.1.2 The 10 Most Commonly Used Keywords

Table 2 lists the top 10 keywords associated with additive manufacturing and sustainable supply chain in the context of Industry 4.0. It shows that the most frequently used keyword is “Industry 4.0,” with 48 occurrences, followed by “Additive manufacturing,” with 26 occurrences, and “3D printers,” with 25 occurrences. The keyword “Supply chain” also appeared frequently, with 24 occurrences. However, some popular keywords like “3D printing,” “Circular economy,” and “Industrial research” had a low number of occurrences, with only 8 each.

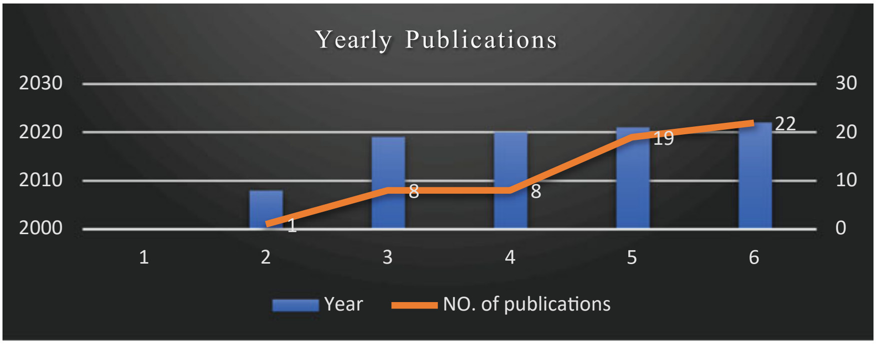

Fig. 1 Yearly trends of publications

Table 2 Top 10 keywords occurrence [2]

Serial no	Keywords	No. of occurrence
1	Industry 4.0	48
2	Additive manufacturing	26
3	3D printers	25
4	Supply chain	24
5	Additives	17
6	Supply chain management	16
7	Internet Of Things	10
8	3D printing	8
9	Circular economy	8
10	Industrial research	8

In Table 3, the data shows the analysis of the top 10 affiliated sources reveals that Germany, being a developed country, leads in terms of a number of publications with contributions from Fachhochschule Flensburg (3 documents), Universität Kassel (3 documents), and Roland Berger (1 document). India and Malaysia, both developing nations, have a combined total of 5 published works, with India contributing 4 from two institutions (Dayalbagh Educational Institute and Indian Institute of Technology Delhi) and Malaysia having 1 from the International Islamic University Malaysia (IIUM). Italy has a total of 6 publications from 3 different institutions, and Scotland has 2 from Politecnico di Milano.

4.1.3 Top 10 Countries with Number of Publications

Table 4 lists the top 10 countries that are engaged in additive manufacturing within Industry 4.0. Italy, as a developed country, leads the pack with 11 documents, followed by India with 10 and Germany with 9. The United Kingdom and the United

Table 3 Top 10 organizations with the number of publications [3]

Serial No.	Affiliation	No. of documents	Country	Developed/Developing
1	Fachhochschule Flensburg	3	Germany	Developed
2	Universität Kassel	3	Germany	Developed
3	Università degli Studi di Modena e Reggio Emilia	2	Italy	Developed
4	Dayalbagh Educational Institute	2	India	Developing
5	Politecnico di Milano	2	Italy	Developed
6	University of Strathclyde	2	Scotland	Developed
7	Universita degli Studi di Urbino Carlo Bo	2	Italy	Developed
8	Indian Institute of Technology Delhi	2	India	Developing
9	IIUM	1	Malaysia	Developing
10	Roland Berger	1	Germany	Developed

States each have 8 and 7 documents, respectively. China and Brazil have 4 and 3 documents, respectively. Canada, Egypt, and Malaysia are tied with 2 documents each. It is noteworthy that India, Brazil, Egypt, and Malaysia are developing countries and are currently making efforts to advance their additive manufacturing capabilities in the Industry 4.0 era. On the other hand, the rest of the countries are considered well-developed. Additionally, it is clear that Italy is making considerable progress in the field of additive manufacturing research, which could potentially benefit their industries.

Table 4 Countries-wise publications

Serial no	Country	Documentation	Developed/Developing
1	Italy	11	Developed
2	India	10	Developing
3	Germany	9	Developed
4	United Kingdom	8	Developed
5	United States	7	Developed
6	China	4	Developed
7	Brazil	3	Developing
8	Canada	2	Developed
9	Egypt	2	Developing
10	Malaysia	2	Developing

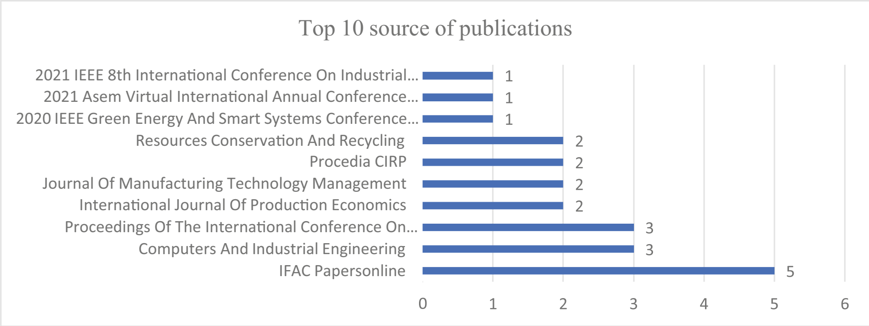

Fig. 2 Top 10 sources of publications

4.1.4 Top 10 Sources of Publications

In Fig. 2, the number of documents is based on the source title. The source with the highest number of documents is IFAC Papers online, with 5 documents. Next, Computers and Industrial Engineering and “Proceedings of the International Conference on Industrial Engineering and Operations Management” have 3 documents each. After that, the “International Journal of Production Economics”, “Journal of Manufacturing Technology Management”, Procedia CIRP, and Resources Conservation and Recycling all have the same number of documents, which is 2. Lastly, the sources with only 1 document each include the 2020 IEEE Green Energy and Smart Systems Conference, the 2021 “ASEM Virtual International Annual Conference on Engineering Management and the New Normal”, and the 2021 IEEE 8th International Conference on Industrial Engineering and Applications.

4.1.5 Word Cloud of Author’s Keywords

Figure 3 shows a word cloud of authors’ keywords which displays the most common words or phrases found in a set of text or documents in a visually appealing way, where the most frequently used words appear bigger and bolder. The top position in this word cloud is taken by Industry 4.0, followed by additive manufacturing and 3D printing. The purpose of this representation is to quickly identify the central themes or subjects in the text, providing users with a general understanding of the content without having to read every document in full.

RQ2. What are the challenges and limitations in this field of research?

There are several challenges associated with the adoption of additive manufacturing and I4.0 technologies in a green supply chain:

- High Cost of Investment: Adopting I4.0 and AM technologies can be expensive, requiring significant investments in infrastructure, hardware, and software. This can be a barrier to adoption, particularly for smaller organizations [8].

Fig. 3 Word cloud of the author's keywords

- Skills Gap: Implementing I4.0 and AM technologies requires a high level of technical expertise. There may be a shortage of skilled workers, which can make it difficult for organizations to adopt these technologies [9].
- Resistance to Change: Change can be difficult, and there may be resistance to the adoption of new technologies within organizations. This can include resistance from employees, as well as resistance from established systems and processes [22].
- Security and Privacy Concerns: I4.0 technologies, such as the "IoT" and "Big Data analytics", generate large amounts of data that need to be stored and processed securely. There are concerns about the security and privacy implications of these technologies, and organizations need to ensure that they are able to protect sensitive data [23].
- Environmental Impact: Additive manufacturing can consume large amounts of energy and generate waste, which can have negative environmental impacts. Organizations need to ensure that they are using additive manufacturing in a sustainable and responsible manner [11].
- Regulations and Standards: There is a lack of clear regulations and standards for the use of Industry 4.0 and additive manufacturing technologies, which can make it difficult for organizations to adopt these technologies [24].

The limitations of adopting additive manufacturing and Industry 4.0 technologies in a green supply chain include:

- Technical Limitations: Additive manufacturing technologies are still in the early stages of development, and there are technical limitations that need to be addressed before they can be adopted more widely in a green supply chain. For example, the range of materials that can be used in additive manufacturing is still limited, and some materials may not be suitable for specific applications [12].

- Cost: Additive manufacturing can be more expensive than traditional manufacturing processes, particularly for larger parts. This can make it difficult for organizations to compete with traditional manufacturing methods [1].
- Lack of Standardization and Certification: AM is still a relatively new technology, and there is a lack of standardization and certification in the industry. This can make it difficult for organizations to adopt these technologies, as they may be unsure of the quality and reliability of the parts produced [8].
- Recycling and Disposal: Additive manufacturing produces waste in the form of unused material and failed prints, and there is a need to address the recycling and disposal of this waste in a way that is consistent with the principles of a green supply chain [13].
- Lack of Understanding: There is a lack of understanding of the potential benefits and limitations of additive manufacturing for green supply chain, and organizations need to be aware of these when considering adoption of these technologies [25].

5 Conclusion

This research adds to the growing body of literature on additive manufacturing in I4.0. For most authors, this topic is considered a new and emerging area of study. The number of research articles in this field is rapidly increasing, with a higher number of articles being published in 2020 compared to previous years. This trend shows that researchers are becoming increasingly interested in the sustainability of Industry 4.0. Italy, as a developed country, has the most published documents, while India, as a developing country, has the highest number of articles published. The majority of authors are from Germany. This study found a total of 20 documents, including conference proceedings papers, with IFAC Papers online having the highest number of publications. However, it is anticipated that the number of documents in this field will continue to grow in the coming years. It is suggested that conference papers be considered in future bibliometric analysis studies, while the adoption of Industry 4.0 and additive manufacturing technologies in a green supply chain has the potential to contribute to a more sustainable supply chain, and there are also challenges that need to be addressed in order to realize these benefits. Organizations need to be aware of these challenges and take a proactive approach to address them in order to fully realize the potential of these technologies. The study suggests that while there are significant challenges and limitations associated with the adoption of Industry 4.0 and additive manufacturing in a green supply chain, there are also significant opportunities to enhance sustainability and improve supply chain efficiency. Organizations need to carefully consider the potential benefits and limitations of these technologies in order to make informed decisions about their adoption. The findings of this bibliometric-based review will have far-reaching implications for organizations, researchers, and policy-makers looking to enhance the sustainability of supply chain operations.

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Production Optimization of a PVC Pipe Manufacturing Industry

Ponnu Jafar, S. Swapnesh, and S. Shyama Prasad

1 Introduction

The study has been conducted in one of the leading PVC pipe manufacturing industries in Kerala. The industry manufactures PVC pipes of different dimensions. The industry has a highly automated production line. The production line here is a 'parallel production line with different capacities' with job-machine compatibility. The capacity utilization for six months is shown in Fig. 1, and it is evident that there is an underutilization of capacity. The underutilized production capacity potentially causes undersupply and an increased makespan. A preliminary analysis of the current capacity utilization has shown us that the capacity is very much underutilized. This underutilization is due to the constraints presented within the production line or the production rather business process in general.

The concept of the theory of constraints (TOC) has been used to identify the constraints. Two important constraints have been identified in this study, the first one was regarding the capacity of the PVC compounding mixture, and this is addressed through a capital investment decision. The second constraint was found to be the random job-machine assignment, which plays a huge role in increasing the makespan and leading to the undersupply of demand. This constraint is addressed by using mixed integer linear programming (MILP) models to facilitate the optimal assignment of jobs to the machines. The new makespan obtained by using the models is then compared each other and also to the original makespan to see the effectiveness of the MILP models. Suitable suggestions are also made at the end based on the results of the study to improve daily production operations.

P. Jafar (✉) · S. Swapnesh · S. Shyama Prasad
Rajiv Gandhi Institute of Technology, Kottayam, Kerala, India
e-mail: ponnujafar34@gmail.com

S. Swapnesh
e-mail: swapnesh.s@rit.ac.in

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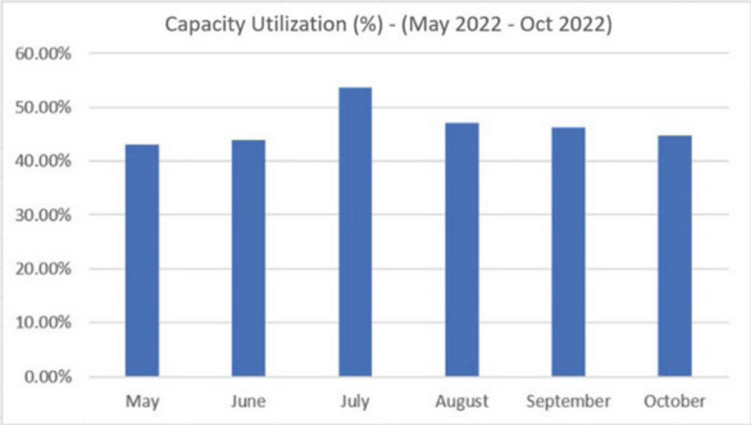

Fig. 1 Current capacity utilization

2 Problem Statement

Production capacity is not always used to its full potential due to bottlenecks like idle time and raw material availability. Key bottlenecks should be addressed to increase capacity utilization and optimize the production line to match the demand and supply.

3 Objectives

1. To identify the bottlenecks within the production process and address the bottleneck.
2. To assign jobs to the machines using mixed integer linear programming.
3. To provide suitable suggestions and recommendations based on the study conducted.

4 Methodology

The bottleneck identification rather, the constraint identification within the production process starts from preparing a process flow chart of the production process. This process flow chart is then analysed by considering the capacities of each machine. The methodology is illustrated in Fig. 2. This will give an idea about the associated bottleneck. Apart from this method, a literature survey has been done to identify other important potential bottlenecks associated with similar production processes. One of the identified bottlenecks shall be solved in the first objective itself. Since the industry is now practising random job-machine assignments, from relevant literature,

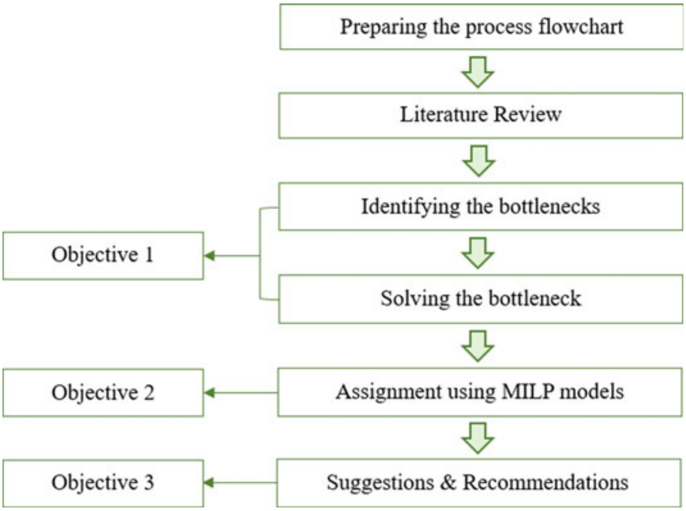

Fig. 2 Methodology

this has been confirmed as a bottleneck. Optimizing job-machine assignments is a classic operations research problem, and mixed integer linear programming is found to be the apt method to solve the problem. Two MILP models are being considered i.e. models with and without the job-splitting property. The model has been executed using Python. The results obtained from both models are then compared to the existing data, and suitable suggestions and recommendations are made.

5 Literature Survey

Mourtzis et al. [1] pointed out the inclusion of new technologies to re-structure the production line. Replacing old machines with efficient ones will enable the optimization of the production line. But for that the constraint of the production line should be identified, only then there is a scope for replacement. Also, a suitable financial analysis should be done to check the feasibility. Pegels and Watrous [2] discussed the concept of the theory of constraints in detail. The effectiveness of the theory of constraints in optimizing a production line is identified. The iterating steps of the theory of constraints are also discussed. We got an idea about how to implement the concept of the theory of constraints. The ideas discussed in the book 'the goal' by Eliyahu M. Goldratt are also integrated with the work which gave us enough clarity regarding the implementation of the concept. We got the concept of throughput accounting from 'the goal' written by Goldratt. Nait Tahar et al. [3] considered the job-splitting property as well as the sequence-dependent setup times. The set-up time here was dependent on the job sequence, and this made the problem complex.

In the scope of our study, the set-up times are not dependent on any sequence, and there have pre-determined values. Oktafiani and Ardiansyah [4] conducted a study on job-machine assignments with and without job-splitting property. But here the set-up time was only dependent on the machine, not on the type of job. In our study, the set-up time is dependent on the job as well as the machine. This study proposed two MILP models, and the results are then compared. We identified different parameters that we could use to arrive at a better management decision. Parameters like the relative percentage of workload imbalance came out to be vital.

6 TOC Concept and Identification of Bottlenecks

The theory of constraints is the concept used to identify the weakest link, i.e. the limiting constraint within a process. The concept of theory of constraints is shown in Fig. 3. The total output of the process will be limited to the output of the identified weakest link. This identified bottleneck has to be addressed to improve the output of the production process. This is done by comparing the capacity of the weakest link to the other parts or links of the production process. After addressing the identified bottleneck, the constraint might propagate to some other link. By addressing each emerging constraint, the production throughput can be improved.

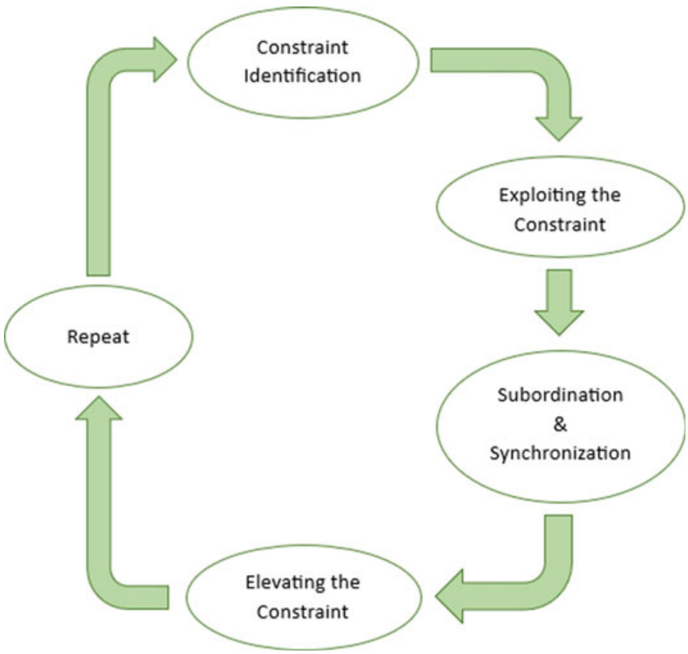

Fig. 3 The concept of theory of constraints

6.1 Production Process Flow Chart

The process flow diagram of the production process in the company is shown in Fig. 4. Two PVC compounding mixers are there for producing the mix which serves as the raw material for the extruder. The mix produced by the compounding mixture consists of resin and other chemical components, which undergo slight differences in composition based on the category of PVC pipes. The important category includes ISI and non-ISI pipes, which in turn will have different varieties based on other specifications like length, diameter, pressure, etc. The PVC mix goes into the extruder after passing through specific vibrators and hoppers associated with each extruder line. The mix is transferred into the vibrator manually. The input to the compounding mixture is also done manually. From the vibrator till the end of the sorting process, all the production processes are automated. The operator can adjust the speed of the process based on the level of operation. After the sorting process, the pipes are manually stacked in the stacking yard. This will then be shipped. The production is based on the weekly demand data the forecasting team gives to the production team. The forecasting teams forecast the demand based on the current capacity utilization of the production line. This tells us that underutilized capacity will eventually lead to the wrong demand forecast.

6.2 Applying the Theory of Constraint

Step 1 and 2: Identifying and Exploiting the Constraint

There is a mismatch of demand and supply is observed in the industry.

Figure 5 plots demand and supply over the past six months indicating that there is a mismatch between the demand and supply. This is expected because even from the preliminary analysis it has been understood that the capacity is underutilized. The graph in Fig. 6 demonstrates that the capacity of the compounding mixers is used to its full potential. The difference between the optimal input weight mix and the actual input weight mix is due to the variables associated with the manual material handling, say, idle time of workers, and the different rates in which they work. The difference between the actual input weight mix and actual production output is due to the loss of raw materials due to material handling as well as the formation of scrap in the final production output. These variables are almost unavoidable. Inculcating the above variables which affect the differences, it is pretty much evident that the capacity of the compounding mixers is utilized to its maximum.

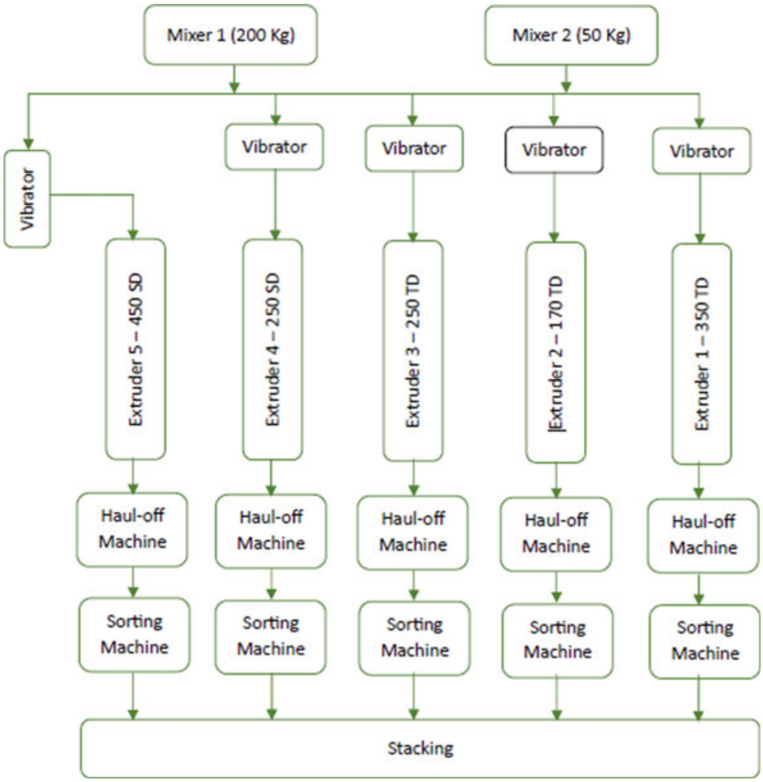

Fig. 4 Process flow diagram

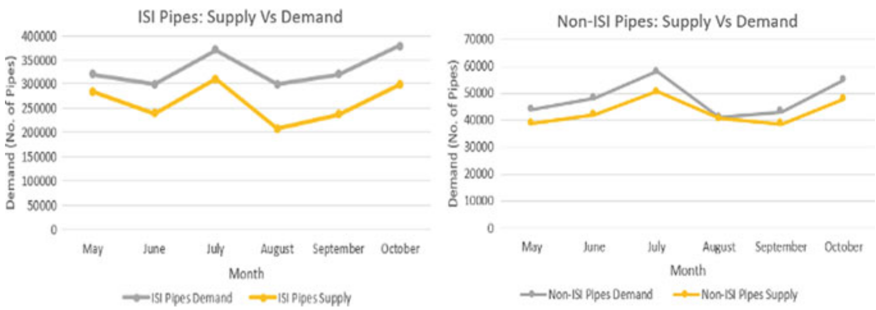

Fig. 5 Demand versus supply of ISI and non-ISI pipes

Figure 7 shows shows the actual production time as compared to the available production time for the extruder. Idle time here is the difference between the available production time and the actual production time. Thus, it is evident that idle time is caused by the shortage of input weight mix. Thus, the first bottleneck is associated

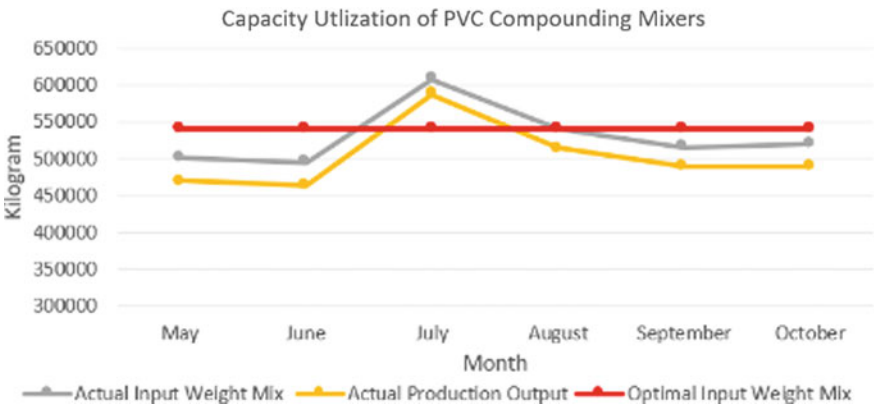

Fig. 6 Capacity utilization of PVC compounding mixers

with the PVC compounding mixer side. There is no way in which we can improve the output of the compounding mixers under the current scenario, as it is already operating to its full capacity.

Step 3: Subordination and Synchronization of the Identified Constraint

This step is about examining the capacities of all machines and comparing them to the identified constraint. Figure 8 illustrates the process of subordination and synchronization of the identified constraint. This process ensures all other links are aligned with the constraint. The links are aligned with the constraint indicating the initial constraint is associated with the PVC compounding mixer side.

Step 4: Elevating the Constraint

To achieve the target production, a new mixer of suitable capacity has to be installed. The capacity of the new mixer has to be a minimum of 250 kg, such that the PVC compounding mixers will produce an overall input mix ranging from 1700 to 2000 kg/

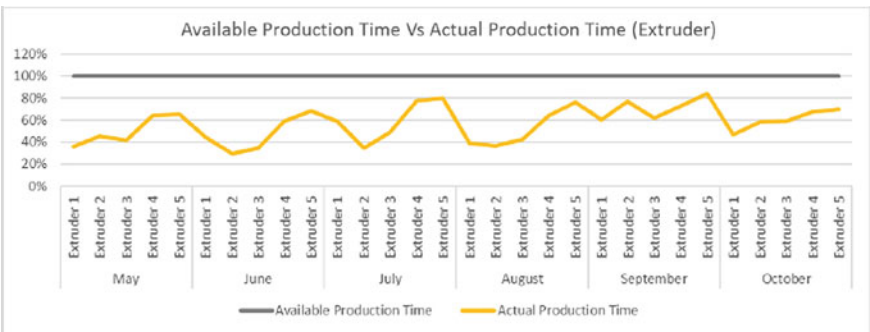

Fig. 7 Available production time versus actual production time (extruder)

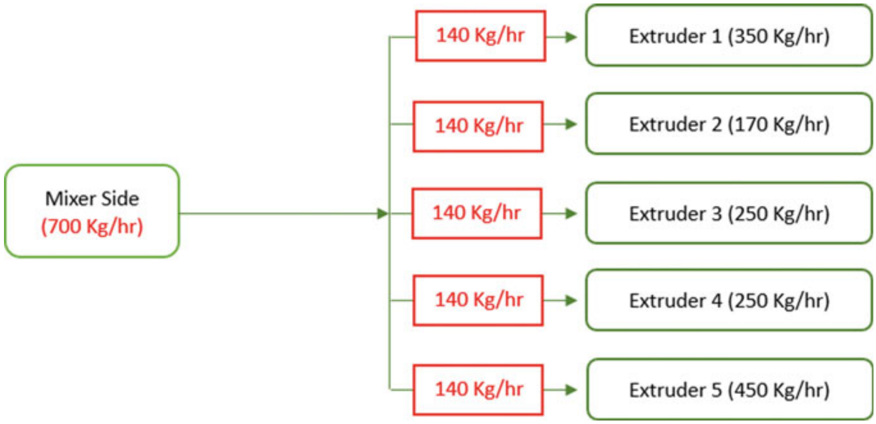

Fig. 8 Illustration to understand the scope of synchronization

hr. A financial analysis has to be conducted to check the effectiveness of the decision. The proposed mixer has a 300 kg capacity, which will meet the demand.

Financial Analysis
The cost of a 300 kg PVC compounding mixer = 20,00,0000 Rupees
Installation cost and other expenses = 10,00,000 Rupees
Total investment cost = 30,00,000 Rupees
Estimated electricity bill per month = 1,50,000 Rupees
Total number of labourers required for the machine = 10 (including two shifting)
Estimated labour cost per month = 2,00,000 Rupees
Raw material cost per month = 20,00,000 Rupees
Scrap cost per month = 2,00,000 Rupees

$$\begin{aligned}&\text{The estimated increase in profit per month}\\&= (\text{Sales amount} - \text{estimated monthly costs})\\&= (30{,}00{,}000) - (25{,}50{,}000) = 4{,}50{,}000 \text{ Rupees}\end{aligned}$$

$$\begin{aligned}\textbf{Payback period} &= \frac{\text{Initial Investment}}{\text{Cash Flow up to the month of recovery}}\\&= \frac{30{,}00{,}000}{4{,}50{,}000} = 6.7 \text{ months(a good-to-go-decision)}\end{aligned}$$

$$\begin{aligned}\textbf{Profitability index} &= \frac{\text{Cash flow after 7 months}}{\text{Initial Investment}}\\&= \frac{31{,}50{,}000}{30{,}00{,}000} = 1.1(\text{a good-to-go decision})\end{aligned}$$

Step 5: Repeating TOC to find the Next Bottleneck

The second bottleneck identified is the random job-machine assignment. This is identified predominantly from the literature survey. Under the current operation which prevails in the industry, the jobs are assigned to the machines in a random sense. The supervisor decides which job should go to which machine, and this is mainly based on the available machines rather than considering the processing capabilities of each machine. Because of this random job-machine scheduling, the makespan will be increased to a great extent. This will thus cause a delay to satisfy the demand at the correct time. The data already shows that undersupply prevails in the industry.

7 MILP Models for Job-Machine Assignment

7.1 MILP Model Without Job-Splitting Property (MILP Model 1)

Here, the job-machine assignment considers each job to be processed cannot be divided into smaller jobs that can be completed simultaneously on another machine. This means once a job is assigned to a machine, it has to be processed till the demand of that job reaches. Job is treated as a single entity here. The objective is to minimize the makespan of the total process.

The parameters are as follows:

M—Number of machines
N—Number of jobs
P_{ij}—Processing time of job i in machine j, $i \in N$, $j \in M$
D_i—Demand of job i, $i \in N$
S_{ij}—Set-up time of job i in machine j, $i \in N$, $j \in M$.

The variables are as follows:

x_{ij}—Binary variable indicating job i is scheduled in machine j, $i \in N$, $j \in M$
y_{ij}—Total processing time of machine j, $j \in M$
$C_{\max}$—Makespan.

Objective Function: Makespan Minimization,

$$\min C_{\max} \tag{1}$$

Subject to:

$$\sum_{j \in M} x_{ij} = 1 \quad \forall i \in N \tag{2}$$

$$y_j \geq \sum_{i \in N} x_{ij}\left(D_i P_{ij} + S_{ij}\right) \quad \forall j \in M \tag{3}$$

$$C_{\max} \geq y_j \quad \forall j \in M \tag{4}$$

$$x_{ij} \in \{0, 1\} \quad \forall i \in N, \quad \forall j \in M \tag{5}$$

$$y_j \geq 0 \quad \forall j \in M \tag{6}$$

$$C_{\max} \geq 0 \tag{7}$$

The objective function (1) here is the minimization of makespan. Makespan simply means the length of time from the start to the end of the job. Constraint (2) ensures that each job is assigned to exactly one machine, moreover, this is a model without job-splitting property. Constraint (3) calculates the time taken by each machine, i.e. y_j values, to process all the jobs assigned to it. Constraint (4) picks the highest time among the calculated y_j values, and this will be the makespan of the job-machine assignment.

7.2 MILP Model with Job-Splitting Property (MILP Model 2)

Each job that has to be processed can be divided into smaller jobs that can be completed simultaneously on another machine. Here, a job can be divided into many portions of a job, say, sub-jobs. The total quantity of these sub-jobs shall be equal to the total demand of that job. This simultaneous processing property will enable better processing of jobs.

The parameters are as follows:

M—Number of machines
N—Number of jobs
T—Number of split jobs
P_{ij}—Processing time of job i in machine j, $i \in N$, $j \in M$
D_i—Demand of job i, $i \in N$
S_{ij}—Set-up time of job i in machine j, $i \in N$, $j \in M$
Z—Sufficient big number.

The variables are as follows:

x_{ilj}—Binary variable job i, which is split in sub-job l, in machine j, $i \in N, l \in T$, $j \in M$
w_{ilj}—Number of a portion of job i, which is split into sub-job l, $i \in N, i \in T$
y_j—Makespan

$C_{\max}$—Makespan.

Here, the objective function is the same as that of the case without job-splitting.

Objective function: Makespan minimization,

$$\min C_{\max} \tag{8}$$

Subject to:

$$\sum_{j\in M}\sum_{l\in T} w_{ilj} = D_i \quad \forall i \in N \tag{9}$$

$$w_{ilj} \leq x_{ilj} Z \quad \forall i \in N, l \in T, j \in M \tag{10}$$

$$\sum_{i\in N}\sum_{j\in M} x_{ilj} \leq 1 \quad \forall l \in T \tag{11}$$

$$y \geq \sum_{i\in N}\sum_{l\in T} w_{ilj} P_{ij} + x_{ilj} S_{ij} \quad \forall j \in M \tag{12}$$

$$C_{\max} \geq y_j \quad \forall j \in M \tag{13}$$

$$x_{ilj} \in \{0, 1\} \quad \forall i \in N, \forall j \in M, \forall l \in T \tag{14}$$

$$w_{ilj} \geq 0, \quad \forall i \in N, \forall j \in M, \forall l \in T \tag{15}$$

$$y_j \geq 0 \quad \forall j \in M \tag{16}$$

$$C_{\max} \geq 0 \tag{17}$$

The objective function (8) is makespan minimization. In this model, the job is split into sub-jobs l. Constraint (9) makes sure the sum of the portions of sub-jobs w_{ilj} assigned is equal to the total demand for that job D_i. Constraint (10) ensures w_{ilj} values are sufficiently large. The Z value could be given based on the demand value D_i. Constraint (11) ensures each split job is processed on only one machine. Constraint (12) calculates the y_j values, which is the time taken by each machine to complete the jobs assigned to it. Constraint (13) selects the largest y_j value and that will be the makespan of the job-machine assignment.

The important assumptions prevailing in the MILP models are as follows:

1. The input weight mix is considered to be unlimited.
2. Machine set-up time is not sequence-dependent.
3. Machines operate without maintenance hours (24×7 for all days).

Table 1 Showing the makespan improvement by both the MILP models

Month	Makespan (Cmax) (minutes)			Improvement (%)	
	Actual	MILP model 1	MILP model 2	MILP model 1	MILP model 2
May	44,640	23,361	22,935	48	49
June	43,200	22,845	22,710	47	47
July	44,640	29,519	27,890	34	38
August	44,640	26,519	25,785	41	42
September	43,200	25,181	24,423	42	43
October	44,640	23,567	22,824	47	49

8 Results Obtained from MILP Models

A comparision of the output of both the MILP models is shown in Table 1. The makespan is found to be improved by using both the MILP models. MILP model 2, the model with job-splitting property is found to be reducing the makespan more than MILP model 1, the model without job-splitting property. Now, this has to be clubbed with other parameters regarding production to arrive at the best MILP model.

9 Recommendations

The relative percentage of workload imbalance (RPI) indicates the job distribution across the machine after a job-machine assignment. If we have a more balanced workload distribution across the machines, this will yield a more optimal output.

$$\text{The relative percentage of imbalance (RPI)} = \frac{C_{\max} - C_{\min}}{C_{\max}} \times 100\%$$

Relative percentage of imbalance is shown in Fig. 9. The MILP model 2 is found to have lesser RPI values as compared to MILP model 1. This indicates MILP model 2, and the model with job-splitting property is engaging the machines more than MILP model 1. This will reduce the risk of breakdowns for the operating machines. Even though the RPI of both models is the same in some months, it is advisable to use the model which gives small values of RPI.

Recommendation 1: The industry shall adopt MILP model 2 (with job-splitting property) for job-machine assignment. As this model had shown considerable makespan reduction as well as a smaller value of relative percentage imbalance.

Recommendation 2: The sensitivity analysis based on MILP model 2 is shown in Fig. 10. Since, the sensitivity analysis is showing a promising increase in profit. The sales team should carefully monitor the new throughput and acquire new markets accordingly rather than assuming the production capacity. This indicates that active

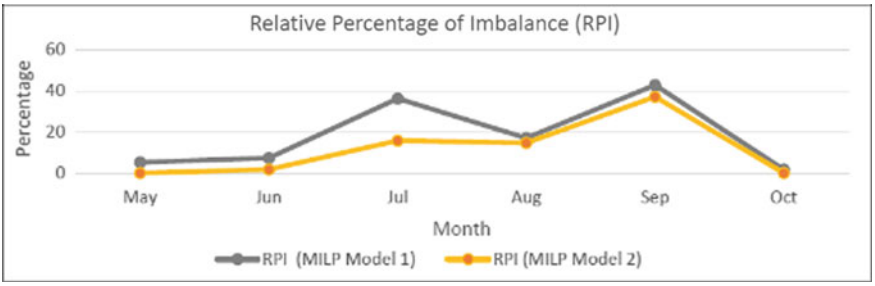

Fig. 9 Relative percentage of imbalance (MILP model 1 and model 2)

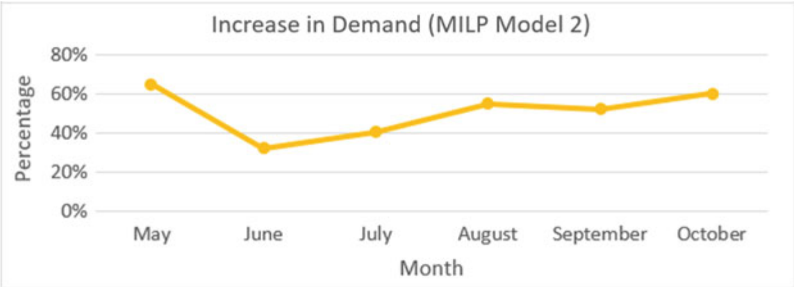

Fig. 10 Sensitivity analysis of MILP model 2

communication between the sales team and the production team is mandatory. The sales team should continuously monitor the throughput of the production side.

Recommendation 3: The company should also focus on throughput accounting apart from traditional accounting, and this helps in process improvement and results in more profit generation. The throughput accounting considers the cost of raw materials as well as the sales revenue, and these two parameters are directly associated with the production line, hence helping to identify the bottlenecks within the production line.

10 Constraint Propagation

It is evident from the above analysis, with the implementation of MILP models the demand the company satisfied in one month will get satisfied way before that. This will lead the constraint to the sales side, and they now have to find new markets to increase the demand. The constraint now ends up with the sales team. They have to now forecast the demand more accurately. The constraint will again travel from the sales to the production side if there is an increase in demand. If the increase in demand is beyond the scope of the current MILP model, then the constraint may be related to the capacity of the extruder side and so on. A more sophisticated mathematical model can also be developed, and this can be done by exploring the scope of job-sequence-dependent set-up time.

11 Future Scope

Our study had several assumptions, which when included in developing the mathematical model will translate itself into a set of constraints. Say, the setup can be considered dependent on the job sequence. This will change the complexity of the problem furthermore. If the setup times are sequence-dependent, then there will be a particular order in which the jobs shall be processed. There will be different completion times for different sequences of jobs. In our study, once the jobs are assigned to the machines, there is no particular order in which the jobs shall be processed. The other scope is to consider the resource the resource to be limited. This will change the assignment problem to a scheduling problem, as there will be time slots subjected to resource availability as well as sequence-dependent setup times for the jobs to be processed. Now, an optimal schedule has to be proposed based on the availability of raw materials. We can also bring in more constraints related to the maintenance activities of the machines, availability of human resources, and amount of buffer stocks to be kept to make the model more realistic.

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Design and Control of Ball-and-Socket-Type Spherical Motor: A Comprehensive Study

Jasvinder Singh, R. K. Lishwanth, P. Akashraj, A. Maria Joseph Mervin, S. Aaron, and V. Ananthashankar

1 Introduction

Spherical motors are characterized by their unique spherical design, which allows for multi-axis movement compactly and efficiently. They are widely used in various industries, including robotics, aerospace, medical equipment, and automation. Additionally, their compact design allows for integration into smaller and more confined spaces, making them ideal for use in a wide range of applications, where complex multi-axis movement is required. The ball-and-socket design is key feature of spherical motors. It refers to the spherical shape of the motor that allows for multi-axis movement, which is achieved by a ball-and-socket joint mechanism [1, 2]. The ball is typically attached to the rotary element of the motor, while the socket is attached to the stationary base. When the ball rotates within the socket, the motor can move in multiple directions, including linear, rotary, and spherical motion. This design allows for greater flexibility and precision in motion control, as well as improved reliability and durability compared to conventional linear motors. The ball-and-socket design helps the spherical motor to move smoothly and efficiently, without any binding or friction. Additionally, the compact design of spherical motors, which is made possible by the ball-and-socket design, allows for integration into smaller and more confined spaces. The spherical motor structure design is comparable to that of conventional motors, but it necessitates a deeper comprehension of a precise magnetic field in three dimensions. Due to the restricted area and magnetic poles, one of the key design problems is to enhance the orientation torque. Utilizing magnetic poles to their greatest potential will optimize the magnetic field interaction between permanent magnet

J. Singh (✉) · R. K. Lishwanth · P. Akashraj · A. Maria Joseph Mervin · S. Aaron · V. Ananthashankar
School of Mechanical Engineering, Lovely Professional University, Phagwara, Punjab 144411, India
e-mail: jas.sliet86@gmail.com

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and electromagnet, which is necessary to generate torque [3]. Theoretically spherical motor has many advantages, but the structure and complexity of magnetic pole arrangement could make the system unstable and complex to achieve the desired trajectory. Precise control system is required to overcome the mentioned drawbacks of spherical motor.

2 Conventional Spherical Actuation

Conventional spherical actuation is the spherical motion created to drive the load in a spherical orientation. Several different principles are used to generate spherical actuation. Serially connected linkages in industrial wrist is a typical example of circular motion. As an alternative, spherical parallel manipulators (SPM) can produce circular motion. Spherical actuators can also be used to produce spherical motion. These actuators are frequently used in spherical robots and comprise spherical motors and internal or externally actuated spheres. Either one degree of freedom or multi-degrees of freedom can be included in a spherical motion system. A pitch-roll wrist or a pointing device, for instance, has two D.O.F.s, but a spherical four-bar linkage has one. Most robots, spherical motors, and SPMs have three DOF.

Multi-DOF can be produced with conventional spherical actuators, but it still has some limitations in design and structure for the wide variety of applications. So to overcome this spherical motor is proposed, spherical motor could produce multiple degrees of motion with a simple and compact design.

3 Spherical Motors

A spherical motor with a ball-and-socket joint is a type of mechanical device that allows for full 360-degree rotation in all axes, providing a high degree of freedom and versatility. This type of motor is commonly used in robotics, motion control systems, and other applications, where precise positioning and maneuvering are required. The ball-and-socket joint in a spherical motor acts as a pivot point, which allows free motion in any direction. This type of joint is composed of a ball that is held in place by a socket, which is typically made of metal or plastic. The ball-and-socket joint is often held together by springs or other tensioning devices, which help to keep the joint tight and stable [4]. There are various types of spherical motors with ball and socket joints, including hydraulic spherical motors, pneumatic spherical motors, and electric spherical motors. The application requirements determine the choice of which type of motor to be used, such as the load weight being moved, the speed and precision of motion required, and the overall cost of the system. Overall, spherical motors with ball and socket joints are versatile and highly effective components that are used in many applications. They offer high precision, reliability, and stability, making them ideal for demanding applications where precise positioning and manoeuvring are essential.

3.1 Difference Between the Conventional Motor and Spherical Motor

The key difference is the shaft of the rotor could tilt in any direction during rotating. The rotating and the position motion are the basic two parameters of the three-degree freedom motor alpha is the positional angle, and beta is the rotational angle (tilting). The parameter is used fully in the current equation for position control; to achieve this motion, design is made in the way the stator and rotor have a gap between them, and this design is vital to produce the rotating and positional torques.

3.2 Types of Spherical Motor

3.2.1 Electrostatic Spherical Motor

An electrostatic spherical motor is a type of spherical motor that uses electrostatic forces to produce motion. This type of motor operates by applying an electric charge to the ball element of the motor, which is then attracted or repelled by electrodes positioned in the socket. This generates a force that causes the ball to move in a specific direction, producing motion.

Electrostatic forces are used to control the movement of the rotor. This is achieved by applying a voltage difference between the rotor and stator, which creates an electrostatic force that causes the rotor to move. By controlling the voltage applied to the rotor and stator, the movement of the rotor can be precisely controlled, allowing for precise and controlled movements in all axes. In summary, an electrostatic spherical motor is a compact and versatile device that can provide precise and controlled movements in all axes. The ball-and-socket joint and electrostatic forces allow for a high degree of freedom and versatility, making it ideal for a wide range of applications.

3.2.2 Ultrasonic Spherical Motor

The ultrasonic spherical motor is the most suitable for applications such as micro-satellite and space robot actuation. It is highly desirable to have spherical motors with a high torque density and strong control performance. It is also extremely challenging to achieve these requirements due to the complicated kinematic design and commutation of electromagnetic spherical motors. High torque density, rapid reaction times, and direct-drive capabilities have all been demonstrated with ultrasonic actuation.

The electromagnetic spherical motor, which is driven by the combined action of the current and magnetic field, has massive windings, whereas the ultrasonic spherical motor does not, and its basic structure makes it lightweight, small, and reasonably easy to regulate. Until now, just one spherical ultrasonic.

The motor consists of a semi-spherical stator, rotor, and frame serving as support with a spherical bearing situated in the middle. A shaft, a piezoelectric component, and an oscillator with a cone form complete the rotor. The piezoelectric component is present between the oscillator and the shaft. Using preloaded springs, the hemi-spherical stator is forced against the oscillator and maintained concentrically centre centred on the main spherical bearing.

3.2.3 Magnetic Spherical Motor

A system with several degrees of freedom needs more than two actuators. As a result, there are drawbacks because of the heavyweight, large volume, high price, etc. Spherical motors were created to get around these drawbacks. In multi-DOF systems, spherical motors can replace several motors, making the systems lighter and more compact. A permanent magnet spherical motor has the advantages of small volume, low cost, and high energy density.

On the surface of the rotor, there are permanent magnets evenly spaced around the equator with an alternate polarity of the N pole and S pole. The magnetic pole of the rotor has the appearance of a dihedral cone [5].

4 Design and Performance Analysis

Research has developed different spherical motors to achieve multiple degrees of freedom, and they succeed in that there are spherical motors that could produce multiple D.O.F compared to conventional motors, but there are some disadvantages; they are spherical motors cannot achieve the efficiency that conventional motors could produce and the design and mechanism is complex for spherical motor. Here are some of the designs that the researcher analysed and experimented with.

4.1 Pure Iron Processed Stator Core

An essential part of research in the spherical motor is to attain the efficiency and multi-degree of freedom far greater than the conventional motor, but still, it has the problem we face in conventional motors like permanent magnet loss, copper loss, and cores eddy current loss. Between them, the eddy current loss plays a major role for conventional motors we laminate the core to overcome the loss, but the spherical motor has some difficulty in lamination which is one of the main reasons for efficiency loss.

4.2 *Powder-Formed Stator Core*

In this design, the eddy current loss can be prevented. The Somaloy SMC is made has been powder formed by the core of the stator to stop the eddy current loss. (The Somaloy SMC is composed of compressing small particles with heat and high pressure). It has low conductivity and high permeability, and productivity is high because of the insulation material between that particle [6].

4.2.1 Structure Guide Frame Spherical Motor

The spherical motor using guide frame is a synchronous motor. The rotor has a permanent magnet, and the stator is slot less. The rotor uses four magnets of type N32SH ND. A coil of 12 for position and rotating each six of them at top and bottom. And the reason why a guided frame is used is to secure the stability of the rotor.

4.3 *Air-Gap-Type Spherical Motor*

The air gap type has two air gaps, namely an external air gap and an internal air gap beside the stator. The paper describes a double-air-gap spherical motor with 3-degree freedom consisting inner rotor core with a permanent magnet and an outer rotor with synchronous speed which are beside the non-slot stator core.

4.3.1 Structure of Double Air-Gap Spherical Motor

This double-air-gap, 3-D.O.F spherical motor has two rotors and one stator. The stator and rotor axis are connected. Structures of the stator coil are parted by armature coils for positional motion and generating rotational, to control separately. Internal rotors consist of four magnets, and the outer rotor conjugates with an internal rotor via a bearing an optical sensor is used to find the internal surface of the rotor for sensing the axis of the rotor.

And the author concludes that the double air gap complements the shortcoming of other spherical motors compared.

Torque

According to the analysis, at 1000 [rpm], the torque was 0.48 and 0.53 Nm, and the eddy current lost is 2.55 and 0.39 W for the stator core models made of powder and pure iron, respectively. As result, eddy current loss has decreased by 80%, the average torque has increased by 10%, and eventually, the efficiency must have increased significantly [7].

4.4 Performance Comparison of Double-Air-Gap Type and Guide Frame Type

A comparison of the models will allow the study to be validated by evaluating each model's performance. To compare simulation output with actual experimental data of back emf, it is first necessary to assess the chance of this occurring.

Additionally, the experiment approach outlined in Section V is used to measure the axial torque and efficiency of each model. Even the double-air-gap variant has an additional 0.77 Nm torque when the stator of the guide frame is made with powder. In addition, processing pure iron costs 35.2% higher, and processing powder costs 37.8% more [8].

4.5 Permanent Magnet Spherical Motor

The spherical motor that is proposed in this study is created as a synchronous motor. The 4-pole permanent magnet on the rotor reveals the spherical motor. Magnetomotive force is produced by a single stator segment. The spherical motor has two air gaps, and the stator is a coreless kind. The stator is composed of two separate coils: a rotating coil and a tilting coil. The tilting and spinning coils rotate and tilt the shaft in the two-dimensional (2-DOF) space. Additionally, the revolving coils have three phases, and six slots with concentrated winding, which create a rotating field with four poles.

The tilting coils are windings in the form of a number 8 with six slots. It describes the coil that has the shape of an eight. Each coil generates an opposing magnetic field when the upper and lower coils, which are connected in series and have different winding orientations. Additionally, because of the electrical symmetry of a 4-pole motor, the currents in the coil directly across the centre of the sphere have the same amplitude but are flowing in the other direction to produce tilting action.

Definition of Angle

The spherical motor has 3-D.O.F so the position of the rotor should be clear before we define the current function. The rotating coil and tilting coil control the spherical motor's position. The stator is configured with six segments, each of which has a revolving coil and a tilting coil. Like a three-phase synchronous motor, the rotor is turned by three-phase current in the rotating coils [9].

Performance of spinning and inclination motion

Analysis of the operation of the performance of 3D-FEA was primarily justified by the spherical shape. However, given the lengthy amount of analysis time needed to complete the using 3D-FEA, only particular positions were analysed. In terms of 3D-finite element analysis and experimental results, the tilting torque, which depends on the current flowing through the tilting coil, is contrasted. Due to the spherical structure's difficulties in measuring tilting torque in an experiment and low tilting torque, the experiment's result is within the tolerance range even though there was a simulation error of 10% to 30% [10].

The current is therefore minimal. The current increases linearly when the tilting torque exceeds 0.3 Nm, although when the tilting torque is less than 0.3 Nm, the current behaves nonlinearly. The mechanical loss is significant at low torque points, contributing to the tilting torque's nonlinear torque behaviour.

Additionally, the effectiveness of the rotating movement was confirmed. The speed of rotation, not the angle of tilt, determines how excited the rotating coil is. It was confirmed through rotational speed investigations and back emf testing and spinning speed experimentation in driving.

When the coil's current is displayed as the rotor rotates at [rpm], the coil's back emf data are displayed. Demonstrates that the rotor tilting has nothing to do with the properties of the rotating coil and is only a consequence of the rotor's rotation. Because the tilting and rotating performances may be adjusted individually, designing and controlling a spherical would be simple.

The rotor's tilting has nothing to do with the rotating coil's characteristic, which is exclusively related to the rotor's rotation. The ability to individually manage the tilting and rotating performance of spherical makes it easy to design and operate.

5 Materials

The material choice for a spherical motor depends on the specific application and requirements of the motor. Some common materials used in the construction of spherical motors include iron, aluminium, steel, bronze, and plastic. It is important to note that different materials have different properties, and choosing the right material depends on the specific requirements of the spherical motor, including the load it needs to carry, the operating environment, and any other requirements such as thermal conductivity or corrosion resistance.

A spherical motor design was proposed by Guo Jinjun et al. and compared the torque of the motor by changing the permanent magnet in the rotor and with the same number of electromagnets in the stator. The design consists of permanent magnet on both the inner rotor and outer rotor with radial and circular spin with the opposite polarity. The author experiments with the design with different materials to find the most efficient one that produces high torque.

The experiment has done with different configurations of the electromagnet in the rotors, and the design was tested by using different materials and current input as a parameter.

Design A consists of a permanent magnet in the inner core and electromagnet core, but it does not contain an outer rotor.

Design C consists of both the inner rotor and outer rotor as a permanent magnet.

whereas the experiments use both inner and outer permanent magnets or all of the inner permanent magnets. When compared to the simplified model, the resultant torque from the calculations and tests is comparable. With less than 8% maximum discrepancy, for optimum design, the SPM torque is validated. Additionally, the outcomes demonstrate designs. While the volume increases by less than 70%, design C generates four times stronger torque than Design A which provides an inclination torque. The significant increase in torque-to-volume ratio attests to the benefits of the suggested Design C over the current Design A. Compared to an aluminium core, the torque produced by the iron core is more than four metal cores. Similar to this, less magnetic flux leakage causes the torque with iron barriers to increase by around 30% [11].

6 Magnetic Pole Arrangement and Magnetic Field of Spherical Motor

To generate the torque with fixed directions, the conventional linear actuator has its rotor poles arranged around the stator poles in only one axis. However, the output torque of the motor should have three perpendicular components to produce a rotating motion with three degrees of freedom (DOF). Therefore, the pole alignment of rotor and stator in spherical motor is different from conventional linear actuator. The magnetic poles should be arranged in three dimension like a sphere to get the desired orientation in three degrees of freedom. Since the magnetic poles are arranged in three dimensions, the understanding of magnetic field in three-dimensional space is essential. Various fundamental magnetic theories have been put forward for the construction of a spherical motor that has three degrees of freedom with permanent magnets and electromagnets in rotor and stator, respectively.

Lee and Kwan et al. suggest a spherical motor with three degree of freedom that uses variable reluctance [12]. The control circuitry enables individual energization of the stator coils. The circumferential parts of the magnetic forces pull the nearby permanent magnets as a pair of the stator coils next to them are activated, creating a magnetic field and matching flux, which causes a torque to be produced on the rotor. The stator coils are excited by the high current pulses, which causes the rotor to rotate in the correct direction. Another pull force must be produced between an extra electromagnetic winding and another permanent magnet in order for the rotational motion to produce 3 DOF motion. Therefore, separate forces that are not aligned in a straight with the rotor centre, they are required at any given moment to produce motion control for rotor stability in a static position. Equally distributed magnetic windings on the bottom of the stator in order to obtain great positional resolution.

And the paper concludes that using permanent magnets for rotor could produce a steady torque, but it also suggests that numerous firings may be required for spherical steppers to move from one step to the next. The pull force produced by the current passing through the stator windings might not be strong enough to overcome the pull force between the magnet on the rotor and its existing matched stator, especially if the space between the windings is large.

To counteract this “unwanted” pull force between the permanent magnets and the electromagnets in stator, a reverse current can be applied. Furthermore, due to external disturbances, the rotor may travel in the opposite direction of the targets and towards the nearby stator teeth.

Wang et al. proposed an actuator with four pole permanent magnet rotor, that is constructed using two parallel sets of magnetic quadrants of the spherical surface, and four coils are arranged using stator winding mechanism [13]. The rotor is mounted inside the stator, which has less friction on the stator and rotor surface. The stator windings are set up such that by energising the relevant coil pairs, three independently controlled torque components can be created. By surrounding the windings in a spherical iron shell, the stator may air-cored or iron cored, increasing its torque capacity. When the stator windings are subjected to current, the ensuing torque will cause the rotor to be oriented to reduce the system potential energy. So, altering the coil currents allows for rotor orientation control. The actuator’s particular torque capacity is comparable to slot less, air-cored tubular linear motors. However, the total volumetric efficiency may be much better since it does not require a complicated mechanical relaying system to achieve the required 3-DOF motion.

Liang Yan, I-Ming Chen et al., on the basis of Lorenz force law, an analytical torque model is proposed [14]. A high flux density can be produced by PMs positioned near the rotor equator. The stator is where the air-core windings are joined, which simplifies the linear torque of the spherical motor. The rotor may tilt in two orthogonal orientations by turning on pairs of windings in opposite lengthwise directions. The rotor may spin around its own axis by passing current through all of the peripheral windings. Therefore, any desired three degree of freedom spherical actuation inside the stator sphere surface may be accomplished by altering the input currents of the windings.

Each of the permanent magnet rotor poles has the form of a cone having two intersecting planes, specified in terms of four parameters: longitudinal angle, latitudinal angle, and outer and inner radius. The permanent magnet rotor poles are uniformly separated (with alternating polarity) across the rotor diameter. The observation of magnetic field of the rotor is separated into three components with such a configuration, the area around the rotor, within the two intersecting planes of the permanent magnet rotor poles, core of the rotor made of ferromagnetic material.

The flux density is not a scalar, it is a three-dimensional vector. As a result, at every measurement location close to the rotor is essential to quantify all three parts of the flux density vector. This uses a triple axis Hall probe. The Hall probe can point to any area close to the rotor since it is positioned on a high accuracy triple axis motion phase. As a result, the rotor may be rotated using the fixture without needing to be reoriented so that the magnetic flux density in the rotor’s longitudinal direction can be measured. At sampling points along the way, the Hall probe shifts along a predefined orientation and measures the flux density. The adjustment is only carried out for the top stator surface since the rotor construction is balanced about the central body of the spherical plane. The estimation route begins at a location next to the rotor surface and with the centre axis of a permanent magnet pole. In comparison with using equal-distance sampling points, which necessitates many sample points, this approach is more efficient.

The paper concludes that the precision of suggested magnetic field model is adequate. The disparity may be less if superior harmonics were included in the model.

Ebihara et al. proposes a spherical actuator having rotor containing permanent magnets and stator containing an iron core [15]. This actuator operates on a similar theory as a permanent magnet linear step motor. The stator, rotor, and support mechanism compensate the spherical motor (bearing). The spherical magnetic poles of the stator are distributed in a lattice of triangles. This actuator makes it possible for the distribution of magnetic poles to drive in the spherical surface. The electromagnetic poles of the stator contain 16 phases.

However, excessive cogging torque caused by the reaction of the contact of the magnetic field with the irregular geometry of the stator and imbalanced speed ripple brought on by unevenness in force dispensation may significantly impair the effectiveness of the actuator. The electromagnetic and dynamic behaviour of the spherical actuators is also challenging to evaluate due to its three-dimensional (3-D) electromagnetic field distribution.

7 Control System

7.1 Control of a Spherical Actuator

Since spherical motors can provide a multi-degree of freedom, they must be smooth, fast, and accurately aligned. These objectives prompted the growth of many spherical actuators with precise motion control. Creating an orientation control system for a spherical motor presents unique problems due to the need for precise manipulation of the rotor while maintaining its desirable wire-free rotor feature. The motion control of SM is divided into two sections. The actuation torque of SM for it to follow the required trajectory and the electrical input to produce the actuating torque. These can be obtained by the feedback system of the control model and uses the control law for determining the desired trajectory.

7.2 External Orientation Sensing System

Mathematical definitions of the control laws for a spherical motor depend on the feedback of the orientation obtained from an external sensor system as most motion systems do. Spherical motor uses an external positional sensing system for the feedback loop to determine the torque requirements to track the path. These external systems depend on variety of multi-degree of freedom input sensing methods such as gyroscope sensors, consecutive single axis encoder with serial or parallel mechanism, vision-based or optical encoders [16], and magnetic field solutions.

7.3 Direct Field-Feedback Control

The direct field-feedback control (DFC) system removes the requirement for an external orientation sensing system by simply requiring measured magnetic fields, and its main components can function independently and support parallel processing. These are systems that uses real-time readings of the rotor magnetic field in a feedback loop system characterized with unnecessary inputs for the control of spherical motor. When used in place of existing techniques that depends on orientation-dependent systems for feedback control of a spherical motor, the DFC method significantly lowers collected errors and time delay caused by serial computations [17]. With the external sensing system, the structural and computational complexities have restricted the control performance, and using DFC method will eliminate these limitations.

The magnetic field of the spherical motor is dependent on torque characteristic vector (TCV) and is directly related to rotor orientation. Furthermore, the TCV estimation and control law derivation only need magnetic field observations, allowing for simultaneous computation of both values. The control can be significantly enhanced by a control system that includes parallel computation and direct magnetic field feedback [18].

7.4 Control Laws

Various control system models have been applied in the study of SM such as PID [18], backstepping and sliding mode [19], open-loop decoupling and fuzzy control. The motion system uses these existing derivations of control laws by acquiring orientation feedback using the above-mentioned methods.

7.4.1 PID

A common feedback control strategy is the proportional derivative control system, and this is a simple design and easy to execute. [20] This paper explored the idea of a proportional derivative position control law along with a proportional integral current law for the control of the spherical motor. In order to design a robust model to calculate the control gain matrices, the current loop's function reduces the impacts of back emf and current on the external position loop. However, because indeterminant and inconsistencies always exist in the model, the effectiveness of the proportional derivative control system will be inadequate in high precision.

7.4.2 Backstepping and Sliding Mode

The spherical actuator exhibits disturbance and model error because of the complexity of the electromagnetic field and mechanical structure, which hinders the effectiveness of standard control systems. To integrate the controller, a backstepping sliding mode technique is used [21], and it is to balance the errors. Backstepping is a repetitive nonlinear control design approach used on the feedback-linear system to ensure performance. He has discussed a design approach of a control system, which combines backstepping and sliding mode control [22]. The entire system is divided into multiple smaller subsystems, each of which receives suitable state variable functions as pseudo-control inputs in accordance with a recursive Lyapunov function. A new pseudo-control design is described in the one from the previous design stage for each backstepping stage. When the process is finished, the Lyapunov function, which is created by adding each control independent input associated with the relevant design stage, is used to determine the actual control input. The backstepping method is used to eliminate the discrepancy of the system to attain the desired orientation [23].

7.4.3 Open Loop and Closed Loop

PM-based electromagnetic actuators have been utilizing both closed-loop and open-loop control. However, it is difficult to construct closed-loop control systems for an electromagnetic actuator with three-dimensional pole arrangement, due to a multitude of unstable parameters regarding force/torque calculation. Due to their complex magnetic fields, nonlinear rotor dynamics, and tough measurement issues, three degree of freedom spherical motor design and control system development are particularly hard. But when a three degree of freedom spherical motor has open-loop functionality, the control could be applied to it. An open-loop controller has been used to demonstrate several electromagnetic actuators. In [24] a step motor uses an open-loop control system for the position of the torque equilibrium. Because the motor has a significant uncertain payload, the controller's ability to reduce rotor oscillation and to be insensitive to changes in motor dynamics are essential for motor control. In

[25] there has been developed an torque control method for a direct-drive permanent magnet motor, suggested with better torque estimation and control characteristics. The push–pull principle and the distributed multipole (DMP) approach to study the magnetic field were developed in response to the desire to create a stable control system for spherical motors [26, 27]. In [28, 29], examples of the DMP approach for determining a spherical motor's torque model are shown.

A model-based controller for open-loop operation of the spherical motor has been designed using the DMP technique [30].

The spherical motor in this model is fundamentally symmetrical, making the creation of an open-loop controller that employs the push–pull principle to keep the rotor stable much simpler. The open-loop control law can be expressed in a closed form. The idea of push–pull operation for a spherical motor is presented in [30].

The research on closed-loop spherical motor is limited. In [31] proposes a spherical induction motor using closed-loop control system, with motor having four inductors next to the rotor which are controlled by a vector control method. It has sensors to detect the rotor's velocities and evaluate the rotor's angular velocity. In turn, this makes it possible to precisely regulate angular velocity and direction (rotational angle). Feedback is used to regulate the torque and orientation of the rotor.

This control method for spherical induction motors includes torque regulation, input sensing, and three-dimensional position control. Closed-loop control system for a desired positional orientation was achieved. But designing a closed-loop control system for a spherical desired orientation remains complex.

7.4.4 Fuzzy Control Using Neural Network

Artificial neural networks, which are frequently used in function approximation, data compression, prediction, and other areas, have very powerful approaches, generalization, and self-adaptation abilities [32, 33]. It has been demonstrated that a two-layer feed-forward neural network (FFNN) utilizing the backpropagation (BP) method may proceed towards a nonlinear complicated function of any level of accuracy [34]. A BP algorithm with added momentum can avoid this issue using a conventional BP method that has a slow Junction speed and a fixed learning speed during training. For permanent magnet spherical motors, there are various uncertainties, such as model estimation errors and outside disruptions.

Dynamic control systems frequently employ the computed torque technique as a model-based control strategy [35, 36] the fuzzy controller decides the control amounts. The CTM structure is given a fuzzy controller (FC) and a neural network identifier (NNI). NNI is used for the identification of uncertainties to produce dynamic decoupling control of SM. Dynamic adjustment torques are used in the control system's feeding forward compensation (FC), which increases the robustness of the system. In SM, there are some serious couplings, and to increase the dynamic and static performances of SM, it is necessary to search for a strategy to remove couplings [36]. CTM performs various tasks more effectively, quicker, and with less computing load. The control system's static and dynamic performances will significantly enhance with strong robustness to uncertainties.

8 Application

Spherical motors with ball and socket joints are used in a variety of applications, some of which are:

- Robotics: Spherical motors are commonly used in robotic systems to control the movement of arms, legs, and other parts of the robot. The high degree of freedom offered by spherical motors allows robots to move in a wide range of directions, making them ideal for applications such as assembly, inspection, and material handling.
- Motion control systems: In motion control systems, spherical motors are used to control the movement of mechanical parts in a precise and controlled manner. This type of motor is often used in applications such as precision positioning systems, medical equipment, and other machines that require precise and repeatable movements.
- Aerospace: Spherical motors are used in aerospace applications such as spacecraft and satellites to control the orientation of the vehicle and adjust its position in space.
- Industrial automation: In industrial automation, spherical motors are used in various applications, including conveyors, packaging machines, and material handling systems. The high degree of freedom offered by spherical motors makes them ideal for applications where precise positioning and manoeuvring are required.
- Automotive: Spherical motors are also used in automotive applications such as power steering systems, suspension systems, and other components that require precise and controlled movement.
- These are just a few examples of the many applications of spherical motors with ball and socket joints. The versatility and precision of these motors make them ideal for a wide range of industries and applications where high performance and reliability are essential.
- Medical equipment: Spherical motors are used in medical equipment such as surgical robots, endoscopic cameras, and other devices that require precise and controlled movements.
- Virtual reality and gaming: Spherical motors are used in virtual reality and gaming applications to provide realistic movements and enhance the user experience. For example, they can be used in gaming controllers to provide realistic motion and feedback.
- Marine: Spherical motors are used in marine applications such as underwater vehicles and remotely operated underwater vehicles (ROVs) to control their movement and orientation in the water.

- Agriculture: Spherical motors are used in agriculture for tasks such as harvesting, planting, and pruning. The high degree of freedom offered by spherical motors allows for precise and controlled movements in challenging environments.
- Amusement parks: Spherical motors are used in amusement park attractions such as simulators and ride systems to provide realistic and immersive experiences.
- Advertising and displays: Spherical motors are used in advertising and display applications to create dynamic and eye-catching displays that capture the attention of viewers.
- Art installations: Spherical motors are used in art installations to create interactive and immersive experiences for the viewer. For example, they can be used to control the movement of sculptures or other objects in an exhibit.

9 Challenges and Limitations

Spherical motors are complex in design and manufacturing, which can increase production costs, and are relatively larger in size compared to other motor types, making them less suitable for small or compact devices. The control of spherical motors is more challenging compared to traditional motors, due to the presence of multiple DOF. The stability of spherical motors is also a challenge, as they tend to vibrate and require sophisticated control algorithms to ensure stability. The maintenance of spherical motors is more challenging compared to other motor types, due to their complex design and the need for specialized components.

10 Conclusion

Despite their advantages, spherical motors are still a relatively new technology and have not yet been widely adopted in many applications. This review paper aims to provide a comprehensive overview of spherical motors, including their design, construction, and operating principles. The paper will also discuss the various applications of spherical motors and their advantages and disadvantages compared to traditional motors. Additionally, the review paper will present the current developments in spherical motor technology and highlight areas for research and development of future. The aim of this review paper is to deliver a comprehensive knowledge of spherical motors and their potential applications and to encourage the wider adoption of this technology in various fields.

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IOT Based Smart Plant Monitoring System

Paras Oberoi, Arohi Jain, Sandeep Goyal, Himanshu Garg, Aarti Kane, and Manish Talwar

1 Introduction

A smart plant or process is one in which all the devices, instruments, and sensors are virtually connected to each other. Plant is made automatic to increase the efficiency of work done and to optimize productivity of goods using machines and other technologies. In industries, many processes involve the engagement of manual work which is not only time consuming but affect the quality of product which is not up to the mark. It is a difficult and tedious task to look after a whole plant and check regularly whether all the processes are operating correctly or not. Sometimes due to human error, mishaps occur which causes a huge damage to the industry as well as the lives of workers working in it. Despite of all the measures taken so that the industry works properly, some accidents do occur due to human mistake. Automation can solve some of these problems using IoT. Internet of Things (IoT) is rapidly increasing technology. IoT is the network of physical objects or things embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data [1, 2]. Through IoT, we can send readings of each and every parameter that is being measured and controlled in the plant to the online portal. Through this, there will be no loss of data and the engineers will get readings of each parameter after a certain interval of time. If any problem occurs in the process or industry, engineers can easily observe that and can communicate about it. It helps in data visualization as the data can be seen in the form of graphs. By using IoT, the engineers can check and analyze the parameters from anywhere across the world and at any time. Not only it helps in transferring of data, it can be used to elevate the safety measures which have always been a great concern. With the help of IoT and Wi-Fi module, messages can be sent to the workers if any device is not working properly, thus informing on the spot, so as to avoid further issues [3, 4].

P. Oberoi · A. Jain · S. Goyal · H. Garg · A. Kane (✉) · M. Talwar
Bharati Vidyapeeth's College of Engineering, New Delhi, India
e-mail: arati.kane@bharatividyapeeth.edu

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Automatic switching mechanism also helps in making the situation better as it turns off the device without any manual help. This paper aims to optimize the process and also make it safe to use. It also provides method for an efficient way of handling and monitoring all the process occurring in the industry.

Modern industrial technologies seek to diminish the tedious efforts of workers, accelerate the speed of operation, improve the quality of products, and protect the plant from dangerous hazards. This paper attempts to extend automation to the industrial sector by incorporating advanced scientific and automation techniques and adjusting them to suit a modern day plant practices.

We have made a prototype of a device which will help the industry to monitor the plant from a control room, i.e., the worker does not have to be physically present in the plant for operating the processes.

The system which will automatically monitor the industrial parameters like temperature, flow, humidity, and level and generate alerts/alarms or take intelligent decisions using concept of IoT. IoT has given us a promising way to build powerful industrial systems and applications by using wireless devices, Android, arduino, and sensors [5–7].

2 Proposed System

Parameters considered in this work for monitoring the plant are:

- Temperature detection,
- Humidity detection,
- Flow detection,
- Level detection.

Features of the smart plant monitoring system:

- Online portal,
- Automatic switching off mechanism.

Figure 1 shows the proposed model of the plant where temperature, humidity, level, and flow are measured with the help of sensors to control the level and temperature of boiler.

2.1 Measurement of Parameters

Temperature Detection

For temperature detection, the senor used is DHT-11. It is a magnetic type of sensor. The temperature measuring range is 0 to 50°. The temperature measurement accuracy is ± 2.0%. Voltage specifications: 3.3–5.5 V. The temperature sensor is placed in

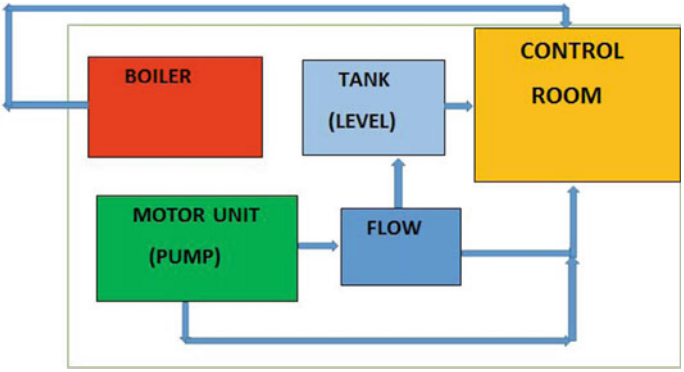

Fig. 1 Block diagram of proposed model of a plant

the plant which detects the temperature of the environment. The sensor sends its readings to the microcontroller ATMEGA 328 and through Wi-Fi module; these readings are sent to the online portal and are continuously observed and monitored by the engineers [4].

Humidity Detection

The sensor used for humidity measurement same as temperature sensor DHT-11. It measures both temperature and humidity. It is a magnetic type of sensor. The humidity measuring range is 20–90% RH (0–50° temperature compensation). The humidity measurement accuracy is ± **5.0%. Voltage specifications: 3.3–5.5 V.** In the plant, the humidity of the atmosphere is detected with the help of humidity sensor. The sensor gives the accurate readings of the humidity of the environment. These readings are sent to the microcontroller ATMEGA 328 and through Wi-Fi module; the readings are further sent to the online portal which are continuously observed and monitored by the engineers.

Flow Detection

The sensor used for flow detection is flow rate sensor. The operating voltage range of the sensor is 5–24 V. Flow sensors are placed in the tank which detects the flow of the liquid. The sensor sends the readings to microcontroller ATMEGA 328, and the engineers sitting in the monitoring room can easily view these readings as these readings are sent to the online portal with the help of Wi-Fi module.

Level Detection

HC-SR04 sensor is being used for the detection of level of the tank. It is an ultrasonic type of sensor. The working voltage of the sensor is 5 V, and the working current is 15 mA. The maximum range of the sensor is 4 m. Level sensor is placed in the tank to measure the level of liquids. The readings are sent to the microcontroller from where it is further sent to online portal through Wi-Fi module. When the tank gets completely filled, the motor is turned off automatically with the help of relay (which acts as a switch). By this, the human interference decreases and it reduces the risk of human error.

2.2 Attributes of System

Online Portal

Online portal is a platform where data can be collected, analyzed, and stored in the cloud. Various parameters can be observed on the portal by the engineers. The advantage is that the engineers do not have to take the readings of each sensor separately, and all these readings can be viewed at a single platform. Also the engineer can login into the portal whenever he wants and he can access the portal from anywhere. Online portal also provides data visualization through which real time graph can be built on the basis of the data sent by the microcontroller to the portal.

Automatic Switching off Mechanism

Whenever the readings of the parameters will exceed the set values, the motor will get turned off by using relay. The relay will receive the signals from the microcontroller which further receives the signals from the online portal. Earlier whenever the readings used to exceed, the engineer has to go and turn off the device which takes some time and is also dangerous for the engineer himself. So through this, many mishaps can be avoided and lives of the workers can be saved. Another feature of this is whenever the readings of these parameters exceed the desired value, a message will be sent to the engineer automatically which will eventually reduce the chances of accident.

3 Development and Implementation of System

Figure 2 shows the implementation of the system which consists of a power source that would provide energy to the motor as well as immersion rod. The motor will start and will provide a water flow to the boiler. The boiler consists of temperature sensor and level sensor. The temperature and level measurement readings are predefined, so that if the reading would cross the range then necessary actions would take place.

The immersion rod as shown in Fig. 3 provides heat to the boiler as a result temperature would increase. The flow of liquid to the boiler would be continued till the level reaches the limit, and then, the control unit would send signals to the flow sensor and the flow would stop. The temperature in the boiler would increase up to the safety limit, if it increases beyond the predefined range, the control unit would send signals to the immersion rod and heating process would stop. All this process can be monitored online on the cloud by accessing the data from all the sensors, and

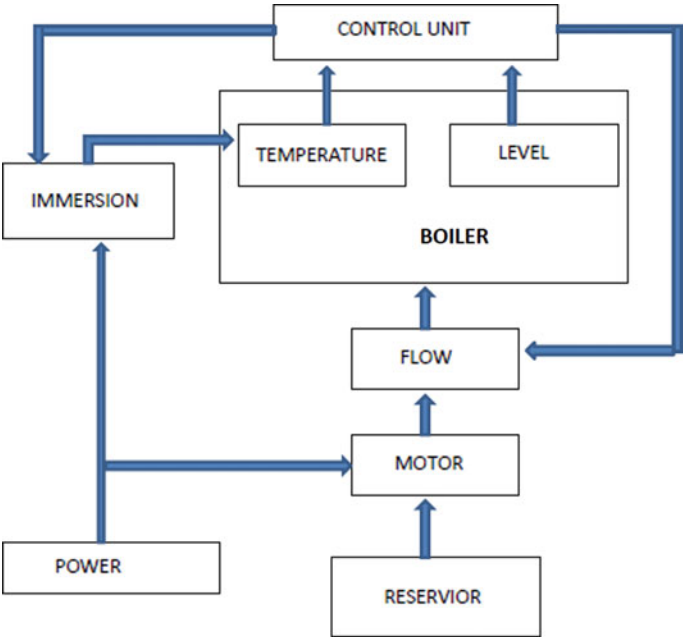

Fig. 2 Implementation block diagram

the data graphs will be continuously updated and can be accessed by anyone having access to the information.

4 Result

The project will transform the sector of industries in our country by automating the process of measurement of different parameters. It aims in converting the whole manual process in automatic measurement process. This is achieved by transmitting the readings of various parameters wirelessly to the secured portal and shutting down the system automatically if the values exceed the safe limit. It is done by using Wi-Fi module (which enables the system to send the readings to the portal) and online portal (which enables to send a SMS to the controller mobile phone). The advantages are reducing the manual efforts of engineers and improving the quality of measurement. Also, the system is easy to operate and is cost effective.

Figure 4 shows the obtained readings for level, temperature, and humidity measurement which are given below.

(a) Level readings from HC—SR04. The limit set for 15 cm.
(b) Temperature readings from DHT-11. The limit set is 30^0C.
(c) Humidity readings from DHT-11. The limit set is 50 RH.

Fig. 3 System prototype

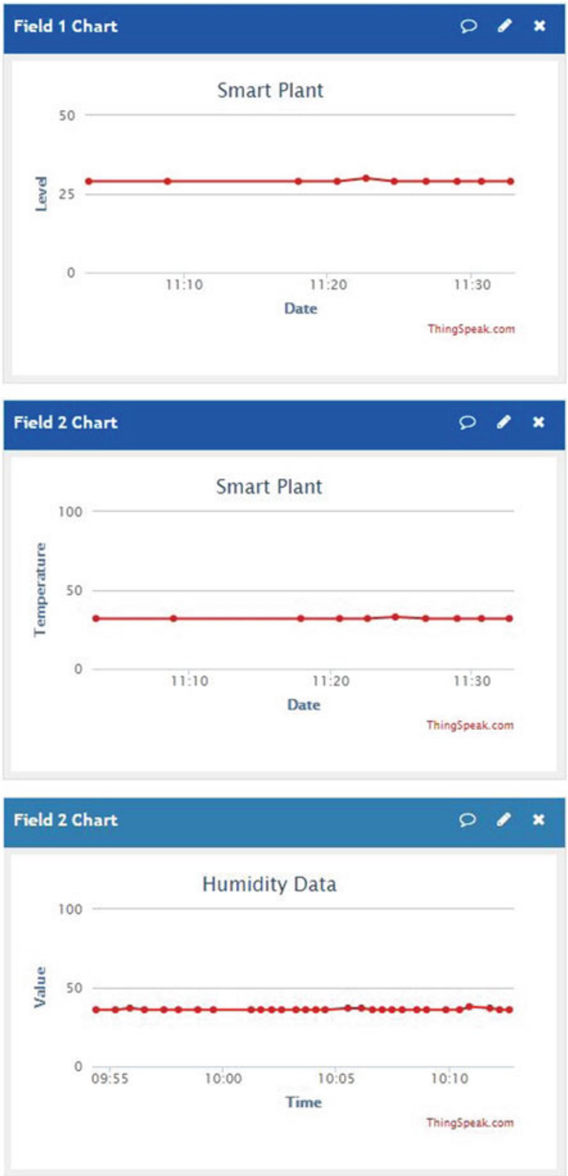

Fig. 4 Profile of measured parameters

5 Conclusion

In this paper, we have tried to come up with an efficient model of smart plant monitoring system. Automation is growing its roots in every field and sector. A new model for monitoring a smart plant is presented to enhance the present conditions and to deteriorate the accident risk. It includes automatic turning off mechanism, detection of temperature, humidity, flow, and level as well as transfer of data on online portal by Wi-Fi module. Detection of temperature and humidity is done to make sure that the environmental conditions of the plant are suitable as desired. Further detection of flow and level is done to make sure the process is working smoothly and no hazardous mishaps occur. The system is made automatic by using Wi-Fi module. This makes sure that the system is protected as the readings are continuously sent to the control room after regular intervals. For this purpose, microcontroller is used which connects with the monitoring system. Switching mechanism is used to make the whole process automatic. Special care of hazardous situations is taken into consideration by implementing a process in which messages will be sent to the engineers if any parameter exceeds its limit. The system can be installed successfully and can be controlled easily. The engineers can easily access the system from anywhere. This system will lead in enhancing the level of industrialization in developing countries like India.

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Limitations of Centralized Version Control Systems (SVN) and Approaches to Its Migration to Decentralized VCS

Vinay Singh and Alok Aggarwal

1 Introduction

Version control system (VCS) is a special type of software that controls the overall software development ecosystem by tracking the versions of software at any given point in time. In other words, it is a system that keeps track of any small minor changes which is committed by developers or a team of developers. VCS plays a crucial role in Agile development or waterfall development environment that makes the development process smoother, less troublesome, and error free [1]. In a typical scenario, a version control set is also known as software configuration management, source code management (SCM), and source code control (SCC). VCS focuses more on the versioning aspects rather than focusing on several terminologies [2].

In a typical day of a development environment, a team of developers works in very strong collaboration, and each software developer makes changes in pieces of codes, commit, push, or revert the changes on software artifacts that involves addition and deletion of a feature [3–4]. It is normally expected that after doing so many revisions and commits there will be a satisfactory end customer-centric product will be ready before producing the final version. After making so many commits, revert, pushes, and creations of several feature branches, it is understood that will be difficult to manage and track the codes and the files because the number of revisions grows larger due to larger and more complex systems.

In the absence of the VCS, the software developers would be bound to keep their own code in several folders locally on their machine, which will be cumbersome to track, merge, and revert with other developers. Hence, this is risky because it is very likely that a code gets deleted, corrupted, or get mixed in the wrong copy of code, resulting in losing entire efforts and work. This will cause to delay in product delivery to the end business and will badly impact “Time to Market”. We

V. Singh (✉) · A. Aggarwal
School of Computer Science, University of Petroleum & Energy Studies, Dehradun, India
e-mail: vsbuild7@gmail.com

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are fortunate that version control systems will take care of this forthcoming issue by tracking, maintaining, and controlling all versions of the code [5]. As its name implies, a version control is a system of truth that records changes made to a software code or a set of files. It is a very special kind of software tool that helps the software team to track and make available the changes in source code whenever needed. It means it provides round-the-clock availability of the code written by developers to a file or set of files so a specific version may be rolled up if required in the future. If two developers are writing on the same set of code, then a version control system keeps the track of who, when, and what. It means it is an important responsibility of the software development team at the right track and right pace while developing the code for business problems. Version control system always ensures that each developer has the latest version of the file so that they can work at the same time simultaneously on the same code and get on the same project [6, 7].

1.1 Different Kinds of Version Control Systems

Local Version Control Systems

It is the simplest type of VCS that has only a local copy without a remote repo. Developers write the code and then make several versions of all the files only within their local system. It means all the changes are kept and maintained only in a local database, and there is no remote server in local version control systems [8].

Centralized Version Control

In centralized version control systems, a replica of your code is resided on the remote server, and commit your changes to this central copy. You pull the files from the remote as per our needs. It means a single "central" copy of code is always present on remote servers [9].

Distributed Version Control

Distributed version control works differently from centralized VCS as they do not store all the versions of a project's files at a centralized location. Instead, developers work in a collaborative manner and make a replica of code and create a separate repository locally [10]. This way developers can work locally and have the full history of the project at any point in time. Two common distributed version control systems are Git and Mercurial. Figure 1 shows the varieties of centralized and distributed VCS, and point-wise comparison is shown in Fig. 2.

A growing percent of form control frameworks used by the development community are now on Git. Many organizations have already switched to Git as their version control system (VCS) [11]. In spite of the fact that the program industry has a few migration tools, their options are somewhat limited, especially when it comes to pre-migration checks like purge registries, failover capability, and detailing as post-migration steps.

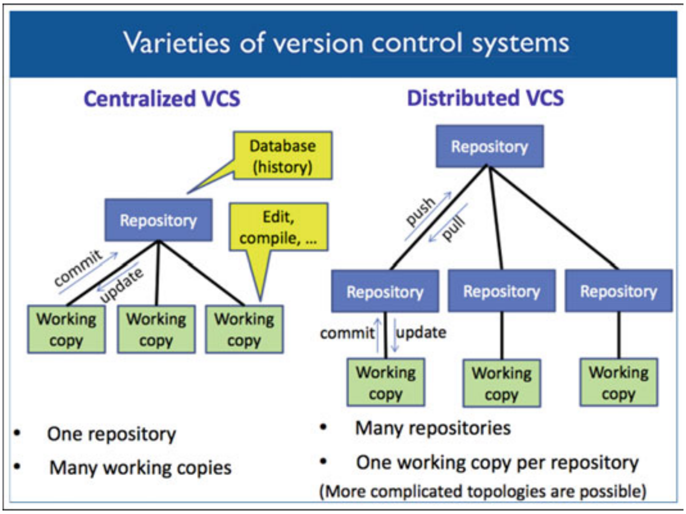

Fig. 1 Centralized VCS versus distributed VCS

Centralized Version Control System	Distributed Version Control System
In CVCS, The repository is placed at one place and delivers information to many clients.	In DVCS, Every user has a local copy of the repository in place of the central repository on the server-side.
It is based on the client-server approach.	It is based on the client-server approach.
It is the most straightforward system based on the concept of the central repository.	It is flexible and has emerged with the concept that everyone has their repository.
In CVCS, the server provides the latest code to all the clients across the globe.	In DVCS, every user can check out the snapshot of the code, and they can fully mirror the central repository.
CVCS is easy to administrate and has additional control over users and access by its server from one place.	DVCS is fast comparing to CVCS as you don't have to interact with the central server for every command.
The popular tools of CVCS are **SVN** (Subversion) and **CVS**.	The popular tools of DVCS are **Git** and **Mercurial**.
CVCS is easy to understand for beginners.	DVCS has some complex process for beginners.
If the server fails, No system can access data from another system.	if any server fails and other systems were collaborating via it, that server can restore any of the client repositories

Fig. 2 Comparative analysis between centralized VCS versus distributed VCS

1.2 SVN and GIT

A single server houses the adaptation history when form control is centrally managed. When it comes time to modify specific files, designers drag documents from that central server to their personal computers [12]. The designer makes changes and then sends the updated records back to the primary server. SVN (Subversion) is a form control system that is free or open-source. Subversion supports a large number of records, commits, and envelopes that undergo circumstantial changes. The engineer

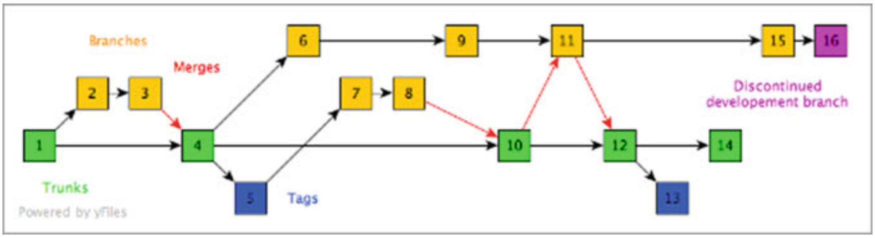

Fig. 3 Holistic SVN workflow

community is able to preserve both modern and outdated versions of documents, source code, and web pages as a result. The aggregate SVN workflow is shown in Fig. 3.

2 Related Work

There is not much distributed work left to do for the use of DevOps in the SVN to Git migration that has been completed. In any case, a few briefly mentioned related works are present. As a result of recent high-profile data breaches, customers now expect the companies they do business with to protect their personal information. An application security program can boost customer [13–20] confidence and advance a company's reputation by proving that an organization is exercising due diligence with regard to client information. Employees who are a part of a company with a strong security culture can actually highlight and advance the value of their employer's security initiative by learning how to protect client information, such as actually identifiable data.

3 Problems with Traditional Version Control Systems

The problem with centralized VCS is that it is centralized in nature and always depends upon developers to commit their changes on a central server. In the initial stages, it looks easy to set up and configure the one goes setup for centralized systems. There are a few examples of centralized VCS, like Subversion (SVN), CVS, and Perforce. But there is an evident risk that comes as a trade-off on relying on a single server [21, 22]. What if, the only copy of a software code becomes corrupted or gets deleted, then developers will not be able to access the code or retrieve previous versions. There might be another scenario if the centralized server gets crashed then the whole code will be wasted or several project futures will be at stake. There is another problem with centralized VCS is that when developers make remote commits they seem extremely slow, as network bandwidth is also involved to fetch the commits to the central repository, which can slow down the development process. In centralized VSC, the repository creation, creation of branches, and merging of several branches are also difficult and confusing, since contributors have to track merges and branches as a single check-in. Figure 4 shows the architecture of SVN.

Even though Subversion is in existence for several years playing a crucial role in tracking the code, it has some special features found in other advanced version control systems like GIT. With intelligent utilize of snares and properties, it is additionally conceivable to urge around a few of SVN's confinements. The taking after may be a list of vital highlights that Subversion either needs or executes with critical restrictions.

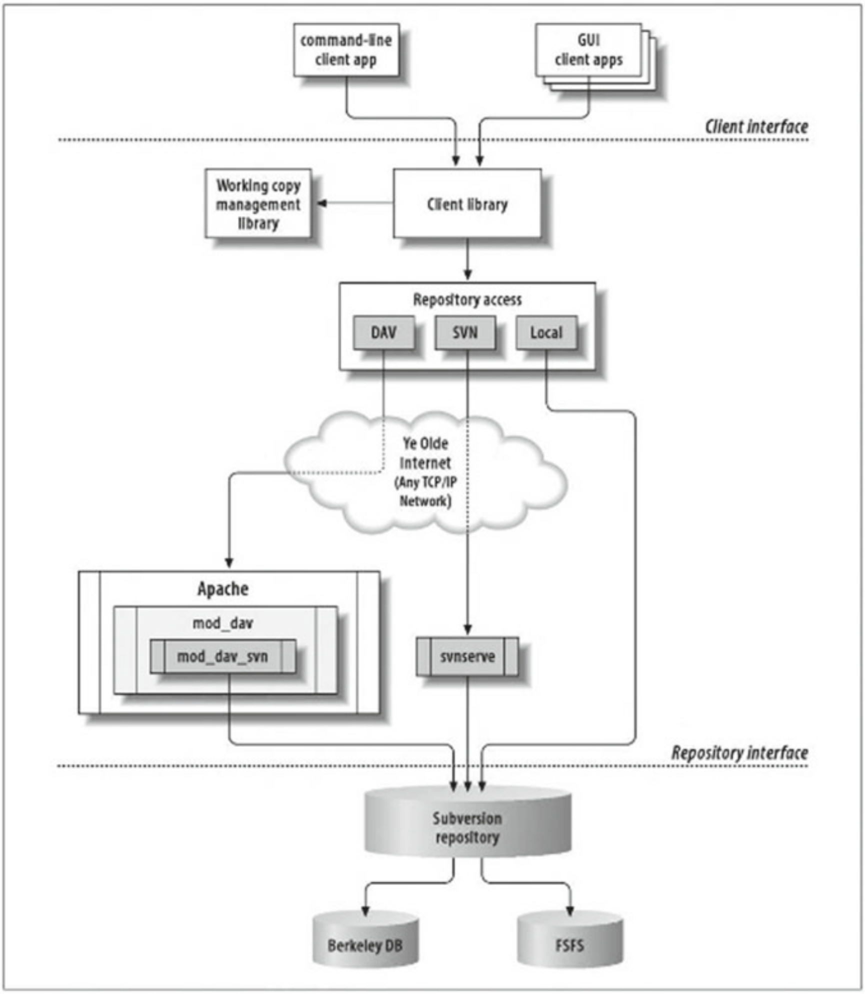

Fig. 4 Architecture of SVN

SVN Does not Have a Locking Feature

Locking files is very important when two developers are working parallel to a single code or piece of code. Unfortunately, Subversion does not support for file locking. It does not prevent more than one person from working on a particular file at a given point in time. It means there are likely chances to see "Merge Conflicts". There are few reports and blogs on it; however, Apache SVN has yet to implement, this feature in the future release with long term release (LTR). There are several third-party software that can fill the gap and provide a locking facility but limitations of centralized version control systems (SVN) and approaches to its migration to decentralized VCS. The irony is that it can only be partially implemented through properties and hooks. Hence, locking feature is considered missing in SVN, and the result is somewhat fragile.

SVN Does not Support Merge History

CVS, Mercury, and SVN almost have the same set of features, especially merging. In fact, in some cases and working style, SVN is better than other centralized VCS. It means that changes in Subversion are similar to CVS. A developer uses Subversion to merge his/her changes committed by any other developers on the same file. Subversion merges together trivial changes and those that do not overlap. In this sense, that is the same working style of other centralized VCSs like Mercury. Where Subversion falls short is identifying the merge conflict and how to resolve this issue and also merging between branches.

SVN Does not Have Visualization Tools

In order to see all the revision graph, merge history of a subversion repo the information the SVN user enters the logs at commit time. There is no visualization tool available; however, some third-party tool like Smart SVN is available to help on this. Figure 5 shows the algorithm for SVN to Git migration.

A common problem in software development is lack of knowledge of business products and insufficient details about a feature. It resulted negatively on finding the futuristic error in the production environment upon an existing feature. Even in cases where product feature is adequately described but restrictive licenses of software make it difficult to use because of license restriction, government laws, and its expensive. There is a workaround to use open-source software and then do some restricted analysis and build a CI/CD pipeline that can be easily taking code from a well-designed branched or forked from unrestricted Git repositories and finally separating the expensive proprietary software with restrictive licenses and non-license code. This helps eventually a well-tracked disciplined versioned data with ample opportunities to retrieve several unmodified and untouched raw files modified without losing some of their utility.

SVN: Distributed Repository

Conveyed stores are backed by a few adaptation control frameworks, which can be exceptionally significant for a few bigger ventures, particularly open-source ventures.

Fig. 5 Algorithm for SVN to Git migration

```
Begin
    Define svn_repo_url
    Define git_repo_url
    Set svn_repo_url
    Set git_repo_url
    If  svnAuthors File is present
         Delete svnAuthors File
    End the construct
    If GitAuthors File is present
        Delete GitAuthors File
     End the construct
     Print:  Removing files previous runs
     Change Directory svn_repo_url
     Find the unique Svn Authors
     Print:  Added list of svn authors to svnAuthors file >logfile
     Change Directory git_repo_url
     Find the unique Git Authors
      Print Added list of GIT authors to GitAuthors file
      If SVNAuthors Not Equal GitAuthors)
           Print SVN and GIT Authors lists do not match
           Email " Users Don't Match"
       Else
            Print SVN and GIT Authors list match
            Email " Users  Match"
       End the construct
End
```

Subversion does not currently have any support for distributed repositories, but there is a wrapper layer on the top of SVN API which can be considered as the secondary project, called SVK. SVK generally provide a distributed wrapper for a Subversion repository.

4 Results and Discussion

Speed and agility are two of the most important aspects of any form of control. Naturally, programming locally is frequently faster than using resources on a public server. Stone monuments' expansive size and higher conditions make the construction and assembly of their parts more difficult and time-consuming. Microservices are less resource-sensitive and flexible. Since the modules are not connected to one another, it is simpler to construct and send. Following the construct's effectiveness, the passing of all unit tests, and the fulfillment of the construct framework, the next crucial step might be a push button or programmed arrangement to generation. Cutting the setup time allows for quick focus and the execution of many excellent coding techniques because of its.

The biggest advantage of monolithic architecture is inherent with fault tolerance. In fault tolerance, if any portion or subsystem does not work or fails in a monolith system, then the entire system may drastically go down. Microservices are more fault-tolerant than monoliths because a single instance or a service can continue working even if another service or instance gets failed. As the monolithic system is complicated and very large in volume. Usually, Monolith systems are very large in volume, and sometimes they are deployed as 1–5 terabytes as a whole. Sometimes Monolith becomes large and very clumsy like time-consuming.

5 Conclusion

Subversion improves upon the many exasperations of other centralized version control systems like Mercury and CVS. SVN working style is straight and easy as it executes its operation directly and provides a very flexible and powerful way to its developers. There are several features incorporated in SVN which include its operation on several branches and keeping the tags on the branches, for example, a file copy command. But some other limitations like merge conflict resolution, its repository database complicated architecture, and its internal APIs for network communications are still expected to be improved. Yes, Subversion provides new features that is missing in other VCS like Mercury and CVS.

It has been proven that Subversion does have its several limits, files in parallel processing, keeping the weak merge history and missing distributed repository. It has been evident that they are well overtaken by Subversion's strengths in most project situations and are considered as general problems that are also present to one degree or another VCS.

Git is very fast and scalable compared to other version control systems which result in the handling of large projects efficiently. Git calls this process as "cloning". It helps faster build and deployment using CI/CD. It has been proven that Git is way faster than SVN because cloning the data of local repository of almost one terabyte is way faster. Git provides a safer and reliable communication among several developers by a better way of collaboration among developers working on their local repository because the central repository is always being backed up in every author. Hence, in the case of catastrophic event happens at central server, the data is still preserved and can never be lost as it can be fetching from author's local machine. SHA1 is a cryptographic algorithm that converts the commit object into a 14-digit Hex code. Git helps developers to write the code offline so in case of a central repository is unavailable due to network issue or server crash, the developer community can still continue development and provide the customer solutions to end customers within defined SLAs.

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Bibliometric Analysis of Green Manufacturing in Automobile Sector

Surender Singh, Omprakash Mishra, and Krishan Kumar

1 Introduction

Industrial sector growth over the last decade generates lot of pollution, which causes health hazards to the living being. Both China and India are economically growing countries, and sustainable development is possible through manufacturing sector by protecting the environment [1]. In India, automobile is one of the largest sectors, growing at very high rate and its growth play an important role in Indian economy [2]. This sector also generates heavy pollution causing deterioration of environment [3]. Pollution produced by the vehicles can be controlled by different techniques like using electric vehicles [4], reducing the vehicle weight [5], technological advancement [6, 7]. A number of ancillary units are linked with the original manufacturers (OEM) like; Maruti Suzuki, Hyundai, Honda, Tata motors, etc., these industries are mostly assembling the components supplied by their ancillary plants. To control the pollution, the green concept was developed around 1994. But low attention was given at that time.

Green manufacturing is to reduce the pollution, reduce use of energy and minimize wastage. GM gained popularity in recent years. But very little work is done in the field of Green manufacturing in automotive sector. From 2015 onward, a lot of works are done in this area in different manufacturing sectors [8]. To get deep insight development in this field, bibliometric analysis adopted for this purpose. With the development of scientific data base like web of science and Scopus made it is easy for the bibliometric analysis that develops the interest among the researchers to know the in-depth knowledge over the world. To perform the bibliometric analysis, the Scopus data base has been used. Further analysis is done using software, that is, VOSviewer, [9]. In earlier bibliometric papers, network analysis was not performed, it is recently

S. Singh (✉) · O. Mishra · K. Kumar
Department of Mechanical Engineering, J C Bose University of Science and Technology, YMCA Faridabad, Faridabad 121006, India
e-mail: surendersngh056@gmail.com

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developed method and used by few authors in their work. This network visualization technique is very helpful in the bibliometric analysis to find out development of concept and actual executions on the suggestions given through academic researches. Bibliometric analysis is used in different fields over the years to discover the trends in particular area, different patterns of research, their linkages.

2 Literature Review

Literature review is first step to get the research in the right direction. Proper literature is done in this chapter that is helpful to deep knowledge of the topic. In this research, bibliometric technique is used to perform the literature review. Kumar et al. [10] had done bibliometric analysis for the comparative analysis of GM in three countries, for this author used VOSviewer for network visualization and NVivo software's to know the different concept of GM on Scopus data. Pang and Jhang [11] had performed the bibliometric analysis on web of science data from 1970 to 1980. In this chapter, they performed the keyword analysis, cluster analysis and MDS analysis for green manufacturing. Dhontu et al. [9] explained how to conduct the bibliographic analysis. In this chapter, they showed that this analysis is divided into two parts, that is, performance analysis, that is, the contribution of research articles and science mapping and the relationship between different constituents. Kazemi et al. [12] had performed the bibliometric and content analysis on reverse logistics and closed loop supply chain. This data initially taken from both Scopus and web of science data base, then from these data papers are selected that are published in IJPR. Yadav et al. [13] had done bibliometric analysis on research on sustainable energy; in this, they used web of science and Scopus data base, they performed different analysis like discipline analysis, country analysis co-citation for the future directions of research. In this chapter, bibliometric analysis was done to know the development of green manufacturing in automotive industries. Bibliometrics analysis is used to measure the interrelation and impacts of articles within a limited area of research.

3 Methodology

Data for the analysis are obtained from Scopus data base by entering the keyword. Analysis and visualization of data are done by vosviewer software. Network can be visualized in the form of countries, authors, author's keywords, keywords, affiliation, most cited papers. There are five steps as shown in the Fig. 1: select Scopus data base, entering the keywords for searching the article, finding the suitable articles for analysis, finding top cited sources, publications and organization, in the last network analysis.

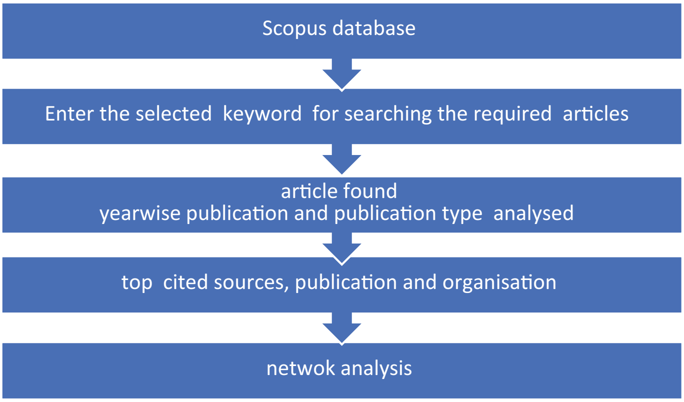


Fig. 1 Methodology of analysis

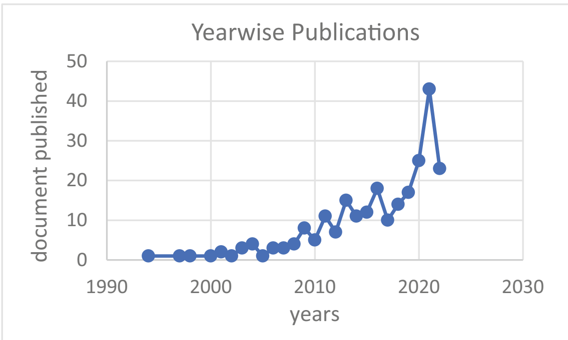
4 Bibliometric Analysis

Aim of this study is to analyze the development of Green manufacturing in automotive sector through bibliometric analysis of Scopus data. By searching the keyword green manufacturing to database, around 6000 (six thousand) articles were found without applying any filter. By applying filter "automobile industry" as keyword, around 244 articles were left. Which shows that lot of work is done in the field of green manufacturing but very little work is done on the GM in automotive industry. Figure 2 shows slow research since 2010, and then gaining momentum after 2015 onwards. It can be seen here that, more than 100 articles are published in last three years, which shows the high interest in the field of GM in Automotive sector.

Figure 3 represents the types of articles published from the selected data. This shows that 137 are Research papers, 76 are conference papers, 16 review paper, 11 book chapter.

Next analysis is done on the basis of publications. In this, only those Journals have been selected which have at least five publications in the selected field. Table 1

Fig. 2 Year wise publication



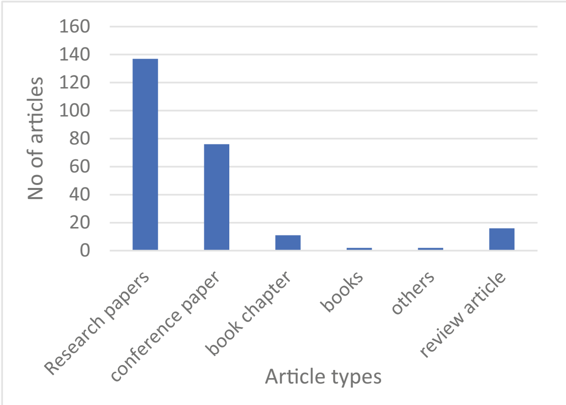


Fig. 3 Type of article published

Table 1 Top cited sources

S. No	Source	Documents	Citations
1	Journal of Cleaner Production	12	1309
2	Materials Today: Proceedings	5	23
3	Advanced Materials Research	5	11
4	Sae Technical Papers	5	6
5	Applied Mechanics and Materials	8	3

shows the maximum number of 12 articles are published in the Journal of cleaner production. These publications also have maximum citation 1309. The second most cited and reference journal is materials today with citations of 23.

4.1 Co-authorship Analysis

Table 2 represents the co-author of different countries. The selection criteria for selection is five articles and only those countries are selected which have at least 5 co authorship. Table 2 shows that more than 60 articles are co-authored by Indian authors means that Indians are working with different countries. Figure 4 represents the co-authorship between countries, size of circle shows that Indian and Chinese authors have maximum co-authorship. In this chapter, three clusters are visible by three colors, same clusters mean they have more co-authorship among them.

Table 2 Co-authorship country analysis

Country	Documents	Citations
India	60	1340
China	59	2685
United States	31	2255
Malaysia	13	452
United Kingdom	11	431
Japan	8	181
South Korea	7	204
Italy	7	176
Germany	7	163
France	7	159
Spain	6	228
Australia	6	190
Denmark	5	391

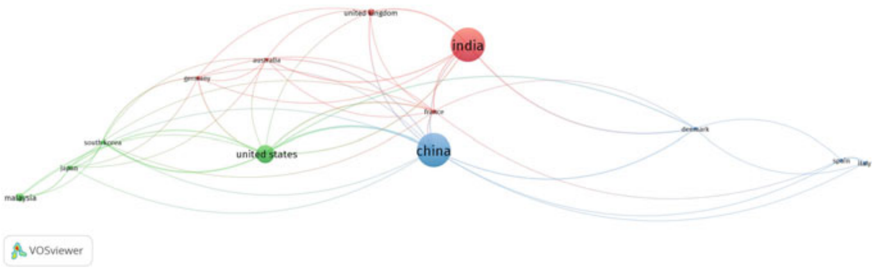


Fig. 4 Co-authorship country analysis

4.2 Co-occurrences Analysis of Keywords

In co-occurrence, analysis represents that a keyword is how many times appears in the selected data. In this analysis only, those keywords are selected which have minimum 10 times appears in the articles. Out of 2536 keywords, 32 keyword meet the threshold. The size of circle represents the appearance of specific keyword. The distance between keyword relates the relationships between the keyword, that is, if distance between them is more, they have weak relationship, if close they are strongly related.

The link strength shows the link of particular keywords with others, in Fig. 5 shows that automotive industry, green manufacturing and automobile manufacture are closely related. The link strength of four keyword automotive industry, green manufacturing, automotive manufacture and sustainable development is more than 150. It means that they are highly linked with other articles. The different colors represent the different clusters. There are four clusters visible.

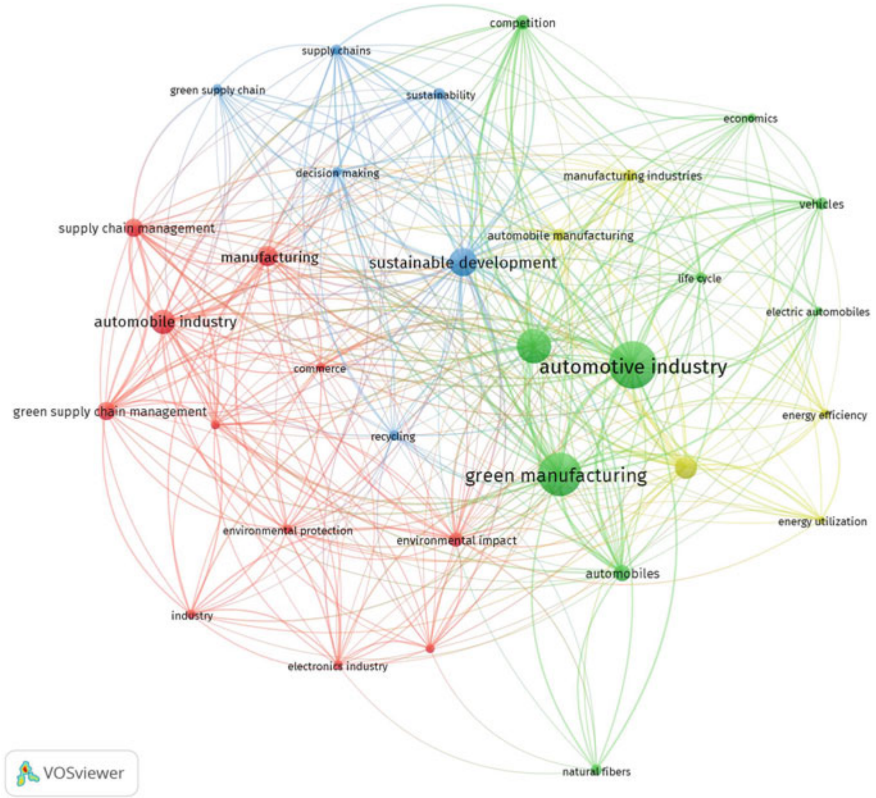


Fig. 5 Co-occurrence analysis of keyword.

4.3 Overlay Visualization

Overlay density represents the development of concept in two colors from blue to yellow. Blue colors represents the low impact and yellow colors represents maximum impacts the use of keyword from 2013 to 2017. In this Fig. 6, word related to automotive industry are very much in use but the keyword related to the green manufacturing, sustainable gain popularity in from 2017.

5 Result and Discussion

Network analysis is performed with VOSviewer software. This software is used for keyword analysis and co-occurrence analysis. From keyword analysis, it has been found that automotive industry, green manufacturing, sustainable development has maximum occurrence means these keywords are related to GM and trend is increasing

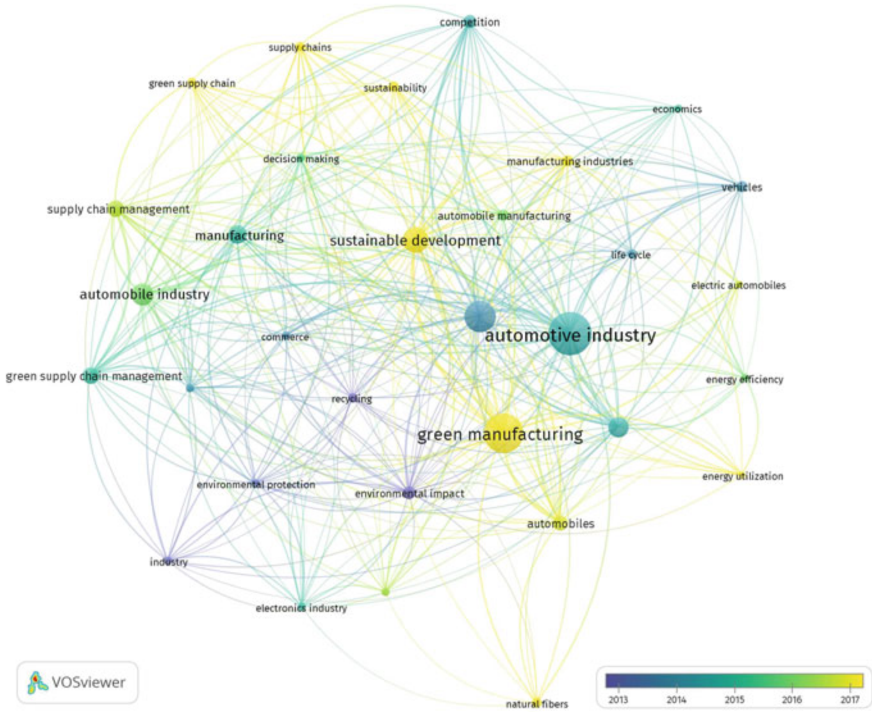


Fig. 6 Overlay visualization of keywords

in the industry towards sustainable development. Co-occurrence analysis shows that Indian authors has maximum co-authorship means India is working jointly on green concept with other countries.

6 Conclusion

This article is attempted to find out the green manufacturing trends in automobile sector. Results shows that the trend is increasing toward the green manufacturing, sustainable manufacturing in automobile sectors. Co-occurrences analysis shows that there is strong linkages in these keywords represents that trends are increasing to towards green concepts. Co-authorship analysis shows that Indian authors are working with other countries to counter the environment issues in automotive sector. More analysis parameters are available in the software which can be performed. The application of this research is obvious to know important aspects of GM specially in automotive sector and growing interest to preserve environment to keep everyone healthy.

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Building a Greener Supply Chain with Blockchain: A Review and Future Research Directions

Raksha Agrawal, Alok Yadav, Rajiv Kumar Garg, and Anish Sachdeva

1 Introduction

"Blockchain is a decentralized database or digital ledger that records transactions across a network of computers"[1]. It operates using a series of blocks that are connected through cryptography, ensuring the security and transparency of transactions. Each block in the chain contains a list of transactions and a unique digital signature that links it to the previous block [2]. The decentralized nature of blockchain means that no central authority is required to verify or approve transactions. Instead, the network of computers involved in maintaining the blockchain works together to validate transactions and update the ledger [3]. This creates a secure, tamper-proof, and transparent system for recording and tracking transactions. Blockchain technology has a wide range of applications, including financial services, Supply Chain Management (SCM), voting systems, and more. Its decentralized and secure nature makes it an attractive solution for various industries, as it reduces the risk of fraud and promotes transparency in transactions [4]. In recent years, there has been an increasing global concern over the environmental impact of supply chain management [5]. With the rise of climate change and the depletion of natural resources, businesses, and consumers alike are looking for ways to minimize their carbon footprint and promote sustainability in all areas of the economy, including the supply chain [6]. At the same time, the rise of blockchain technology has the potential to revolutionize the way that businesses manage and track their supply chains. With its decentralized, secure, and transparent nature, blockchain is ideally suited to help promote sustainability in the Supply Chain (SC), by enabling businesses to track their products from source to end user, monitor the use of resources, and ensure the ethical and environmentally friendly production of goods. The integration of "blockchain technology"

R. Agrawal (✉) · A. Yadav · R. K. Garg · A. Sachdeva
Department of Industrial and Production Engineering, Dr B R Ambedkar National Institute of Technology Jalandhar, Jalandhar 144027, India
e-mail: rakshaa.ip.20@nitj.ac.in

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with I4.0 and GSC management has the potential to revolutionize the way businesses manage their supply chains [7]. By leveraging the strengths of blockchain, I4.0 and GSC management can improve the efficiency, transparency, and sustainability of SC operations. Blockchain technology has the ability to provide a secure and tamper-proof record of transactions. This makes it an ideal tool for tracking the flow of goods and materials through the supply chain [8]. In a GSC context, this can help to promote transparency and accountability in the use of natural resources, as well as reduce the risk of fraud and counterfeiting in the SC. "Blockchain technology" has the ability to enable real-time monitoring and tracking of supply chain activities [9]. This can provide valuable insights into the performance of SC operations and allow businesses to identify areas where they can improve their sustainability and efficiency. I4.0 technologies, such as the "Internet of Things" (IoT) and "Artificial Intelligence" (AI), can be integrated with blockchain to provide even more advanced SCM capabilities [10]. For example, sensors and other IoT devices can be used to gather real-time data on SC operations, which can then be analyzed using AI to identify opportunities for improvement. The integration of blockchain technology with I4.0 and GSC management has the potential to create a more efficient, transparent, and SSC that is better equipped to meet the challenges of the twenty-first century. By leveraging the strengths of these technologies, businesses can improve their supply chain operations and help to create a more sustainable and equitable global economy. Present study aims to explore the innovations and challenges of building a GSC with blockchain, through a bibliometric analysis of existing research. The study will examine the role of blockchain in promoting sustainability in the SC, the key challenges and limitations facing businesses as they seek to adopt blockchain technology, and the future trends and innovations that will shape the use of blockchain in the supply chain. Current investigation aims to address the following key Research Questions (RQ):

RQ1. What are the current trends in publication, which author, country, and institutions working in this field?

RQ2. What are the key challenges of building a greener supply chain with blockchain, and the limitations facing businesses?

The results of this study will be of interest to a wide range of stakeholders, including businesses, policymakers, academics, and consumers, who are looking to promote sustainability and efficiency in the SC, and who are interested in the potential of "blockchain technology" to drive change in this area. The findings will provide a valuable resource for those seeking to understand the benefits and challenges of adopting "blockchain" in the SC and will offer practical insights and recommendations for businesses looking to adopt this technology in order to promote sustainability and efficiency in their SC.

The upcoming part of this study is structured as follows: Sect. 2 provides an overview of the literature review, Sect. 3 details the methodology employed in the study, Sect. 4 offers the results and discussions of the study, and finally, Sect. 5 will present the study's conclusion.

2 Literature Review

The literature review has shown a growing interest in the integration of blockchain technology with I4.0 and GSC management, which we can see in the result section. Researchers have explored various aspects of this integration, including the use of blockchain for tracking and traceability in SC operations, the integration of I4.0 technologies such as “IoT” and “AI” with “blockchain” to improve SCM, and the potential of blockchain to improve the sustainability of SC operations [11]. One of the key findings from previous studies is the potential of blockchain technology to provide a secure and tamper-proof record of transactions, which can be used to track the flow of goods and materials through the supply chain [12]. This can help to promote transparency and accountability in the use of natural resources and reduce the risk of fraud and counterfeiting in the SC. Studies have also shown that the integration of I4.0 technologies, such as “IoT” and “AI” with “blockchain,” can provide even more advanced supply chain management capabilities [13]. For example, sensors and other IoT devices can be used to gather real-time data on supply chain operations, which can then be analyzed using AI to identify opportunities for improvement. In terms of sustainability, previous studies have shown that blockchain technology can play a key role in promoting transparency and accountability in the use of natural resources, and in reducing the risk of fraud and counterfeiting in the SC [14]. By leveraging the strengths of blockchain and I4.0 technologies, businesses can improve the efficiency, transparency, and sustainability of their supply chain operations. A literature review has shown that the integration of blockchain technology with I4.0 and green SCM has the potential to revolutionize the way businesses manage their SC. Further research is needed to fully realize the potential of these technologies, and to address the challenges associated with their implementation [15]. Table 1 represents the existing study on blockchain implementation in SC.

These studies demonstrate the potential for BC technology to bring about positive changes in the SC and improve sustainability. However, as with any new technology, there are challenges to be overcome, including the need for collaboration between stakeholders and the development of standardized solutions.

3 Methodology

To conduct the bibliometric analysis, we utilized the Scopus database to search for documents containing the keywords “Industry 4.0” and “Green supply chain” in their titles, abstracts, or keywords. A total of 122 documents were identified on Scopus as of February 11, 2023, and we applied exclusion and inclusion criteria to filter out irrelevant documents [17]. For example, we only included English-language documents of the source type Journal and conference proceedings, and document types limited to article, conference paper, and review. We gathered information on the universities, countries, and publication years of the selected documents, which

Table 1 An existing study on blockchain implementation

Type	Focus area	Outcomes	Authors
Empirical study	Sustainability in supply chain management	Implementation of BC technology in the SC improved transparency and accountability, leading to a reduction in waste and an improvement in sustainability	[13]
Empirical study	Supply chain efficiency and fraud prevention	It has been found that the integration of BC technology with I4.0 technologies, such as "IoT" and "AI", improved SC efficiency and allowed for real-time monitoring of supply chain activities. The study also showed that the use of blockchain reduced the occurrence of fraud and counterfeiting	[16]
Survey-based study	Traceability and operational cost reduction in supply chain management	Found that a significant number of companies are interested in using blockchain technology to improve the sustainability of their supply chains. The survey also revealed that many companies face challenges in implementing blockchain technology, including a lack of understanding about the technology and its potential applications in the SC, data privacy, and security concerns, and the need for standardized solutions	[14]
Review	Traceability and operational cost reduction in supply chain management	It has been seen that the use of BC in the SC can lead to an improvement in traceability and reduced operational costs but also identified the need for more education and awareness about the benefits and limitations of BC technology in the SC	[12]
Review	Traceability and sustainability in the fashion supply chain	The study found that the implementation of BC technology in the fashion industry can improve the traceability and transparency of products, reducing the occurrence of sweatshop labor and promoting sustainable practices	[3]

we used in the bibliometric analysis to identify publication trends and patterns. This approach allowed us to obtain insights into the most influential authors, journals, and countries in the field, as well as the development of research themes related to the GSC and I4.0 technologies.

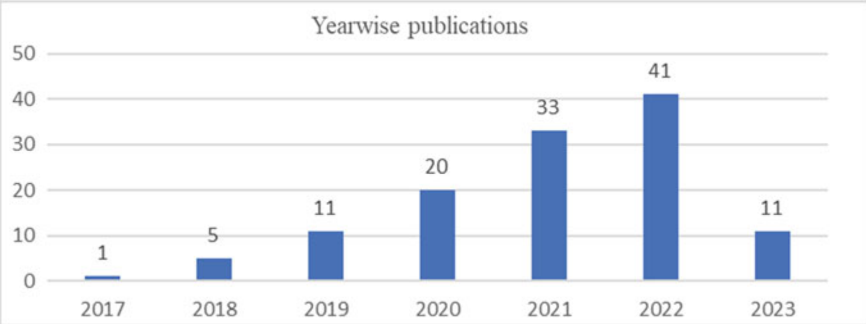

Fig. 1 Trend of publications

4 Result and Discussion

4.1 Discussion on Descriptive Analysis

RQ1. What is the current trends of publication, and which author, country, and institutions working in this field?

4.1.1 Growth Rate of Publications Annually

According to Fig. 1 in the study, the number of publications related to machine learning and I4.0 in the context of GSC has been increasing each year. The data show that in 2017, only one publication was recorded in this area. However, this number has been growing every year since then. By 2022, the number of publications had reached its highest point, with 41 publications being recorded. This trend indicates that there is a growing interest and importance in researching sustainable Blockchain in the context of Industry 4.0 and GSC. The increasing trend of publications in this area is an encouraging sign for the development of sustainable and efficient supply chains. This research area has the potential to contribute significantly to creating a more sustainable future for businesses and the environment. The rise in publications may be due to the increasing use of I4.0 technologies, which has led to more research being conducted to explore their potential to create sustainable supply chains. Additionally, the growth of Blockchain as a tool for analyzing and optimizing supply chain operations has also contributed to the increased interest in this area.

4.1.2 Citation Structure Yearly

The term "citation structure" typically refers to how citations are employed within a given document or group of documents, and the connections between the works

Table 2 Yearwise mean citation structure

Year	N	Mean TC per art	Mean TC per year	Citable years
2017	1	0.00	0.00	6
2018	5	123.40	24.68	5
2019	11	87.64	21.91	4
2020	20	52.60	17.53	3
2021	33	23.30	11.65	2
2022	41	3.80	3.80	1
2023	11	0.45		0

that are being cited. As shown in Table 2, the citation structure in this case exhibits a maximum mean citation rate of 123.40 in the year 2018, followed by a rate of 87.64 in the year 2019.

4.1.3 Top 10 Affiliations

Table 3 shows that universities from developed countries such as France and England, as well as a university from developing countries like India, have published works on I4.0 and SSC. In fact, the top spot on the list is held by an institute from India with a total of 8 publications. It is worth noting that other developing countries such as South Africa, Morocco, and Iran have their institutes ranked in the top 10 affiliations.

Table 3 Top 10 Affiliations with publications

Affiliation	No. of documents	Country	Developed/Developing
National Institute of Industrial Engineering	8	India	Developing
University of Johannesburg	5	South Africa	Developing
Vellore Institute of Technology	5	India	Developing
University of Plymouth	5	England	Developed
Montpellier Business School	5	France	Developed
Plymouth Business School	5	England	Developed
Université Ibn Tofail	4	Morocco	Developing
University of Tehran	4	Iran	Developing
O.P. Jindal Global University	4	India	Developing
Ecole Nationale des Sciences Appliquées	4	Morocco	Developing

Table 4 Top 10 authors with publications

S. No	Name of Author	No. of publications
1	Mangla, S. K	6
2	Bag, S	5
3	Jenoui, K	4
4	Luthra, S	4
5	Raut, R. D	4
6	Chiappetta Jabbour, C. J	3
7	El Abbadi, L	3
8	El Maalmi, A	3
9	Garza-Reyes, J. A	3
10	Jayakrishna, K	3

4.1.4 Top 10 Authors Working in This Field

The statement summarizes the findings from Table 4, which is likely a list of authors and the number of publications they have contributed to the field of study being examined. The highest number of publications that any one author has produced is 6, while the lowest number is 3. This indicates that, overall, there are not a large number of publications written by individual authors in this field. This could suggest that the field is still in a relatively early stage of development, and there is much more research to be done. Alternatively, it could mean that collaboration among researchers and institutions is highly valued in this field, and the emphasis is on producing work as a team rather than as individual authors.

4.1.5 Top 10 Keywords

Table 5 displays the top 10 keywords in the field of study being examined. The most commonly occurring keyword is "Industry 4.0," which appears 88 times. The second most frequent keyword is "sustainable supply chain," which appears 51 times, and in third place is "supply chain management," which is mentioned 49 times in connection with this research.

4.2 Top 10 Countries with Publications

Table 6 indicates that India has the maximum number of publications in the field of SSC integrated with I4.0, followed by the United Kingdom, France, and other countries. Interestingly, the fact to be highlighted is that India, despite being a developing country, is ahead of some developed countries like France, United Kingdom,

Table 5 Top 10 Keywords used

S. No	Keywords	No. of times used
1	Industry 4.0	88
2	"Sustainable supply chains"	51
3	"Supply chain management"	49
4	"Sustainability"	44
5	"Sustainable development"	44
6	Supply chains	28
7	Circular economy	27
8	Sustainable supply chain	24
9	Sustainable supply chain management	18
10	Decision making	17

and the United States in terms of the number of publications on this topic. Additionally, Morocco, another developing country, is also ahead of the United States. This suggests that research on SSC integrated with I4.0 is not limited to developed countries but is being actively pursued by developing countries as well. It is an encouraging sign that developing countries are making significant contributions to the field of SSC and I4.0. This could be due to a number of factors, such as a growing awareness of the importance of sustainability and the potential benefits of I4.0 technologies, as well as a desire to catch up with developed countries in terms of technological advancements and innovation.

Table 6 Countries with the number of publications

S. No	Country	No. of publications
1	India	33
2	United Kingdom	23
3	France	15
4	Morocco	11
5	China	8
6	Spain	8
7	United States	8
8	Germany	7
9	Turkey	7
10	Brazil	6

Table 7 Top source titles

S. No	Source title	No. of publications
1	Sustainability Switzerland	14
2	Journal Of Cleaner Production	9
3	Lecture Notes in Mechanical Engineering	6
4	Production Planning and Control	5
5	Resources Conservation and Recycling	5
6	Computers And Industrial Engineering	4
7	"Proceedings Of the International Conference on Industrial Engineering and Operations Management"	4
8	"2022 IEEE 14th International Conference of Logistics and Supply Chain Management Logistiqua 2022"	3
9	"International Journal of Productivity and Performance Management"	3
10	"Journal Of Self Governance and Management Economics"	3

4.2.1 Top 10 Sources of Publication

Table 7 presents the top 10 sources of publication in the area of research being examined. The three sources with the highest number of publications are Sustainability Switzerland, which has published 14 articles related to this research topic, followed by the Journal of Cleaner Production, with nine articles, and Lecture Notes in Mechanical Engineering, with six articles. The prominence of these sources indicates that they are major contributors to the field and are playing a significant role in advancing knowledge and understanding of SSC integrated with I4.0. Researchers and practitioners interested in this area may find these sources to be highly informative and valuable, as they have produced a substantial amount of research on the topic. By reviewing the articles published in these sources, researchers and practitioners can gain insight into the latest findings, trends, and best practices in the field, and use this knowledge to inform their own work.

4.2.2 Co-citation Network Analysis

The co-citation network analysis of authors is a method that is used to investigate the relationships between researchers within a particular area of study by examining the frequency with which they are cited together in academic works [18]. When several authors are cited together in a specific set of scholarly works, each instance is considered a co-citation, and a link is formed between those authors. Figure 2 illustrates the outcome of this analysis, where the network is represented by two clusters, denoted by the colors red and blue.

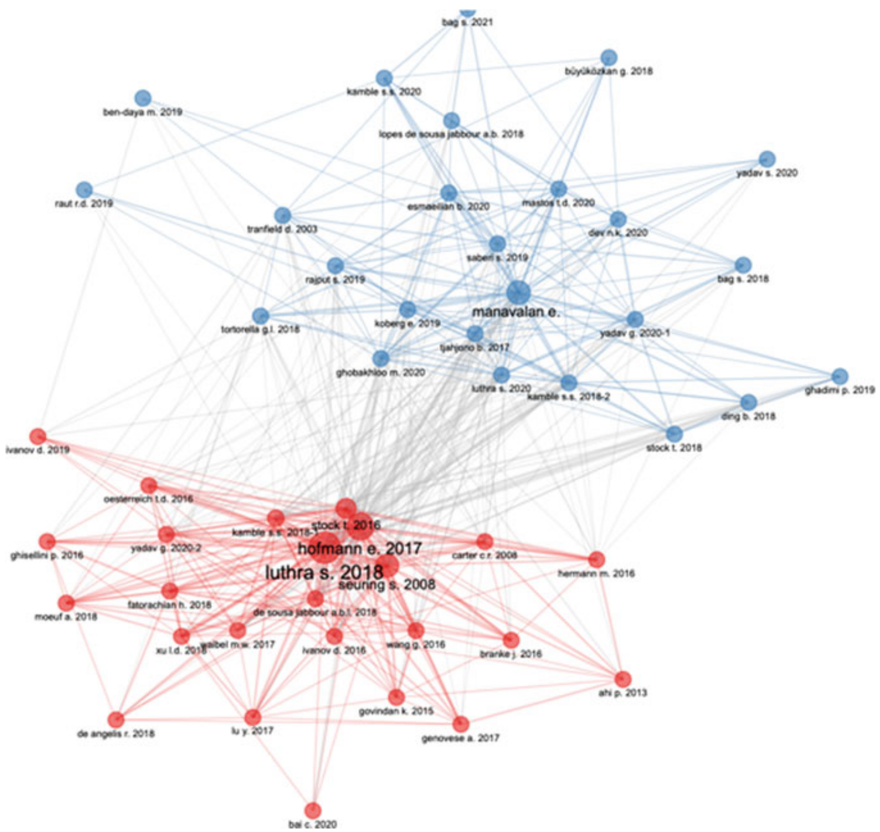

Fig. 2 Co-citations structure of authors

4.3 Discussion on Challenges and Limitations

RQ2. What are the key challenges of building a greener supply chain with blockchain, and the limitations facing businesses?

The adoption and implementation of blockchain technology in green supply chain management face several challenges, including:

- Technical Complexity: The technical complexity of blockchain technology can be a barrier for organizations that are not familiar with the technology. This can make it difficult for organizations to fully understand the potential benefits and challenges of implementing BC in their SC operations [19].
- Interoperability: Different blockchain platforms have different specifications, making it difficult for organizations to integrate BC into their existing systems and processes. This can lead to issues with interoperability and data sharing between different organizations [20].

- Security Concerns: Blockchain technology is often used to store sensitive and confidential information, such as financial transactions or personal data. Ensuring the security of this information is critical, and organizations need to be aware of the potential security risks associated with the implementation of blockchain [2].
- Scalability: Blockchain technology can struggle to scale to meet the needs of large organizations and their supply chains, which can limit its adoption in some cases [21].
- Cost: The implementation of blockchain technology can be expensive, especially for organizations that are just starting to explore the technology. This can make it difficult for small and medium-sized enterprises (SMEs) to adopt blockchain in their supply chains [22].
- Regulation: Blockchain technology operates in a largely unregulated environment, which can make it difficult for organizations to ensure that their implementation of blockchain complies with existing laws and regulations [23].
- Lack of Standardization: There is a lack of standardization in the use of BC technology in the SC, which can make it difficult for organizations to adopt and implement blockchain in a consistent and effective manner [24].
- Adoption by Stakeholders: For BC technology to be successful in GSC management, it is important that all stakeholders, such as suppliers, customers, and intermediaries, adopt and implement the technology. This requires a coordinated effort to educate stakeholders about the benefits and challenges of blockchain and to encourage them to participate in its implementation [25].
- Data Quality and Accuracy: Blockchain relies on the accuracy and quality of data input into the system. Ensuring that data is accurate and up-to-date is a challenge, especially in supply chains that are complex and involve multiple organizations [26].
- Integration with Existing Systems: Integrating BC technology with existing systems and processes can be challenging, especially for organizations with complex and established SC. This can require significant investment in technology and resources [27].
- Resistance to Change: The implementation of new technology, especially in established supply chains, can be met with resistance from employees and other stakeholders who are familiar with existing systems and processes. Addressing this resistance requires a comprehensive change management strategy that focuses on educating stakeholders about the benefits of blockchain and addressing their concerns [28].
- Trust and Transparency: Building trust and transparency in the SC is one of the key benefits of blockchain technology. However, this requires a high level of cooperation and collaboration between organizations, and the development of standardized protocols and data-sharing agreements [29].
- Privacy: Privacy concerns are a major challenge in the implementation of blockchain technology, especially in industries where sensitive and confidential information needs to be protected. Ensuring that privacy is maintained while still leveraging the benefits of blockchain requires a careful balancing of technology and policy [30].

Addressing these challenges requires a collaborative effort from organizations, technology providers, and governments, as well as the development of standardized solutions and best practices.

5 Conclusions

This bibliometric analysis reveals the current trends and patterns of research on the GSC integrated with I4.0 and Blockchain. The results demonstrate a growing interest in this area of study, with a significant increase in the number of publications in recent years. The study highlights that while developed countries such as France, the United Kingdom, and the United States are major contributors to the research in this field, developing countries such as India, South Africa, Morocco, and Iran are also actively engaged in producing important research. The analysis identifies the most common research themes, with I4.0, SSC, and SCM being the most frequently occurring keywords in the publications. The co-citation analysis of authors provides a deeper understanding of the network of researchers working in this field, revealing the most influential and well-connected scholars. The integration of blockchain technology with I4.0 and SSC management holds great potential for creating a greener supply chain. This is due to blockchain's ability to provide increased transparency, efficiency, and security in supply chain transactions. However, the implementation of BC in the SC faces several technological and operational challenges, such as data quality and accuracy, integration with existing systems, resistance to change, trust and transparency, and privacy. Despite these challenges, previous studies have shown that the adoption of BC technology in the SC has the potential to significantly reduce waste, increase efficiency, and improve sustainability. The bibliometric analysis of previous studies has revealed a growing interest in the use of blockchain in green supply chain management, with a focus on the benefits, challenges, and future directions of its implementation. Further research is needed to explore the long-term impacts of blockchain on the supply chain, and to address the technological and operational challenges that currently exist.

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Simultaneous Optimization of Power Consumption and Surface Roughness in Machining Using NSGA-II and Weighted Sum Method

Vijaypal Poonia, Rishi Kumar, Deepika Choudhary, Rakhee Kulshreshta, and Kuldip Singh Sangwan

Nomenclature

ANOVA	Analysis of Variance
GRA	Grey Relational Analysis
GA	Genetic Algorithm
NSGA II	Nondominated Sorting Genetic Algorithm II
PCA	Principal Component Analysis
PSO	Particle Swarm Optimization
RSM	Response Surface Methodology
WSM	Weighted Sum Method

1 Introduction

Machining is a value-added manufacturing process that removes material from a workpiece to transform raw materials into finished products of desired shape and size. A significant amount of energy is consumed in machining processes like turning, milling, drilling, etc. This results in increased costs, negative environmental impacts like climate change, global warming, and biodiversity losses. Similarly, product quality, often represented by surface finish, is a priori demanded by a customer, functional requirements of the component, and the component itself [1]. It is an indirect representation of the energy and resources utilized in the machining process. This makes it necessary for a manufacturing company to meet the standards for

V. Poonia · R. Kumar · D. Choudhary · R. Kulshreshta · K. S. Sangwan (✉)
Birla Institute of Technology and Science Pilani, Pilani Campus, Pilani 333031, India
e-mail: kss@pilani.bits-pilani.ac.in

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product quality and adopt energy-saving practices in order to remain competitive globally, comply with governmental regulations, deal with rising electricity prices, and customer awareness.

Optimization is one of the several strategies that can be utilized for enhancing the energy and resource efficiency of the machining process [2]. Multi-objective optimization has become a crucial step in determining the optimal combination of machining parameters [3] to deal with conflicting responses simultaneously. Optimization of cutting parameters directly impacts the machining process efficiency, carbon emissions [4], productivity, machining cost, and product quality [5].

Turning is the most widely used material removal process and involves roughing, and finishing operations [6]. It is used to manufacture components in metal working industries like aerospace, automobile, electronics, mechanical, medical, military products, etc. Rough turning removes maximum material from the workpiece in the shortest possible time while consuming the least amount of energy, but at the expense of surface finish. On the other hand, finish turning removes minimum material from the workpiece and produces a smooth surface finish, but at the expense of higher energy consumption.

Researchers have obtained optimal solution(s) in the turning process using several optimization techniques such as GRA integrated with PCA and RSM, GA, PSO etc. Although multi-objective optimization techniques have been widely used to address conflicting responses, Pareto solutions have been obtained to provide multiple options to a practitioner in selecting process parameters depending on management requirements. There is hardly any literature where Pareto solutions have been provided that depend on the weight assigned to the response function. Winter et al. [7] determined weight-dependent Pareto-optimal solutions using WSM for the simultaneous optimization of technological, economic, and environmental objectives. However, the work was performed on grinding operations, and its applicability in the turning process still needs to be discovered. Most of the researchers have provided Pareto solutions for either rough or finish turning process. There has been hardly any attempt to provide optimal combination of parameters for rough as well as finish turning process.

Kant et al. [8] determined the optimal combination of turning process to reduce power consumption and surface roughness, simultaneously using GRA integrated with PCA and RSM. The developed regression models were statistically significant, reducing 6.59% and 2.56% in power consumption and surface roughness, respectively, using optimal solution over the best experimental run. However, only a single solution was obtained without any attempt to generate Pareto solutions and weight-dependent Pareto solutions, thereby limiting its industrial applicability. The regression models were developed without the backward elimination technique, and some insignificant terms with a p-value greater than 0.5 were included in the developed models.

This chapter aims to simultaneously optimize power consumption and surface roughness in turning process. This is achieved by developing regression models using backward elimination technique that automatically removes the insignificant terms. Pareto solutions are then generated using WSM and NSGA-II methods for rough as well as finish turning operations. Results are then compared with existing literature to validate the developed regression models. The novelty of this chapter lies in proposing a methodology to generate Pareto solutions that depend on the weight assigned to the response function. This would assist a practitioner in better decision-making for selecting optimal parameters to simultaneously optimize conflicting responses, that is, power consumption and surface roughness in rough as well as finish turning operations, and depending on managerial requirements.

The present work is structured as follows: Sect. 2 presents the research methodology. Section 3 discusses the modelling results obtained using NSGA-II and Weighted Sum Method and compares them with existing literature. Finally, Sect. 4 concludes the present work and provides outlook for future work.

2 Research Methodology

The research methodology employed for the simultaneous optimization of surface roughness and power consumption is shown in Fig. 1. This is broadly divided into three stages, namely experimental planning, model development, and model solutions.

2.1 Experimental Planning

Experimental planning consists of four steps. The first step is to select the machine tool, workpiece material, cutting tool, process parameters, and responses. In the second step, pilot experimentation is performed to select levels of process parameters. The third step is to design experiments based on Taguchi L-27 orthogonal array. Lastly, experiments are performed to acquire power consumption and surface roughness data. The data for the present work was obtained from Kant et al. [8], where simultaneous optimization of surface roughness and power consumption was performed during the turning of a cylinder-shaped workpiece on a lathe machine. The workpiece of diameter 47 mm was made of AISI 1045 steel. Turning operation was carried using tungsten carbide inserts, varying cutting speed (v), feed (f), and depth of cut (d) based on the Taguchi L-27 orthogonal array.

2.2 Model Development

Regression models were developed using backward elimination technique that automatically removes the insignificant terms. The developed regression models for surface roughness and power consumption are denoted using Eqs. 1 and 2, respectively. Table 1 depicts the ANOVA results for the developed model. The p-value for

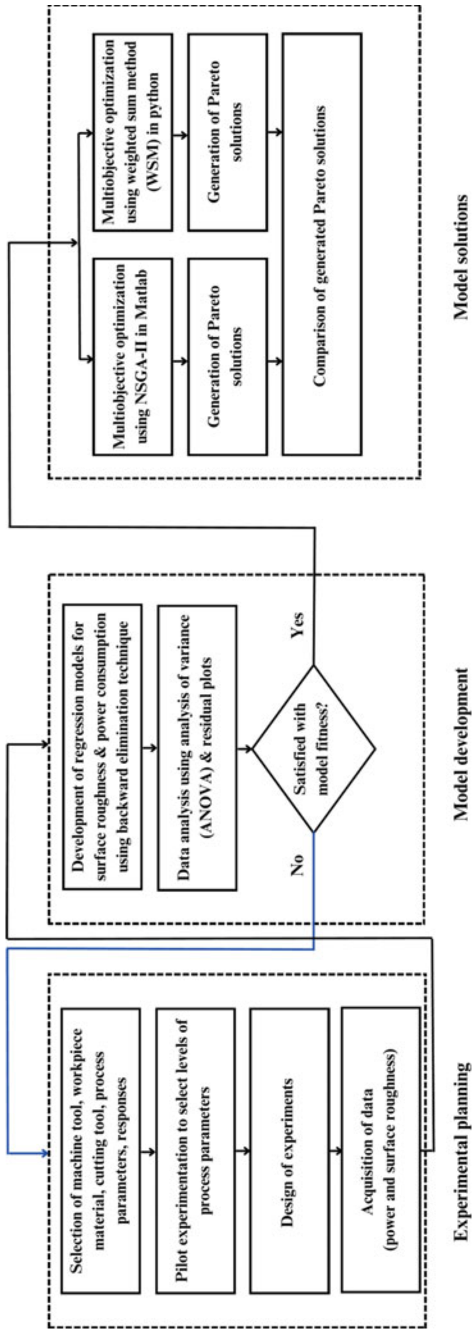

Fig. 1 Research methodology adopted for the simultaneous optimization of surface roughness and power consumption

all the terms is less than 0.05. This indicates that the developed model is adequate and statistically significant. The R-squared values indicate that the model explains 92.32 and 97.56 percent of the total variations in surface roughness and power consumption, respectively.

$$\text{Surface roughness(Ra)} = 2.41 - 0.0573v + 26.00f + 0.000191v * v \quad (1)$$

$$\text{Power consumption}(P) = 1.557 - 0.00994v - 8.64f - 0.934d + 0.0610v * f + 0.00710v * d + 5.71f * d \quad (2)$$

$$s.t.\ 103.31 \le v \le 174.14;\ 0.12 \le f \le 0.2;\ 0.5 \le d \le 1.5$$

Table 1 Analysis of variance (ANOVA) for surface roughness and power consumption

Analysis of variance (ANOVA) for surface roughness					
Source	DF	Adj SS	Adj MS	F-value	P-value
Model	3	20.1427	6.7142	92.11	0
Linear	2	19.8577	9.9289	136.21	0
v	1	0.391	0.391	5.36	0.03
f	1	19.4667	19.4667	267.06	0
Square	1	0.3335	0.3335	4.57	0.043
v * *v*	1	0.3335	0.3335	4.57	0.043
Error	23	1.6765	0.0729		
Total	26	21.8193			
Model summary	R-square = 92.32%				
Analysis of variance (ANOVA) for power consumption					
Source	DF	Adj SS	Adj MS	F-value	P-value
Model	6	6.46235	1.07706	133.21	0
Linear	3	6.13106	2.04369	252.76	0
v	1	1.08603	1.08603	134.32	0
f	1	0.87766	0.87766	108.55	0
d	1	4.16737	4.16737	515.41	0
2-Way Interaction	3	0.43692	0.14564	18.01	0
v * *f*	1	0.0901	0.0901	11.14	0.003
v * *d*	1	0.19041	0.19041	23.55	0
f * *d*	1	0.15641	0.15641	19.34	0
Error	20	0.16171	0.00809		
Total	26	6.62406			
Model summary	R-square = 97.56%				

2.3 *Model Solutions*

The developed empirical mathematical model is solved to obtain Pareto solutions using the multi-objective optimization algorithms, namely WSM and NSGA-II methods.

2.3.1 Weighted Sum Method

The WSM [9] integrates all the multi-objective functions into a single scalar, composite objective function using the weighted sum as shown in Eq. 3.

$$F(x) = w_1 * f_1(x) + w_2 * f_2(x) + \cdots + w_n * f_n(x) \tag{3}$$

$$s.t x \in \varphi(x)$$

where $\sum_{i=1}^{n} w_i = 1$, $w_i \in (0, 1)$ and $\varphi(x)$ is represent feasible set. The solution to the problem represented by Eq. (3) is Pareto solution for each positive $W = (w_1, w_2, \ldots w_n)$.

2.3.2 NSGA-II

NSGA-II is a widely used approach for multi-objective optimization. The method identifies Pareto solutions, which are non-dominated solutions, for addressing problems with multiple competing objectives. It uses a genetic algorithm-based strategy to find solutions. It begins with an initial population of candidate solutions and then ranks them based on their dominance relationships using a fast non-dominated sorting method. The algorithm also employs crowding distance to preserve solution diversity. For more information on NSGA-II method, readers may refer to Deb et al. [9].

3 Results and Discussion

The optimization problem is solved using the WSM in python using pyomo library and 'ipopt' solver with an Intel® Core i5-processor at 2.50 GHz and 8 GB of RAM. The value of w_i can be adjusted by the decision maker between 0 and 1. To quickly cover all Pareto-optimal solutions, the decision-maker starts with a coarse range. However, after investigating the area of interest, decision-makers can fine-tune, or use a denser grid, to find the most preferred solution. As depicted in Fig. 2a, an initial solution set is generated using $w_i = [0, 1]$ with an increment/decrement of 0.05. In Fig. 2b, the Pareto-optimal solutions are constructed using a $w_i = [0.70,$

0.82] increment/decrement 0.02 increment/decrement. The computational time is 8 s. The optimization technique NSGA-II in MATLAB R2020b solves the optimization problem with an Intel® Core i5-processor at 2.50 GHz and 8 GB of RAM. Figure 3a demonstrates the Pareto solutions that illustrate the surface roughness-power consumption trade-off and find the area of interest. After investigating the area of interest, decision-makers can fine-tune, or use a denser grid, to find the most preferred solution, shown in Fig. 3b. The computational time is 5.364 s. Table 2 represents the comparative study of the weighted sum method and NSGA-II. The results show that our approach is best compared to Kant et al. [8]. According to Table 2, the optimal value of power consumption and surface roughness is almost the same for all methods, which means the proposed methodology is robust. The most preferred solution (Ra = 1.2325 µm, $P = 0.5352$ kW) for the weighted sum method was obtained at $w_1 = 0.76$ and $w_2 = 0.24$. If the value of the weights of response functions changes, then the optimal value is changed. The proposed approach contains all optimal solutions (Pareto solutions), including the optimal solution obtained by Kant et al. [8].

4 Conclusions

The present work proposes a methodology utilizing NSGA-II and WSM to simultaneously optimize surface finish and power consumption in turning process. The following conclusions can have been drawn:

- The developed regression models are adequate and statistically significant.
- Pareto solutions provide a wide range of optimal parameter solution sets applicable for rough as well as finish turning operations.
- Prior to machining, knowing the optimal values of power consumption and surface roughness in advance would facilitate managerial decisions such as shop floor planning and scheduling.
- The proposed methodology is computationally fast and can be easily implemented using widely used software like Minitab, MATLAB, and python programming without requiring high computational demand.

The proposed methodology is general and can be applied to other machining operations such as milling, grinding, etc., considering additional responses such as material removal rate, tool life, force, etc.

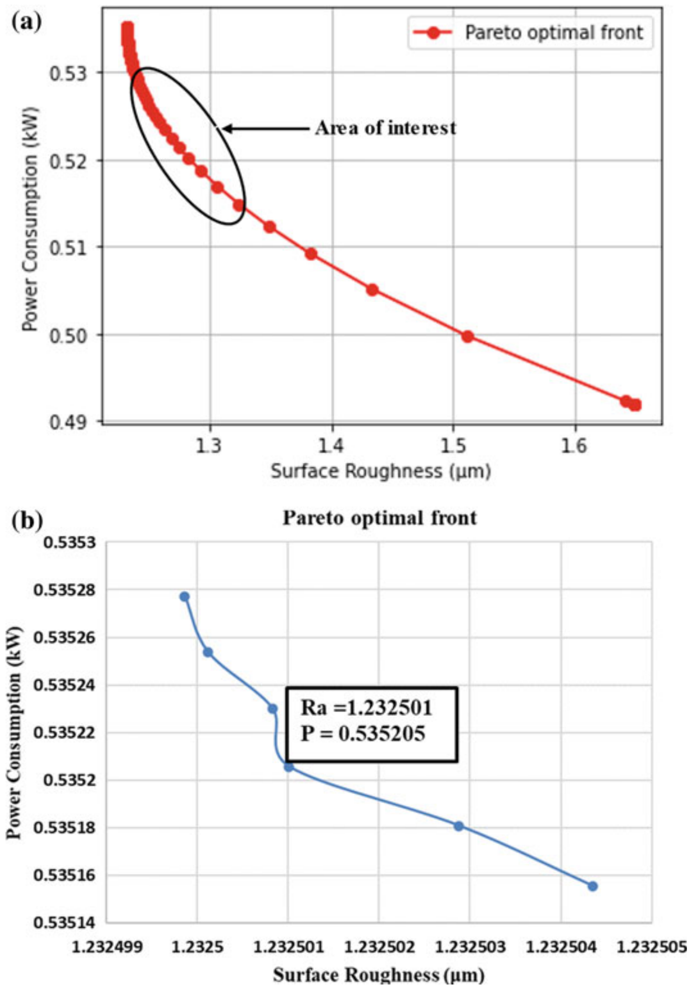

Fig. 2 **a** Pareto front for surface roughness and power consumption using weighted sum method in the first iteration. **b** Pareto front for surface roughness and power consumption using weighted sum method in the second iteration

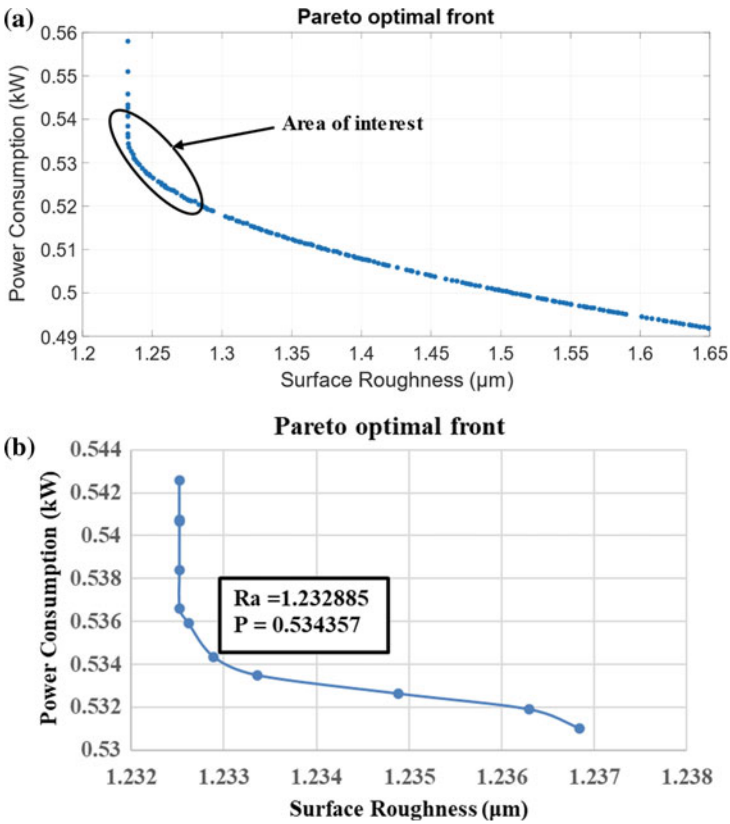

Fig. 3 **a** Pareto front for surface roughness and power consumption using NSGA-II in the first iteration. **b** Pareto front for surface roughness and power consumption using NSGA-II in the second iteration

Table 2 Comparison of WSM and NSGA-II techniques and results for power consumption (kW) and surface roughness (μm)

Methods	*v* (m/min)	*f* (mm/rev.)	*d* (mm)	Power consumption (kW)	Surface roughness (μm)
Best run	134.30	0.12	0.50	0.5740	1.2840
Weighted sum method	149.39	0.12	0.50	0.5352	1.2325
NSGA-II	144.12	0.12	0.50	0.5343	1.2328
Kant et al. [8]	127.63	0.12	0.50	0.5362	1.2500

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Solar-Powered Dehumidification System with Double Sorbent Wheel

Shruti Dikshit, Vijaykumar Javanjal, Akash Ashok Raymule, Shreyas Vitthal Kakade, Sudarshan Ramkrishan Gunjakar, and Girish Yuvraj Chopade

Nomenclature

Symbol	Description Units
$\dot{m}$	Mass flow rate of ambient air (kg/s)
R. H.	Relative humidity (%)
ρ	Density (kg/m^3)
v	Velocity of ambient air (m/s)
T	Temperature (°C)
ξ	Effectiveness
ω	Humidity ratio (kgv/kgda)
χ	Heat of adsorption (kJ/kg)
M	Molecular weight of water ($M = 18$)
R	Universal gas constant J/mol-K
P	Pressure of inlet air
V	Volume of inlet air
MRC	Moisture removal capacity
SSSD	Single solid sorbent dehumidifier
TSSD	Two-stage solid sorbent dehumidification system

S. Dikshit · V. Javanjal · A. A. Raymule (✉) · S. V. Kakade · S. R. Gunjakar · G. Y. Chopade
Department of Mechanical Engineering, Dr. D.Y. Patil Institute of Technology, Pimpri, Pune, Maharashtra 411018, India
e-mail: akashraymule321@gmail.com

S. Dikshit
Department of Mechanical Engineering, D.Y. Patil University, Ambi, Pune, Maharashtra 410507, India

A. Bhardwaj et al. (eds.), *Optimization of Production and Industrial Systems*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-99-8343-8_14

Subscripts

a	Air
e	Equilibrium
i	Inlet
m	Moisture
o	Outlet
s	Solution
m	Molecular weight of water

1 Introduction

The comfort of building occupants, the durability of building materials and the functionality of program types that manage hygroscopic materials are all impacted by indoor moisture. One of the most important considerations in the design of an air conditioning system is the capacity to keep precise humidity levels within a particular range by eliminating moisture from supply air. By blowing air over a chilled coil (made of water, glycol or refrigerant) that has been cooled below its dew point, moisture is traditionally removed. In a vapor compression refrigeration system, the refrigerant enters the evaporator in a liquid condition, absorbs heat, transforms into vapor, and then, with the aid of the compressor and condenser, returns to a liquid state.

In many cases, the air is subsequently heated back up to the desired supply temperature after this sub-cooling. Sorbent dehumidification is one strategy that may be used, depending on the particulars of the project. With an evaporative cooler, adding water to the space is the opposite of dehumidification, which releases heat instead. As a result, an in-room dehumidifier always heats the space while indirectly lowering the relative humidity as well as more directly lowering the humidity by removing and condensing water.

Several researchers have studied the performance of the single-stage solid desiccant dehumidification system (SSDD) by conducting experiments [1–4]. Dehumidifiers put sorbent materials to work absorbing moisture from the air. By double sorbent wheel the maximum moist air can convert be into dry air and then one air stream is ducted through the rotor with the air that has to be dried or processed in it. The first sorbent wheel adsorbs maximum amount of moisture and remaining moist air is dried further in second sorbent wheel (Fig. 1). The moist sorbent is heated by the rotor when it is introduced to the reactivation air stream. The hot air from the heater for reactivation or regeneration process is provided separately so that the process carried out effectively. The heater is powered by solar (Fig. 2). Water vapor is released as moisture from the sorbent substance. In the temperature range of 50–70 °C, a two-stage solid sorbent dehumidification system is preferable for deep drying applications. To increase moisture absorption capability and operate at low temperature

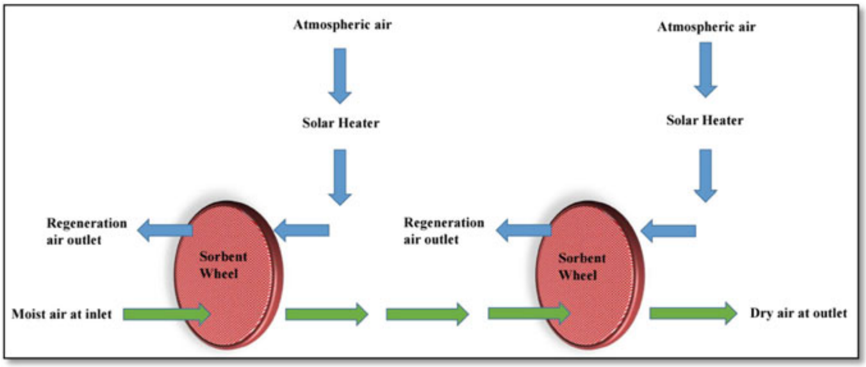

Fig. 1 Schematic of two-stage solid sorbent dehumidification

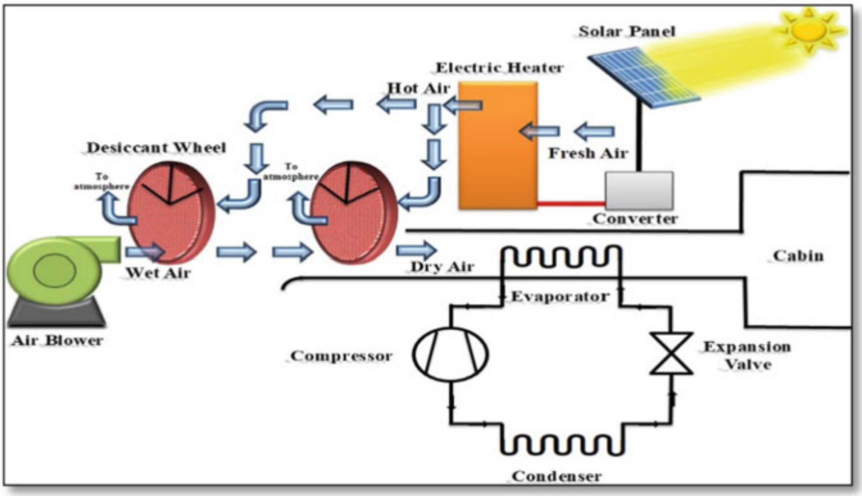

Fig. 2 Solar-powered dehumidification and cooling system with double sorbent wheel

two stage solid desiccant system is used [1–3]. Very few researchers have studied the performance of the two-stage solid desiccant dehumidification system and concluded that, although the system works at low regeneration temperature, the dehumidified ambient air outlet temperature is high [1, 2].

2 Experimentation

To find out the moisture removal capacity in single rotary sorbent wheel and in double sorbent wheel We have,

$$\text{MRC} = \frac{(\rho_{\text{air}} \times 60 \times Q \times \Delta\text{GPP})}{7000}$$

ΔGPP = Mass of water vapour in air at inlet—Mass of water vapour in air at outlet.

To find out the mass of water we have,

$$Pv = nRT$$

$$n = m/M$$

The following relationships are used to define the thermal and moisture effectiveness (T and m) [5–8].

$$\epsilon_T = \frac{\text{T}_\text{a}^o - \text{T}_\text{a}^i}{\text{T}_\text{s}^i - \text{T}_\text{a}^i}$$

$$\varepsilon_\text{m} = \frac{\omega_\text{a}^o - \omega_\text{a}^i}{\omega_\text{e} - \omega_\text{a}^i}$$

Table 1 gives information about operating parameters given in the system. Table 2 gives specifications of the solid desiccant system.

Table 3 case 1 and case 2 describes the difference between output parameters such as moisture removal rate and regeneration output temperature of SSSD system and TSSD system. In these tables, it is observed that in the SSSD system (Case 1) the moisture removal rate is lower compared to the TSSD system (Case 2). In the first case of the SSSD system the moisture removal rate is 4.8 g/s at an inlet air temperature of 29 °C and a RH of 58%, but in the case of a TSSD system at the same inlet air temperature and RH it is about 7.5 g/s. it is same with the regeneration outlet air temperature. In the SSSD system, the outlet temperature of the regeneration air is 48.2 °C with an inlet air temperature of 29 °C and 58% RH, but in the case of TSSD it is 59.8 °C, so it is increased in TSSD.

Table 1 Operating parameters for the analysis

Parameters	Operating range
	Solid desiccant
Desiccant material	Silica gel
Desiccant wheel length (m)	0.2
Desiccant wheel diameter (m)	0.38
Silica gel specific heat (J/kg K)	921
Silica gel thermal conductivity (W/mk)	0.175
Silica gel density (kg/M^3)	1129

Table 2 Specifications of the solid desiccant dehumidification systems

Parameters	Operating range	
	Solid desiccant	
	Inlet air value	Regeneration air Value
Air inlet temperature (K)	304	334
H_2O mass fraction of air (W/mk)	0.07	–
Rotation speed (rpm)	10	10
Mass source/sink (kg/m^3 s)	0.7	0.3
H_2O source/sink (H_2O/kg)	13 g	6 g

Table 3 Performances of single- or two-stage solid sorbent dehumidification systems under various intake circumstances

Inlet parameters			Outlet parameters	
Air flow rate (kg/s)	Air temperature (°C)	RH (%)	Moisture removal rate (g/s)	Air outlet temperature of regeneration (°C)
Case 1: SSSD system				
1	29	58	4.8	48.2
1	29	86	6.1	48.7
1	36	58	9.8	53.5
1	36	86	5.3	52.4
1.8	29	58	8.4	45.5
1.8	29	86	10.2	47.9
1.8	36	58	10.1	52.8
1.8	36	86	8.8	51.1
Air flow rate (kg/s)	Air temperature (°C)	Relative humidity (%)	Condensation rate (g/s)	Air outlet temperature of regeneration (°C)
Case 2: TSSD system				
1	29	58	7.5	59.8
1	29	86	8.8	61.2
1	36	58	12.5	64.4
1	36	86	7.9	64.2
1.8	29	58	12.2	55.4
1.8	29	86	14.7	58.6
1.8	36	58	15.6	63.5
1.8	36	86	12.8	61.3

3 Results and Discussion

Sorptive dehumidifiers let people live in houses even when it's wet outside. SSSD and TSSD moisture removal and condensation rate are used to measure performance. Figure 3 shows how the air flow rate, humidity ratio, and temperature affect the condensation rate and moisture removal efficiency of SSSD and TSSD systems for a given dehumidification system capacity. Figure 3a, b show how the rate of air flow affects the rate of condensation and the amount of moisture removed from the system for a given input state (Tables 1 and 2). Since moisture from the surrounding air is quickly absorbed at the air-sorbent contact, as the condensation rate goes up, the gradient of the air-humidity ratio goes down and the rate of transfer goes up.

Figure 3a shows that when the air flow rate goes from 0.8 to 1.8 kg/s, the condensation rate goes up by 39% for the SSSD system and by 51% for the TSSD system. For an air flow rate of 1.8 kg/s, the SSSD and TSSD systems had 8 and 12 condensation rates, respectively, and removed 25% and 35% of the moisture from the air, as shown in Fig. 3a, b. Figure 3c, d show how the temperature of the air coming in changes the rate of condensation and how well moisture is removed in Tables 1 and 2. In all dehumidifiers, the rate of condensation is lower when the air intake temperature is higher (Fig. 3c). As the air entry temperature goes up, the difference in temperature between the air outside and the sorbent fluid goes down. The air pressure difference and condensation rate drop. Figure 3c shows that when the air intake temperature goes from 27 to 34° C, TSSD systems cut the rate of condensation by 59% and SSSD systems cut it by 21%. TSSD is better than SSSD at taking water out of the air. This is because silica gel can absorb a lot of wetness and has a double sorbent wheel.

Figure 3c shows that SSSD and TSSD systems compress at 5.7 and 7.5 g/s at a temperature of 35° C. Tables 1 and 2 show that the rate of condensation is lower for SSSD than it is for TSSD for the given range of air temperatures. Figure 3d shows that the best way to remove wetness is when the temperature of the air coming in is low. The low temperature at which the air comes in lets the sorbent material soak up more water from the air. Figure 3d shows that when the air input temperature goes from 25 to 35° C, SSSD systems reduce by 44% and TSSD systems reduce by 32%. This study shows that both SSSD and TSSD remove less moisture when the temperature of the air coming in is higher. This shows that the sensible heat transfer rate is more important for solid sorbents than liquids at the contact between the air and the sorbent. Figure 3d shows that the SSSD system removes 39% and 20% of wetness at 25 and 35° C, while the TSSD system removes 57% and 36%. TLDD works better than other dehumidification methods. From Tables 1 and 2, Fig. 3e, f show how the air input humidity ratio changes the condensation rate for a certain entry situation. Figure 3e shows that the rate of condensation goes up with the humidity ratio of the air going into the dehumidifier. The relative humidity of the air going in makes the vapor pressure go up. This improves air moisture absorption. Figure 3e shows that at 30 gwv/kgda air intake humidity, the SSSD and TSSD condensation rates are 6.8 and 10, respectively. This study found that the rate of condensation was higher for TSSD than for SSSD.

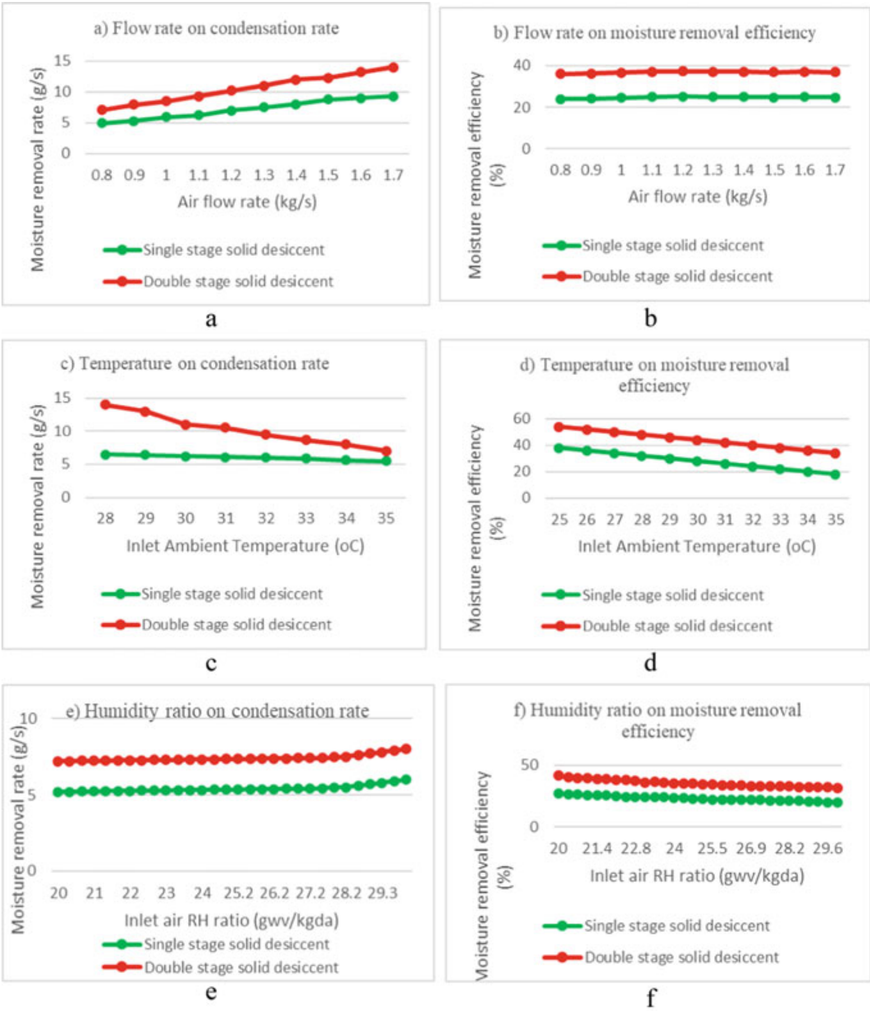

Fig. 3 Effect of air inlet parameters. **a** Effect of flowrate on condensation rate; **b** effect of flow rate on moisture removal efficiency; **c** effect of temperature on condensation rate; **d** temperature on moisture removal efficiency; **e** effect of humidity ratio on condensation rate; **f** effect of humidity ratio on moisture removal efficiency

Figure 3e shows that the condensation rate for the SSSD and TSSD systems goes up by 34% and 25%, respectively, when the air inlet humidity ratio goes from 20 to 30 gwv/kgda. This study shows that when air humidity goes up, TSSD systems condense faster than SSSD systems. Figure 3f shows that the SSSD and TSSD methods remove less moisture as the relative humidity of the air goes up. This shows how small the rigid sorbent-based device for getting rid of moisture. Change in the ability to move water or that the solid sorbent material's rate of water removal stays the same even when the air humidity is high.

Figure 3f shows that when the air input humidity ratio goes from 20 to 30 gwv/kgda, the SSSD and TSSD lose 24 and 28% of their ability to remove water. At 30 gwv/kgda, the SSSD and TSSD processes take out 22% and 33% of the moisture in the air, respectively. This study shows that TSSD is a good way to get rid of moisture.

The SSSD system works best at temperatures between 30 and 50° C for uses that need a lot of dehumidification. The TSSD system works best at temperatures between 50 and 70° C. It was found that raising the air flow rate and humidity ratio, especially when the air input temperature was lower, made the systems (SSSD and TSSD) better at cooling rooms. That is to say, places with both a lot of wetness and a lot of rain tend to have the best conditions for the systems being studied to work. When it came to deep drying uses, the studied systems (SSSD and TSSD) did a little bit better with lower air flow rates and higher air intake temperatures. The study shows that sorbent dehumidification systems can be used as an alternative to industrial deep drying and for drying farm goods at low temperatures (below the germination temperature of 70 °C) in humid areas. This means that these devices could be used in places where it is wet.

4 Conclusion

This piece looks at how the performance of SSSD and TSSD systems differs when applied to a 25 kW dehumidification system. The temperature of the air coming out of a deep dryer shows how well it works, while the rate of dampness and how well it removes wetness show how well a room air conditioner works. For a certain set of working parameters, such as air inlet temperature, air flow rate, and air inlet humidity ratio, the condensation rate, moisture removal efficiency, and air output temperature as a function of air inlet parameters are studied in detail. From this study, we can come to the following conclusions:

- The SSSD works best for jobs that need deep drying at low temperatures, between 35 and 55° C. The TSSD system can be used for tasks that need deep drying at high temperatures, between 55 and 75° C.
- Both the SSSD and TSSD systems need a low air input temperature and a high air flow rate and humidity ratio in order to cool the air in a room as well as possible.

Note: No third party material (Tables and Diagrams) Involved in this Research paper.

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Productivity Improvement in Refrigerator Manufacturing Plant by Using Yamazumi—Line Balancing Technique

Gajanan Gambhire, Nupur Aher, Abhay Joshi, Avadhoot Rajurkar, and Prerna Sarode

Nomenclature

3M	Muda, Mura, Muri
VAA	Value Added Activities
NVAA	Non-value Added Activities
SVAA	Semi-value Added Activities
UB	Unbalancing
OEM	Original Equipment Manufacturer

1 Introduction

Manufacturers aim for reduced costs and higher efficiency in production lines [1]. In order to achieve maximum efficiency, the focus must be to optimize the number of workstations and evenly distribute the workload/cycle time on each workstation of the assembly line [2]. Hence, line balancing is done to reduce the overall idle time of the stations in an assembly line.

The OEM where the project was carried out is one of the largest home appliances manufacturers renowned in the Indian market. The company's product portfolio includes washing machines, water purifiers, refrigerators, dishwashers, air conditioners and other household appliances. In this paper, 3M analysis is conducted

G. Gambhire (✉) · N. Aher · A. Joshi · A. Rajurkar
Vishwakarma Institute of Technology, Pune 411037, India
e-mail: gajanan.gambhire@vit.edu

P. Sarode
Industrial Engineer, The Toro Company, Pune 411001, India

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to identify the VAA, NVAA and SVAA in each process of the targeted assembly line. These activities are diagnostically shown using the "Yamazumi Chart", which is a stacked bar outline that demonstrates the equalization of process duration and outstanding tasks at hand between various operators commonly in an assembly line or work cell. This process helps in identifying the Muda's and eliminating them using lean techniques.

2 Methodology

2.1 Data Collection

In the refrigerator assembly line, three different areas viz. Final Assembly area, Cabinet Housing Unit and Door Prefoam area were undertaken for data collection. Time and Motion Study is a proven methodology for data collection across various industries [3] and [4]. Hence, Time and motion study methods are used to accurately record the time that each activity takes to perform and also the motions that manifest themselves at intervals. Video recording was done for all activities to capture exact timings and to minimize variation in the measurement methods. The accuracy of time and motion study helps in improving the precision of the Yamazumi charts [5]. Variability in the same job is ensured by the series of videos. The job at each station is further stratified into a series of operations. These operations are later categorized into four categories namely Value-Added Activities (VAA), NonValue-Added Activities (Yamazumi) and Semi-Value-Added Activities (SVAA) [6]. The time required for these categories is then extracted from the videos (average time required for the same job by same operator and different operators working on the same station) and is tabulated in a sheet. Then the graph is plotted which is basically the stacking of VAA, SVAA, and NVAA of a particular station. The difference between the value of takt time and the addition of VAA, NVAA & SVAA is the unbalancing of that station. The same is repeated for other stations. Based on the addition of VAA, NVAA and SVAA, pie chart is plotted to get a clear understanding of the overall VAA, NVAA & SVAA of that area [7]. From the identified NVAA, further stratification of is done to develop a Pareto of the components of the NVAA.

2.2 Analysis and Measures

This paper focuses only on the final assembly area as a model area. It includes 17 different workstations with 17 operators. Data was collected for all 17 workstations and analyzed for Muda, Mura and Muri in a detailed manner below.

- **Stage 1**—Muri Reduction:

Operating a machine or an operator beyond their natural capabilities leads to a difficult or unnatural operation. Overburdening people causes many safety and quality problems, and overburdened machines results in machine breakdowns and defects [8]. Muri can be avoided through standardized work procedures. There are 3 levels of Muri conditions, level 1 (Red) the most undesirable one, level 2 (yellow Muri) and level 3 (green Muri). Thus, the aim of our project was to eliminate or bring down the level 1 red Muri conditions. Table 1 i.e., Muri analysis data collection template shows the different Muri conditions associated with the activities involved in workstation-1.

After detailed observation and analysis (As shown in Table 1) of all the operators at 17 workstations in the Model Area, 57 Red Muri conditions, 63 Yellow Muri conditions and 528 green Muri conditions were observed. Red, Yellow and Green Muri conditions assigned weightage of 3, 2 and 1 respectively. Hence the priority is given to eliminate all Red Muri conditions and the action plan was prepared for all workstations. All red muri conditions are eliminated from the Model area with the help of various kaizens.

- **Stage 2**—Mura Reduction:

Compared to the ideal condition the operator can perform the operation in many different ways that lead to an irregular operation. Possible causes that lead to Mura:

- Generic Work instructions
- Work instruction not properly spread
- Lack of training—Lack of standards
- Weak technical devices.

Steps to perform Mura analysis are given below:

Table 1 Muri analysis data collection template

	Flexion angle of the waist			Rotation angle of the waist			Height of the working arm			Flexion stretching angle of the knee			Rotation angle of the wrist			Pick up parts and materials			Working range			Walk			Transport			Total		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3			
Activity Description	More than 30°	15°–30°	0°–15°	More than 45°	15°–45°	0°–15°	Higher than shoulder	Same as shoulder ht.	At the ht. of waist	More than 60°	30°–60°	0°–30°	More than 180°	90°–180°	0°–90°	Difficult to handle,	Its possible to pick up	Its easy to pickup wit	More than 90°	45°–90°	0°–45°	More than 10 steps	5–9 steps	0–4 steps	More than 11 lb	6.6.–11 lbs	0–6.5 lbs	Critical	Need improvement	OK
Element1			1			1			1			1			1			1			1			1			1	0	0	9
Element2			1			1		1				1		1		1					1			1			1	1	2	6
Element3			1			1		1				1		1		1					1			1			1	1	2	6
Element4			1			1		1				1	1			1					1			1			1	2	1	6
Element5			1			1	1					1		1		1					1			1			1	2	1	6
Element6			1			1		1				1		1		1					1			1			1	1	2	6
Element7			1			1		1				1	1				1				1			1			1	1	2	6
Element8			1			1		1				1	1				1				1			1			1	1	2	6
Element9			1			1		1				1	1				1				1			1			1	1	2	6
SCORE	0	0	9	0	0	9	1	7	1	0	0	9	4	4	1	5	3	1	0	0	9	0	0	9	0	0	9	10	14	57

1. Deviation in standard time for repetitive activities and different sequence of operation being followed
2. Procedure for selection of the Mura study is prepared
3. Two operators observed for the activities considered for Mura study
4. Data collection done for 20 cycles per station per operator
5. Pareto chart is plotted to plot Mura of all station.

The variations in workers standard time were determined for all the workstations of Model Area. As per Pareto principle, workstation S24 (Door Taping), with highest variation, was given the 1st priority to eliminate Mura and then followed by other workstations. Figure 1 depicts the MURA priority for all stations. Mura is eliminated by standardizing the procedures and giving training to the operator. All the SOPs are updated as per the standardized procedure for the respective workstation.

After detailed analysis of procedures of both the operators, Fig. 2 shows the Mura analysis of two operators. The standard deviation shows, Mura within the operator's working procedure and the difference between means shows, variation in working procedure of two operators. We need to minimize the standard deviation and minimize the difference between the mean of both operators to minimize Mura. After detailed analysis of procedures of both the operators, the observations are as given below:

Operator 1.

Taking 4 tapes at once

1. Consistent tape length (Short)
2. Anti clockwise application on cabinet
3. Higher number of tapes taken at once
4. No walking
5. Faster way of operating

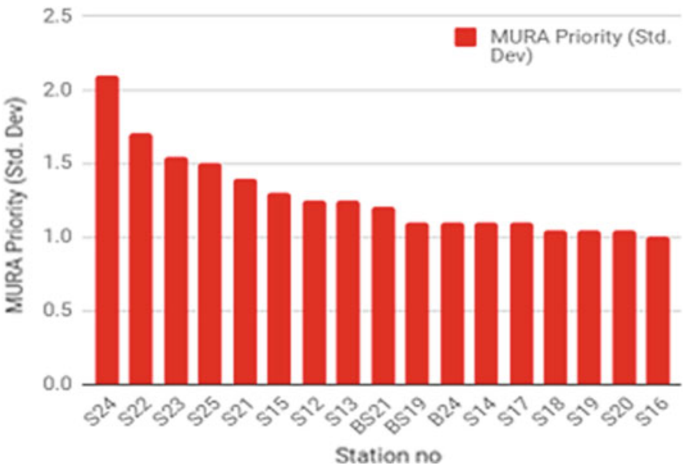


Fig. 1 Mura Pareto chart

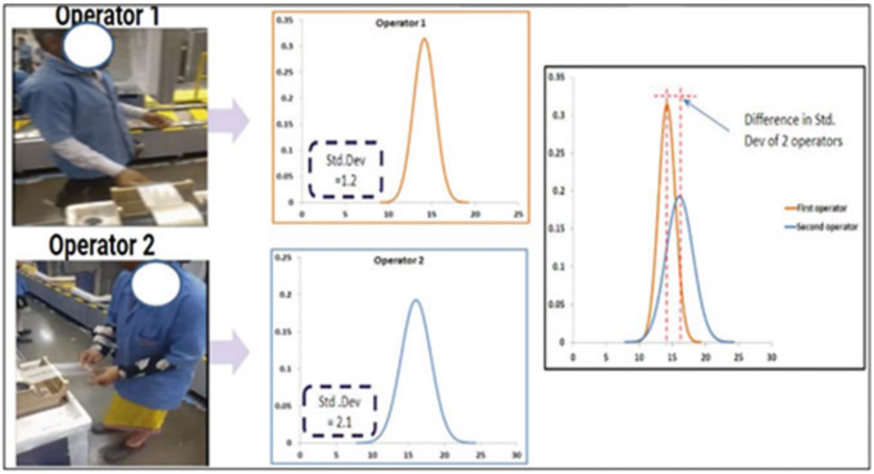


Fig. 2 Mura analysis of two operators

6. Higher height of operator.

Operator 2

1. Taking 2 tapes each with both hands at once
2. Tape length is longer and inconsistent
3. Direction of application is zig zag on the cabinet
4. Lesser tapes taken at once
5. Walking observed during operation
6. Lesser Motion economy.

The root cause analysis is done with the help of fishbone diagram as shown in Fig. 3. To eliminate the root cause, the sequence of operations is updated on the workstation and the SOP of that workstation were standardized. Also, the job cover matrix was updated and standardized. Proper training is given to the operator and supervisors.

- **Stage 3**—Muda Reduction:

Any element of the process that does not add value to the finished product is considered to be Muda or Non-Value Added. The Muda's are classified into various terms such as quality check, body motion, difficult picking, repositioning/double handling, material handling, jig and tool usage, cleaning, unravel and separate, waiting in the process, product in motion etc. According to this, data is collected by analyzing the videos of the process the Yamazumi chart is plotted as shown in Fig. 4.

From the identified NVAA, further stratification is done to develop a Pareto of the components of the NVAA as shown in Fig. 5. The Pareto will provide the information about the component causing highest losses in the system, that is, Muda. Then

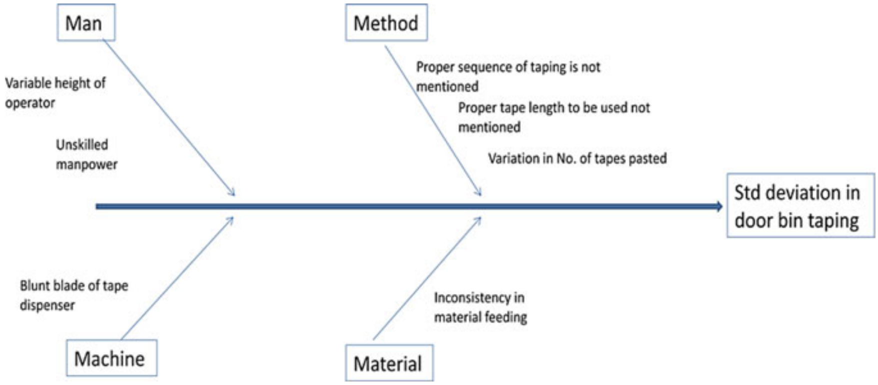


Fig. 3 Root cause analysis

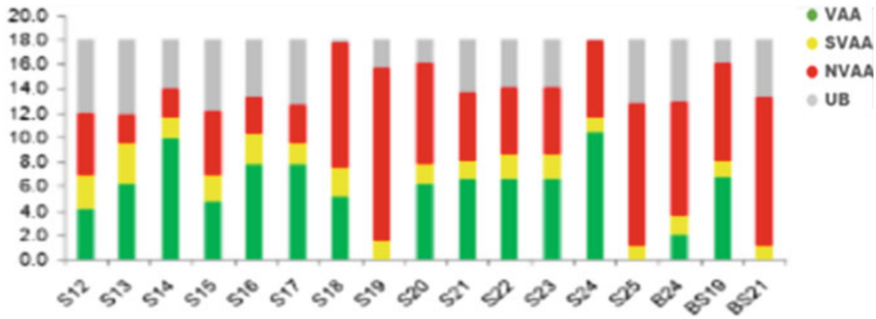


Fig. 4 Yamazumi chart for Muda analysis

elimination of Muda is done according to the priority of losses provided by the Pareto principle.

From Fig. 5, we can understand that the maximum NVAA of 22% is due to the operator movement for the part picking process. To reduce the NVAA of part

Fig. 5 NVAA stratification diagram

picking the 5G (Gemba, Gembustu, Genjitsu, Genri, Gensoku) technique is used. In the component picking, the highest Muda is for the Door fitment station. Door picking operator needs to walk more than four steps. To avoid the Muda of door picking, we need to feed the door into the golden zone of the operator. To feed the door in the golden zone, the solution finalized was door sequencing. With the help of a door sequencing conveyo, r the single point picking of the door is achieved. Due to door sequencing, the Muda for part picking is reduced and also the defect like wrong door fitment, door dent due to handling of door is also reduced. After Muda elimination the NVAA of the Model Area is reduced from 29 to 24%.

- **Stage 4**—Line Balancing:

After the reduction of Muri, Mura and Muda, the Yamazumi is plotted (as shown in Fig. 6) taking into consideration the reduction in the Non-Value-Added Activities due to 3M reduction. Then work content is split as per available scope in the final Yamazumi.

Guidelines followed to balance the line:

1. Draw a diagram to highlight the priorities existing among operators in each workstation
2. Calculate required Takt Time for the line
3. Calculate manpower needs
4. Analyze operations and reduce non-value-added activities
5. Assign work operations to each station, considering standard cycle time and priority constraints
6. Collect all waiting times in one position and isolate in it just NVAA and SVAA; they are visible and you could try to eliminate them with focused improvement activities
7. Measure line effectiveness.

The difference between the value of takt time and the addition of VAA, NVAA & SVAA is the unbalancing of that station. After eliminating/reducing Muri, Mura and Muda, the Yamazumi is plotted again so as to get a clear understanding of the unbalanced present situation at each station. Remaining unbalanced operations are

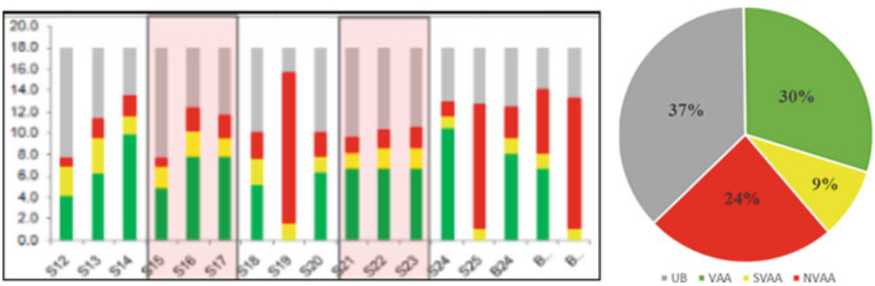


Fig. 6 Yamazumi chart before line balancing

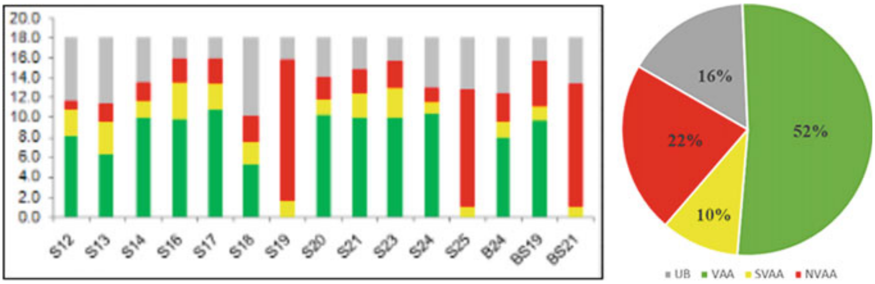


Fig. 7 Yamazumi chart after line balancing

examined closely and it is observed whether the work content can get split into some other station [9]. This has to be done in accordance with the activities of those stations on the shop floor as the theoretical consideration and practical implementation may complement each other. After analyzing the activities of workstation S15, S16, S17 the activities of S15 are split in between S16 and S17 which results in elimination of workstation S15. Similarly, after analyzing S21, S22, S23 the activities of S22 are split in between S21 and S23 which results in the elimination of workstation S22.

After the line balancing of the model area the work content is divided equally and the unbalancing was reduced from 37 to 16% as shown in Fig. 7.

3 Results and Discussions

Table 2 depicts the stage wise journey started from its original state to final line balancing state via Muri, Mura and Muda reduction stages. NVAA reduced from 39% in original stage to 22% in line balancing stage.

4 Conclusions

Analysis of 3M (Muri, Mura, Muda) for identifying the NVAA in all the operations enabled overall efficiency improvement as shown in Table 3. A manpower of two is optimized from the model area which results in hard saving of 0.86 Mn INR and 21.84 Mn INR of virtual savings.

Table 2 Stagewise results (from original state to final state)

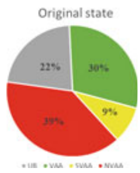
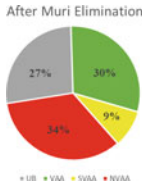
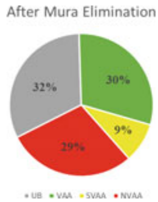
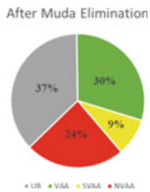
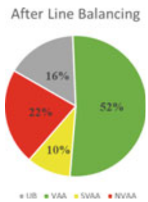
Stage 0	Original state	
Stage 1	**Muri Reduction**: All red Muri conditions are eliminated from the Model area with the help of various kaizens	
Stage 2	**Mura Reduction**: Mura was eliminated at all the stations with maximum variation in operations. Due to Mura elimination the NVAA of model area is reduced from 34 to 29%. SOPs were redefined and standardized	
Stage 3	**Muda Reduction**: After Muda elimination the NVAA of the model Area is reduced from 29 to 24%	
Stage 4	Final state after **Line Balancing** by using Yamazumi charts	

Table 3 Final Results

Category	Target (%)	Achieved result (%)
Productivity	↑ 20	↑ 26.2
Unbalancing	↓ 15	↓34
NVAA	↓15	↓15
Muri conditions	↓100	↓100

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Sustainable Waste Management: An Analysis of Current Practices and Future Prospects

Harshith Sourav Gosula and Amit L. Nehete

1 Introduction

Efficient waste management is crucial for sustainability and environmental protection. Urbanization has made it challenging, despite significant government efforts. In order to make the identification, collection, and sorting of waste at the ground level by the citizens to increase the efficiency of recycling and decrease the burden on municipalities, we need a change in the system and also in the infrastructure. Section 2 covers our idea of waste. Research in this paper analyzes waste management in the Indian context focusing on the problem of (1) inefficient organic waste management, (2) improper waste sorting leading to inefficiency in recycling, and (3) the issue of waste accumulation in uneven surfaces presented subsequently in Sects. 3, 4, and 5, and Sect. 6 concludes the paper. This paper examines India's waste management system, discusses three issues, proposes solutions to improve recycling effectiveness, and reduces the burden on municipalities. It covers problem identification, analysis, proposed solutions, and potential outcomes.

2 Our Idea of Waste

There's a prime misconception about the word waste. We use it to describe a material that cannot be used for any purpose, and we give it zero importance. But actually, any material which is not in its assigned place is known as waste. So, the goal should be to put it in its assigned place. Zero waste community and management are about delivering the wrongly placed materials to their assigned places efficiently. This will

H. S. Gosula (✉) · A. L. Nehete
School of Electrical Engineering, Dr Vishwanath Karad MIT World Peace University, Pune 411038, India
e-mail: harshithsourav123@gmail.com

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make the earth sustainable and reduce the risk of many problems in a marvelous way, and also, we can use the materials to their maximum potential [1]. In the Indian context, 77% of waste is dumped in open landfills, 18% is composted, and only 5% is recycled. So, despite the fact that we have companies in India that can recycle garbage, we are unable to recycle the expected amount of waste because the specific type of waste does not reach the precise sort of area where it is supposed to be recycled [2].

3 Problem 1: Inefficient Organic Waste Management

For better understanding of the problem and accuracy in the details, we took the example of Pune city. This populous metropolitan has a garbage management problem due to its population, commercial industries, hospitals, and residential buildings, which generate 0.12 kg of waste per capita/day [3]. The Uruli Devachi depot receives roughly 1200–1300 metric tons of mixed rubbish of various types [4]. A total of 87.5% of Pune's total municipal rubbish is collected by more than 3,000 women workers who provide waste collection services to more than 600,000 homes in the city. Insufficient resources and equipment make it difficult to sort and dispose of waste correctly in many parts of the city [5]. Pune city is good at reusing organic waste to generate electricity and biofuel as 273,750 of organic waste tons per year to generate 44.55 million units of electricity, and the biofuel produced is used for the city's transportation and fertilizer requirements [6], but transportation is an issue since it takes a lot of energy and resources to collect the waste with the help of hundreds of workers, transport it to recycling facilities, sort it again, and recycle it to make biofuel. To increase effectiveness, lower energy consumption, and conserve resources, it is necessary to develop a system that can handle the majority of organic waste right at the source.

Solution to Problem 1: Ground-Level Waste Processing
To solve the problem of organic waste, we need to install a network of miniature waste processing plants near areas where waste production is high, such as societies and hotels, to process the majority of the waste at the source. For areas where building a plant is not feasible, a medium-sized plant can be set up in the center of the area [7]. This ground-level organic waste processing yields bio-CNG which can be used for cooking. Upon further processing at the appropriate industries, it can be made into a vehicle fuel, etc. It can also be used as vermicompost in agriculture. For example, a plant installed in a large residential society with 100 flats can produce a waste of 21.7 kgs a week from which we can process 146.66 kgs of biogas, which can be used by the society for 10 days straight. The proposed design and for the optimized ground-level organic waste processing plant which is shown in Fig. 1, saves a lot of space.

Figure 2 shows the process flow of a ground-level organic waste processing plant. Waste is crushed to break down complex masses into simple form in a crusher which is then mixed up with 10% water and enzymes in the mixing tank. Digester regulates the pH, followed by heating it to 38° in the fermenter. Anaerobic digestion of organic waste converts it to a Bio-CNG which is a potential replacement for LPG. With further processing, it can be utilized as a vermicompost for agriculture as well as a fuel for vehicles.

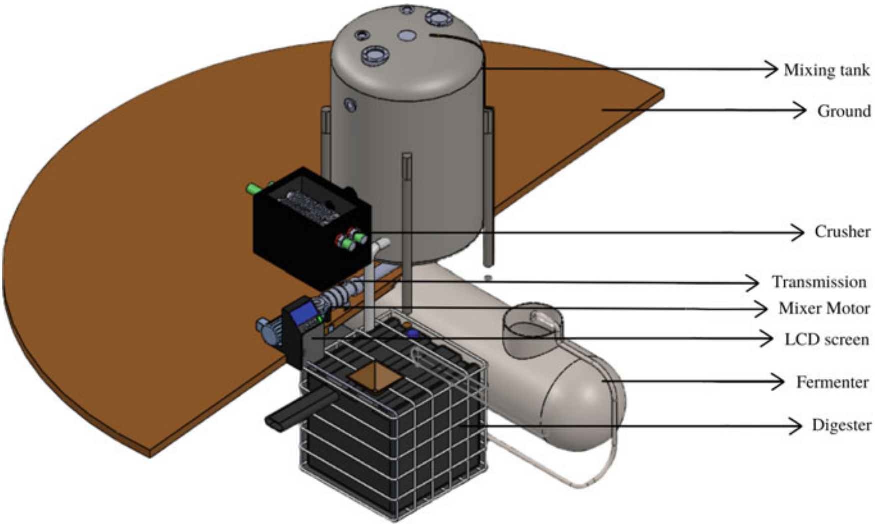

Fig. 1 Proposed design of the ground-level organic processing plant

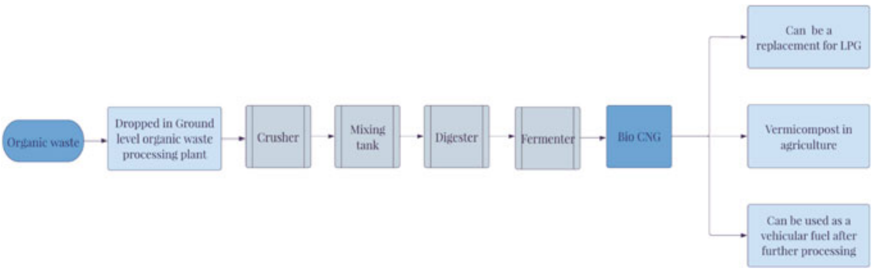

Fig. 2 Process flow of ground-level organic processing plant

4 Problem 2: Improper Waste Sorting Leading to Inefficiency in Recycling

To improve recycling efficiency, waste sorting needs to be more precise. The traditional approach of dividing waste into two categories makes it difficult for recycling facilities to process materials, leading to contamination and wastage of resources. Sorting waste into seven categories—organic, plastic, glass, paper, metal, e-waste, and medical waste—will positively boost the chances of recycling as this categorization is made in such a way that one kind of waste will not contaminate or decrease the chances of recycling of other wastes. Organic waste should not be mixed with other waste due to the potential for bacteria and fungus growth. Plastic waste is non-biodegradable and has negative effects on the environment. Halting new plastic manufacturing and recycling existing plastic can have significant benefits. Glass and metal waste can be recycled without losing quality. E-waste contains hazardous compounds and can be treated through urban mining. Medical waste is hazardous and must be properly disposed of. When these wastes are mixed together, sorting them into categories and sending them to their respective industries for recycling is a huge task and even the smallest of the errors can make them non-recyclable [8].

Solution to Problem 2: Waste Sorting Hubs
The major goal is to make the collection and sorting process at the ground level which will reduce the burden on municipality workers and make the sorting process accurate after which we can directly send it to the respective recycling centers via "Waste Hubs" which essentially provides storage for the seven categories of waste in a smart way which will be described in Sect. 4.1. This will prevent the wastage of WASTE.

Figure 3 shows the complete flowchart describing all the seven aforementioned waste segregation categories.

4.1 Proposed Design and Working Waste Sorting Hubs

Each of the hub's seven compartments has a different size depending on where it is located, and those sizes are to be determined by the kinds of garbage that those places produce. 2× People should regularly dispose of their waste in the designated areas of the dustbin hubs. Waste monitors will then transport the waste to the "Recycling Hub," where it will undergo a second level of safety sorting to prevent human error, before being boxed and sent to the appropriate recycling stations. By cutting down on the time we spend sorting and recycling, we may save both time and money. If this approach is implemented properly, waste can be sent directly to recycling industries, which boosts recycling efficiency as we were able to achieve ground-level waste collection-sorting and we are able to transform the waste pickers into waste managers. Creating a sustainable environment is not a one-time event. It takes

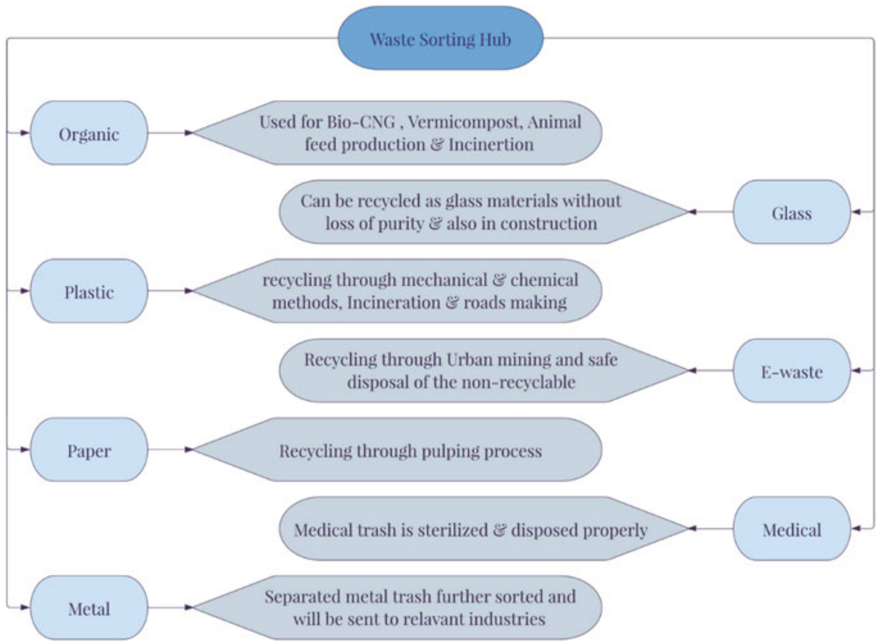

Fig. 3 Sections for seven categories of waste segregation

time; thus, we must adapt these adjustments gradually and level by level in order to meet our goals.

5 Problem 3: Waste Accumulation in Uneven Surfaces

Even in areas that appear litter-free due to diligent municipal cleaning, uneven surfaces can cause waste to accumulate, leading to problems such as environmental and water pollution, waterlogging, and unclean roads [9]. This problem could be solved by using the collected waste in the right way. A picture describing the difficulty is mentioned in Fig. 4.

Solution to Problem 3: Using Plastic Trash to Address the Issue of Waste Accumulation

Due to its chemical resistance, strength, light weight, and ease of production, plastic has penetrated every aspect of our everyday life. Along with the benefits that were introduced into our lives, drawbacks including soil contamination, drainage blockage, preventing rainwater from percolating, and harmfulness also appeared. Even recycling plastic can only be done a few times, and even then, it leaves behind some undesirable byproducts like toxic fuels. Many countries are looking for a way to appropriately dispose of single-use low density plastics and other materials for

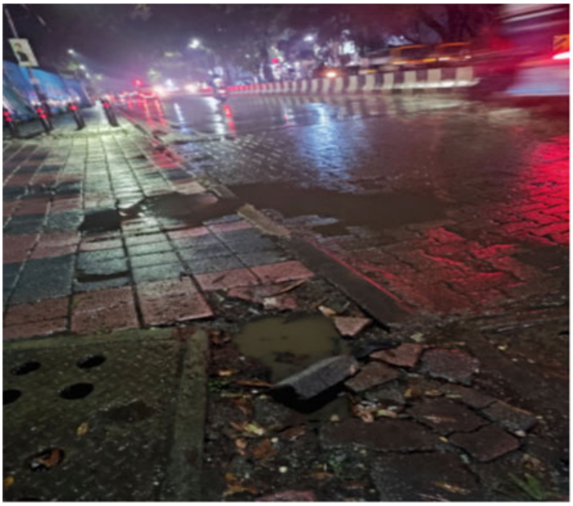

Fig. 4 Picture describing the problem of waste accumulation in uneven surfaces

the same reason. One of the ways in doing so is by using the plastics in road construction because plastics have great potential for use in bituminous construction. Studies have shown that addition of small amounts of plastic into bitumen while road making increases its strength, service life, and other desirable properties and helps in construction of green roads. Bitumen, a substance made by the distillation of crude oil, has been used in the construction of roads in India since the early 2000s. It is a cost-effective material with excellent adhesive and water resistance properties that prevent the components of the road mix from forming weak bonds. Other advantages include ease of construction, recyclability, adaptability, reduced noise, resistance to temperature changes, and encouragement of plastic waste management. However, its lower durability, poor tensile strength, and reduced friction over concrete make it a less popular choice for construction. Nevertheless, bitumen combined with plastic trash can be the ideal material for filling landfills, mending damaged roads, and constructing walkways and bicycle lanes. This not only enables us to maintain roads more effectively and create greener roadways, but it also lessens the problem of waste accumulation caused by uneven surfaces [10].

6 Conclusions

The paper discusses how implementing ground-level waste processing can help reduce resources and efforts required to transport organic waste to processing plants. Additionally, sorting waste into seven categories instead of two can help increase the chances of recycling materials and reduce the workload for waste workers. The paper also suggests utilizing collected plastic waste to address waste accumulation on uneven surfaces and improve pavement and road strength. Overall, these solutions have the potential to reduce pollution, improve sanitation worker conditions, increase material lifetimes, and save energy and resources.

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A Comprehensive Study on Industry 4.0 Technologies

Atharva Kadne, Pratham Kamath, Manav Karvat, Mohan Bodkhe, and Sanjeev Sharma

1 Introduction

Industry 4.0 has drastically changed the scenario of manufacturing industries and distribution networks with the help of cloud computing, AI and machine learning, edge computing, digital twin, cybersecurity, and the most cardinal of all Internet of Things. The upcoming generation is applied for three mutually inter-related factors: Digitization and integration of simple and complex technical-economical networks, new market models, and the digitization of products and services which are being offered [1]. One key feature Industry 4.0 is bringing to the table, the amalgamation of Information Technology and Operational Technology systems thus creating meticulous network between autonomous manufacturing equipment and wider computer systems. As the industry progresses forward across various parameters and dimensions, "Smart Factory" has created rippling effects throughout the industry and has allowed customer requirements to be fulfilled by amelioration in productivity and quality aspects [2]. Industry 4.0 is not called a revolution just because it improved the productivity and efficiency of production and distribution systems, rather it completely revolutionized how the products and goods were produced and how exactly work was done.

A. Kadne (✉) · P. Kamath · M. Karvat · M. Bodkhe
Department of Mechanical Engineering, SVKM's NMIMS Mukesh Patel School of Technology Management and Engineering, Mumbai 400056, India
e-mail: atharvakadne09@gmail.com

M. Bodkhe
e-mail: mohan.bodkhe@nmims.edu

M. Bodkhe · S. Sharma
Research Scholar, Department of Mechanical Engineering, Amity University Haryana, Gurugram, India

A. Bhardwaj et al. (eds.), *Optimization of Production and Industrial Systems*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-99-8343-8_17

2 Literature Review

Renault Industry 4.0—The authors have suggested that the convergence of technologies, namely the Artificial Intelligence, Robotics, Internet of Things (IOT), Blockchain, and Augmented reality, presents both opportunities and challenges for companies like Renault [3]. As autonomous driving shifts from a moon-shot to an imminent reality, these technology shifts are shaping the next industrial revolution, known as Industry 4.0.

A comprehensive overview on of how the automotive giant, Renault, has successfully implemented Industry 4.0 technologies to improve its manufacturing processes and increase efficiency. Renault faces significant challenges in the highly competitive automotive industry, including the need to produce vehicles faster, cheaper, and with better quality [4]. To address these challenges, Renault has integrated various Industry 4.0 technologies, including automation, data analytics, and artificial intelligence, to enhance its production processes. The article provides specific examples of how Renault has incorporated these technologies in its factories, including the use of collaborative robots, real-time production data monitoring, and predictive maintenance. These technologies have enabled Renault to boost its production capacity, reduce waste, and enhance product quality.

Overall, a valuable case study of how Industry 4.0 technologies can be successfully implemented in the automotive industry to improve manufacturing processes and drive business success. The article is well-written, informative, and provides useful insights for companies looking to implement similar technologies in their own operations.

Smart Factory Industry 4.0—It is also referred to as the fourth Industrial Revolution, is causing significant changes for companies. This transformation is affecting their organizations, strategies, processes and business models, value and supply chains, skills, products as well as relationships with stakeholders. Whilst Industry 4.0 presents new opportunities for businesses, it also brings about potential vulnerabilities that need to be managed and governed in order for it to have a positive impact on both the society and economy. A case study of an industrial company transformation into Smart Factory discusses how an industrial company successfully transformed its production facilities into a smart factory by the adaptation of Industry 4.0 technologies.

The study initially introduces the concept of Industry 4.0 and highlights its advantages for manufacturing industries. Figure 1 depicts the different kind of technologies that are prominent in Industry 4.0. It then presents a specific case study of an industrial company and how it transformed its production facilities into a smart factory by incorporating several Industry 4.0 technologies, involving the big data analytics, cloud computing, and Internet of Things (IoT) [5–7]. The article offers a comprehensive analysis of the benefits and obstacles encountered during the transformation process and the strategies employed by the company to overcome them. It delves into the company's internal logistics and production processes, emphasizing the role of Industry 4.0 technologies in boosting efficiency and reducing waste.

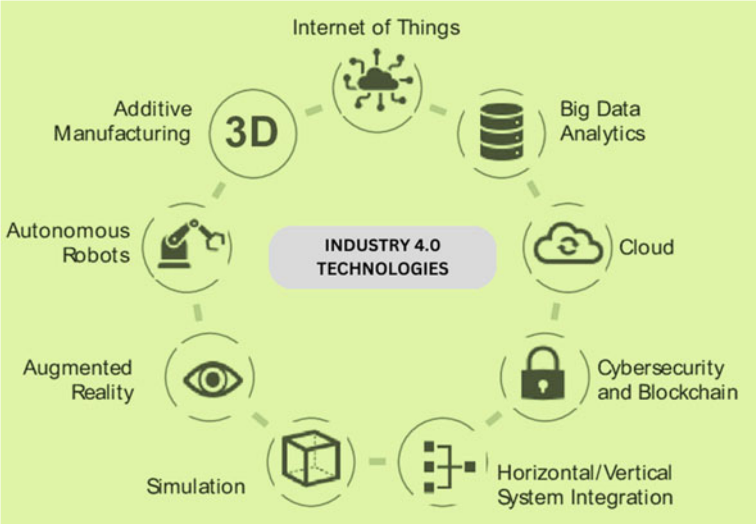

Fig. 1 Technologies of Industry 4.0

A useful case study of how Industry 4.0 technologies can be successfully implemented in industrial settings to improve production processes and drive business success. The study is well-written, informative, and provides valuable insights for companies looking to undertake Industry 4.0 technologies in their own operations. It should be noted, however, that the case study emphasizes on a particular organization, and the conclusions may not be generalizable to other companies or sectors.

McKinsey Supply Chain 4.0—Implementing Industry 4.0 across factory networks can be a challenging task for manufacturers, which may require them to take a step back in order to make progress. Leading companies in this area are enjoying a wide range of benefits throughout the manufacturing value chain. These benefits include increased production capacity and decreased material losses, better customer service and delivery times, higher employee satisfaction, and reduced environmental impact. By scaling these advantages across networks, a company can significantly transform its competitive standing.

The article commences by describing the issues faced by traditional supply chains and discusses how these can be resolved through the integration of digital technologies. The article goes on to present various examples of how firms can leverage these technologies to enhance their supply chain operations, including predictive analytics, real-time visibility, and blockchain. The article also highlights the advantages of digital supply chains, such as increased flexibility, cost reduction, and higher customer satisfaction. It presents case studies of companies that have effectively implemented digital supply chain strategies, including Amazon and Zara, and how they have gained a competitive edge through their utilization of technologies [8–10]. The potential benefits of digital technologies in transforming traditional supply chain operations into next-generation digital supply chains. The article is well-written, research-based, and provides valuable insights for companies looking to adopt digital technologies in their supply chain operations.

Aerospace and Defence—Deloitte Survey Aerospace and defence (A&D) companies are facing intense competition, and Industry 4.0 technologies can be the essence to unboxing future competitiveness. According to a survey of A&D executives conducted by Deloitte, 84% of respondents identified the utilization of new digital technologies as a crucial factor in differentiating themselves in the market. However, only 25% of Aerospace and Defence companies currently make use of these techniques to manage, access, analyse, and validate data from their digital assets for real-time decision-making. Incorporating digital transformation throughout their organizations could help A&D companies improve their operations and gain a competitive advantage.

The article discusses the challenges faced by the aerospace and defence industry, including intense competition, regulatory pressures, and the need for operational efficiency. The paper emphasizes the ability of Industry 4.0 technologies like automation, data analytics as well as robotics to overcome these difficulties and create a competitive advantage [11, 12]. Case studies of companies, such as Boeing and Lockheed Martin, illustrate how Industry 4.0 solutions have been successfully implemented in aerospace and defence operations. These examples demonstrate the benefits of such solutions, including improved production efficiency, cost reduction, and increased agility. The article provides a useful and informative overview of how aerospace and defence companies can validate Industry 4.0 solutions to improve their operations and gain a competitive advantage. The article is well-written, research-based, and provides valuable insights for companies in the aerospace and defence industry looking to undertake Industry 4.0 solutions in their operations.

3 Industry 4.0 Case Analysis Based on Covid-19

Industry 4.0 was initiated in 2011 in Germany, and predominantly in 2015, it has received more attention, moreover, its benefits have also been extended in large scale. Italy and Germany are prominent countries with 2314 and 3174 publications, respectively, for Industry 4.0 [13]. Figure 2 shows the relevant publications survey all around the world for Industry 4.0, hence, we have selected the Italian-based company for survey, because Italy is leading in survey of I4.0.

Also, Fig. 3 roughly depicts that there is a significant rise in publication of Industry 4.0, where in the year 2021, above 5000 articles have been published successfully in different journals. Many authors emphasized on economic, environmental, and social stability, even concluded that one of the foundational principles of smart manufacturing is sustainability. Along with sustainability, the world economy has slowed down since 2020, as a result of the Covid-19 epidemic, and businesses of all sizes and in all industries struggle to survive. The Covid-19 dilemma is now having an effect on several industries, businesses, and manufacturers. Due to a reduction in commercial activity, travel limitations, and varying interest rates, the Covid-19 impacts have

Fig. 2 Relevant publications survey for Industry 4.0 throughout the globe

shocked the supply chain. As a result, businesses began developing alternate supply techniques to deal with this situation [14].

An Italian organization X functioning in equipment sector was the focus of a case study that was being conducted. Concentrating on 4.0 adoption levels both prior to the Covid-19 (Sect. 3.1) and during the epidemic (Sect. 3.2), this part intends to highlight the findings obtained through the representative of Business X's interview in detail.

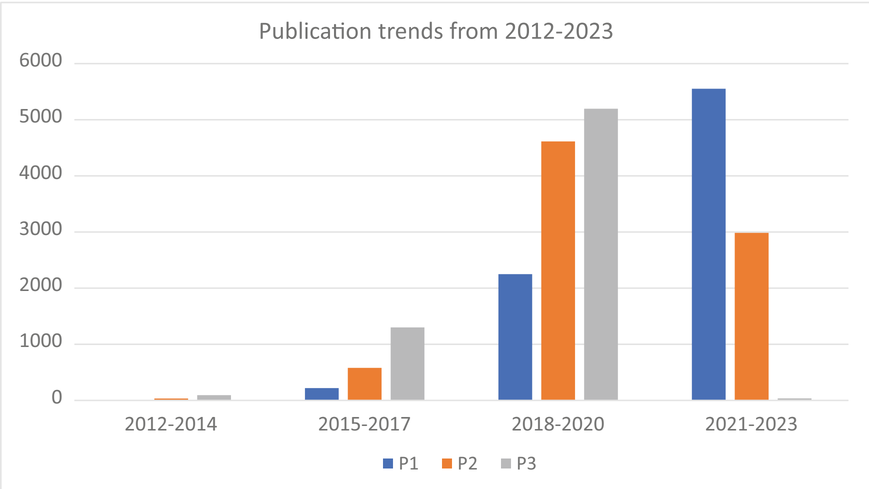

Fig. 3 Publication trends from 2012–2023

3.1 Company X and 4.0 Before the Pandemic

With less than 250 people and a revenue of between 10 and 50 million euros prior to the epidemic, Company X works in the Italian equipment sector. The sale of new products accounts for less than 10% of this turnover, whilst exports account for 9% to 51%. The considerable distance (informational, physical, and interpersonal) between consumers and users of the company's products and the adoption of Industry 4.0 were two major factors in the business's pre-pandemic success. Technology 4.0. The construction of an "open" information system for consumers was especially targeted as a way to shorten this gap. The business also emphasized important problems with the integration with suppliers and retailers. The main motives for effecting Industry 4.0 are:

1. Improvising the response speed to customer orders.
2. Lowering the costs and duration of painting, hence lowering worker exposure to paint.
3. Better integration between customers and dealers.

The suitable reasons for improvising the above issue were introducing an automated guided vehicle, the use of robots directly connected to manufacturing to obtain information on equipment specifications, and finally improving the company's management software. The company was already current with internal integration and computerization solutions, as well as utilizing automatic drawing assembly and 3D drawing software prior to implementing Industry 4.0. However, they had intentions of further automating production, order management, and integrating with customers and suppliers. The management of the business was fully aware of smart manufacturing technologies and analysed them to determine whether they might be used to any of the business's operations. The digital transformation approach included deploying cloud computing, cloud manufacturing, and information integration technologies throughout the full value chain, from suppliers to customers. The ability to extend integration with resellers and customers through the upgrading of current software solutions had the greatest influence on the integration strategy and enhanced the range of goods and markets the organization could access. By implementing robot-assisted painting procedures and introducing Wi-Fi or GPS-guided vehicles, it can be argued that the corporation advanced in improving its business model whilst emphasizing the demands of its workers. The management has, in fact, always shown a keen interest in the wellbeing and professional development of its employees. As a result, the process of digital transformation has gone smoothly since the staff is youthful and continually being taught.

3.2 Company X and 4.0 During the Pandemic

Overall, it didn't affect much as technology implementation plan was not changed; which was a positive factor nevertheless, initial months, it was a slow start. The technological strategy was favourable for the business, with regard from the perspective of the IT terms; in fact, having access to all of the platforms was really helpful. The firm produced at 50% throughout the lockout months, but owing to the digitizing process, output never ceased. All employees participated in smart working and had a 50% attendance rate in order to meet client demands for necessities (such as those from petrochemical and pharmaceutical companies). The implementation of I4.0 at the testing facility enabled the firm to undertake tests with clients even when they were not there, because data was delivered online and collected by cameras [15]. The foreign ties were well maintained and targets were fulfilled at the end of year; thanks to Robotization. This offered a big benefit.

4 Conclusion

From the above review papers and case studies, we have understood the implementation and its importance in transforming industries to next level. With the help of Industry 4.0, a higher order of efficiency and responsiveness has been wired into supply chains and production lines by optimization of manufacturing processes. The galvanizing effects and changes, which have been brought about by Industry 4.0, can be felt across myriad of levels: whole ecosystems, and also at organizational levels and also the relations between businesses and customers. Whilst the new generation of technologies is evolving, we can't anticipate the complete scenario which might manifest itself in 20 years from now, but amelioration of current processes and systems is still viable.

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A Novel Design of Robotic Fruit Plucking Manipulator Using a Sliding Cutter for Agricultural Drones and Robots

Abhishek Ashok Dethe and B. Rajiv

1 Introduction

Labor scarcity and unskilled labors, both problems have given rise to automation of agricultural works. In the last few years, robotics and artificial intelligence like technologies have stepped into the field of agriculture in a way to reduce human efforts and increase the pace of working [1]. It also helps mapping and maintaining the record of crop health, autonomous harvesting of crops, etc. Some paper reviews indicate that the manual fruit plucking techniques involve the intensive risk and requirement of crude equipment with manual labors [1]. These circumstances are forcing robotics and AI (artificial intelligence) systems to step in. In this paper, the design of fruit plucking manipulator is proposed that can be used by robotic system and drones [2] for efficient fruit plucking. The sliding cutter mechanism is designed in such a way that it tries to overcome challenges faced by other types of end effectors used by this fruit plucking system.

2 Fruit Shape Analysis

Majority of fruits targeted by fruit plucking drones and robots include apple, orange, tomatoes, mandarins, pomegranate, etc. All of these can be considered as spherical in shape mostly. So, the design of the manipulator is such that even roughly spherical fruits also can be grasped easily without bruising the fruit. This facilitates to use this manipulator design by many fruit plucking manipulators and drones.

A. A. Dethe (✉) · B. Rajiv
COEP Technological University, Pune, India
e-mail: detheaa21.mfg@coep.ac.in

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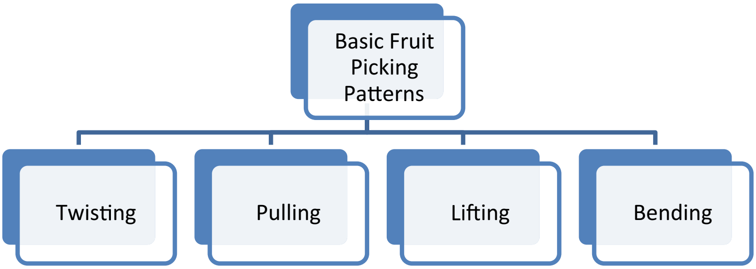

Fig. 1 Fruit plucking patterns

3 Fruit Picking Patterns

Fruit picking can be done in mainly two methods: manual and mechanical. Some paper reviews indicate that it involves crude equipment with manual labor and intensive risk. Despite multiple available fruit picking patterns and robotic advancements, fruit plucking by robotic manipulator still faces challenges [3]. Some widely used basic fruit picking patterns are shown in Fig. 1.

The torsional force required to cut some fruit exceeds sometimes the force generated by rotational grippers, resulting in failure. The rotation angle required for fruit detachment varies from 360° to 1200° [4]. Experiments have shown that rate of damages of fruit increases with greater angle of rotation, where greater angle also indicates the higher rate of successful detachment [4]. This implies that in successful detachments, the fruit is put at risk of harm. In the pulling off method also, there is higher risk of peeling of skin of fruit at the main stem. Sometimes, this torn stem also causes negative consequences for other fruits of the cluster, giving heavy losses.

4 Other Available Gripper Analysis

As summarized in Table 1, various types of grippers currently used for fruit harvesting applications have been studied for considerations for designing this robotic end effector which is using a sliding cutter for fruit detachment. From this study, it can be concluded that these grippers might have problems like applying excessive force on skin of fruit, bruising, peeling of fruit skin or stem while detaching fruit by pulling and twisting methods.

In every aspect, the design proposed by this paper is beneficial, as it does not require any extra arrangements for rotation of gripper, vacuum system arrangements, no fluidic mechanism for soft grippers, making design less complex and less heavy. Also, by using 3D printing technology, we can use lightweight material to manufacture its parts, offering a lighter mechanism that will make it easy to handle and control by robot or drone.

Table 1 Literature survey

S. No.	Type of gripper	Problem analysis	Reference paper
1	Multi-finger grippers	1. Damages due to multiple fruit grasping and squeezing of fruit 2. The need of pulling and twisting the fruit requires excess pulling/twisting force 3. Need of extra mechanism in rotational grippers, also extra mechanism increases weight of system	Development of An Autonomous Tomato Harvesting Robot with Rotational Plucking Gripper [5]
2	Soft grippers	1. The need of pulling and twisting the fruit requires excess pulling/twisting force 2. Need of extra mechanism in rotational grippers, also extra mechanism increases weight of system	Soft Grippers for Automatic Crop Harvesting: A Review [6]
3	Vacuum grippers	1. The need of pulling and twisting the fruit requires excess pulling/twisting force 2. Need of extra mechanism in rotational grippers, also extra mechanism increases weight of system 3. Also, an extra mechanism for vacuum system is required	Development of an adaptable vacuum-based orange picking end effector [7]
4	Blade cutter	1. Stem identification is necessary before cutting 2. Slippage might happen	An Autonomous Fruit and Vegetable Harvester with a Low-Cost Gripper Using a 3D Sensor [8]

5 Assembly Design Components and Process of Fruit Detachment

Figure 2 tries to give a visual idea about the design of fruit plucking manipulator using a sliding cutter, which is being discussed in this paper. This figure shows the assembly of various components used to perform the fruit detachment and grasping operation. The components being used are discussed below.

5.1 Stationary Fingers Cup and Shaft

Shaft is the main base of this complete mechanism, on which the stationary fingers of the cup are joint permanently for making it a rigid and durable structure as can be

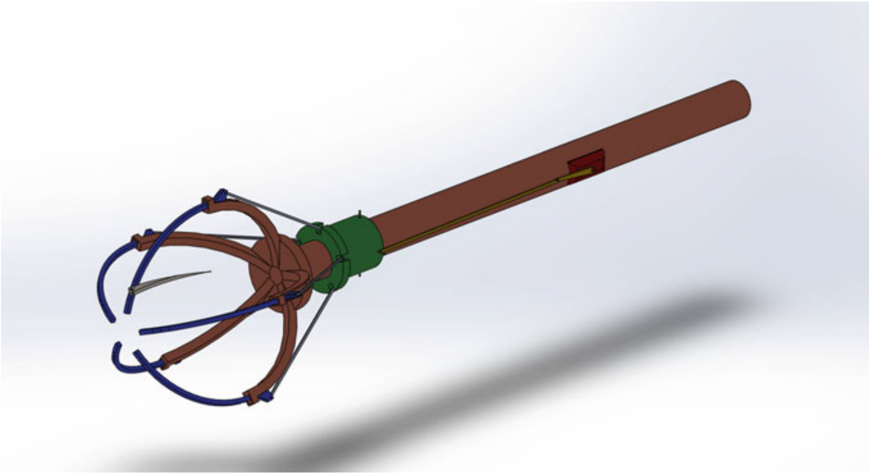

Fig. 2 Assembly design for robotic manipulator for fruit plucking

seen in Fig. 3. The linear bearing design will travel on this shaft for opening/closing and cutting of peduncle with blade sweeping motion.

This design of a stationary (no centripetal finger movement for grasping) cup for grasping the fruit fulfills the aim of avoiding an unintentional crushing or squeezing of fruit that causes multi-fingered grippers while bending, twisting, or pulling the

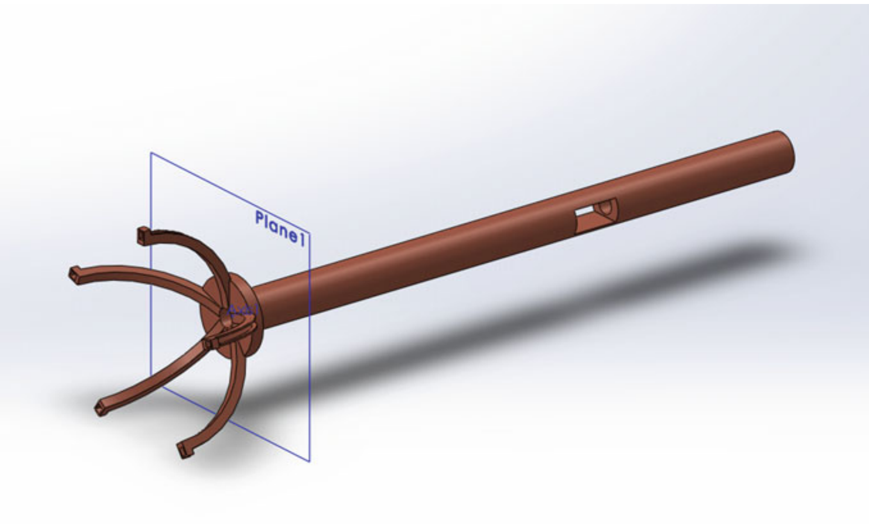

Fig. 3 Stationary finger cup attached to main shaft

fruit for detachment. This helps in reducing the losses due to fruit damage. The size of this cup is designed such that almost any sized fruit can be handled seamlessly.

5.1.1 Soft Padding

Inside the stationary fingers, foam like soft cushioning is attached for smooth grabbing of fruit and avoid bruises on peel of the skin. This avoids the possible damage to the fruit while handling and detaching the fruit.

5.2 Touch or Force Sensors

These touch sensors or force sensors are proposed to be attached on the internal side of stationary finger cup, preferably near the opening of shaft inside the cup. This will make passage for wires of sensors to pass through shaft, to transmit output signals to controller of drone. While proceeding with drone, when the fruit touches this sensor, the output signals will be sent to controller to initiate the process of closing the cup and cutting the abscission layer of peduncle of fruit.

Some preferred sensors will be piezoelectric force sensors, high frequency oscillator sensors, TTP223 1 channel capacitive touch sensor, etc. These sensors can be easily interfaced with commonly used controllers like Arduino and Raspberry Pi units.

5.3 Sliding Fingers for Opening and Closing of Fruit Holding Cup

After fruit gets within reach of manipulator and touches the touch sensor inside, the controller will send signals to motor to close the cup. For this process, linear bearing will be pushed toward the stationary finger cup, and the connecting rod will make sliding fingers slide over the stationary finger groove, closing the cup. This will ensure the fruit is grabbed appropriately and the peduncle is cut by the blade simultaneously.

Also, the soft material on the tips of the sliding fingers will reduce the impact of bruises that might cause other fruits on the branch while opening and closing of the grasping cup than other kind of grippers.

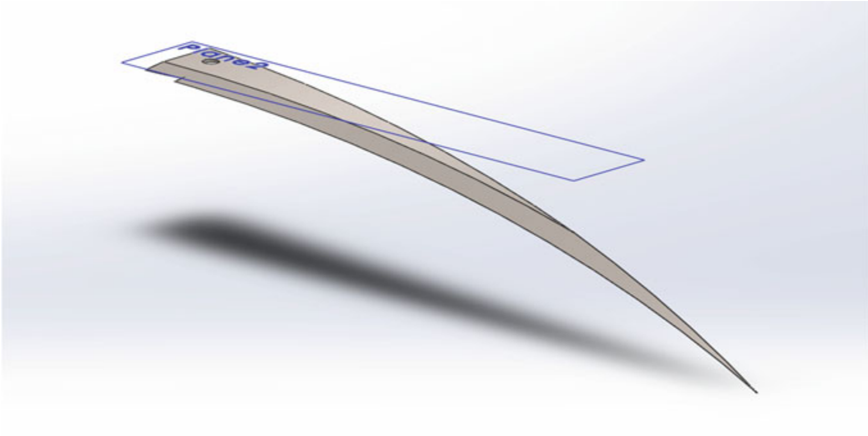

Fig. 4 Sharp blade for fruit stem cutting

5.4 Sharp Blade for Peduncle Cutting

The blade is fixed on one of the sliding fingers at top of manipulator with fixed joint as shown in Fig. 2. This makes sure the blade is immovable and rigid, making it firm for cutting the peduncle exerting more cutting force on it. Also, to ensure the successful detachment of fruit from stem, sharp blades will be used. During the motion of sliding finger from initial position to final position, the blade will sweep the area, by which the peduncle will cut successfully.

Figure 4 shows the profile of the blade designed for this application. This blade has slight bend to make it curved blade. This curved design avoids blade from having its sharp edge going much out of the assembly's working area and harming other parts of tree, to avoid the excessive cutting of other leaves or harming other fruits from the cluster.

5.5 Connecting Rods

Connecting rods are the main mechanism used for opening and closing of the fruit grasping and cutting process in this system. One end is connected to linear bearing and another to rear end of sliding fingers as can be seen in Fig. 2. Its rigid nature is responsible for exerting maximum thrust on the peduncle via blade connected to one of the sliding fingers, to ensure cutting of abscission layer of fruit peduncle and detachment of fruit from stem.

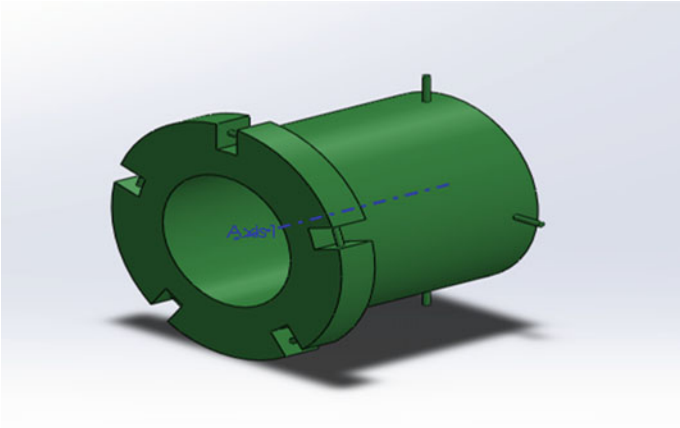

Fig. 5 Linear slide bearing

5.6 Linear Sliding Bearing

This part is designed for pushing and pulling the connecting rods with sliding fingers and blade attached to it (Fig. 5). Being a bearing, this sliding process becomes frictionless, offering a seamless process of grasping a fruit and cutting a peduncle with less effort. These linear bearings are used for achieving high-precision smooth travel along the circular shaft. This bearing is designed similar to LMK12UU [9] linear bearing with some changes like additional construction of circular shaft with five equidistant grooves having pin structure inside to facilitate holding for connecting rod to push and pull sliding fingers for opening/closing of cup and cutting peduncle of fruit as shown in Fig. 5.

The bearing movement can be controlled with the servo or stepper motors mounted on the shaft itself by slider–crank mechanism [10] as shown in Fig. 6. There is also hollowness given to the shaft internally, to provide gap for electrical wiring arrangements inside the shaft itself that will run throughout the shaft and open inside the drone, where it will be connected to the other components like battery and controller for operation and control of opening and closing of fingers. This will also benefit in hiding wires inside the shaft to avoid disturbances that might occur due to unintentional interaction of open hanging wires with tree parts or any other mechanism components of drone or manipulator.

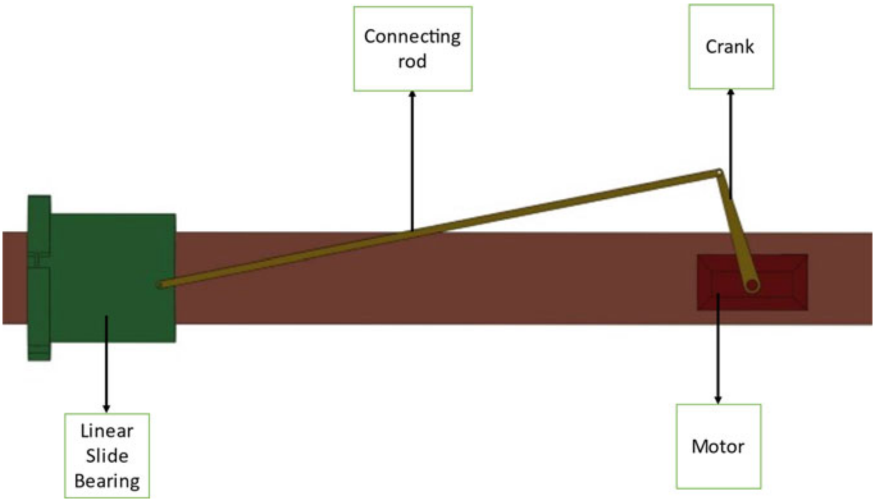

Fig. 6 Slider–crank mechanism

6 Process of Fruit Peduncle Cutting and Grasping

This is the initial (stationary) position of the manipulator (Fig. 7), while the drone or robot will be searching for the fruit. In this position, linear slide bearing is the most retracted position. When the drone will move toward the fruit and will confirm that it is within appropriate reach for detaching and grasping the fruit, it will start pushing the linear slide bearing using motor.

When the fruit is identified by the computer vision system, the drone or robot, along with the manipulator, will approach near the fruit and try to place the fruit inside the non-squeezing fingers safely. It will have soft cushioning inside to avoid scratches and bruises on the inside of fruit.

When the fruit touches the internally attached touch/force sensor, it will start closing the front fingers with the help of backend programing and cut the fruit

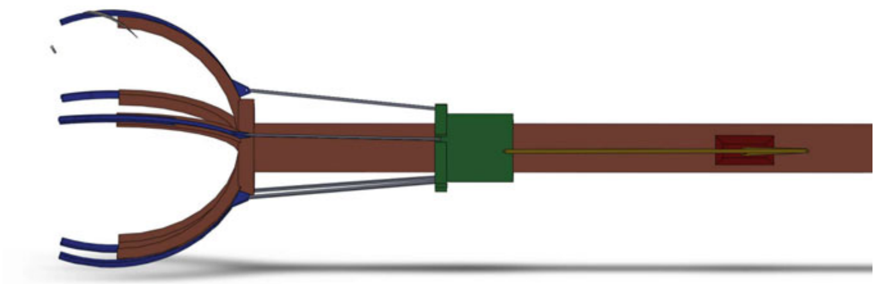

Fig. 7 Initial position of linear bearing

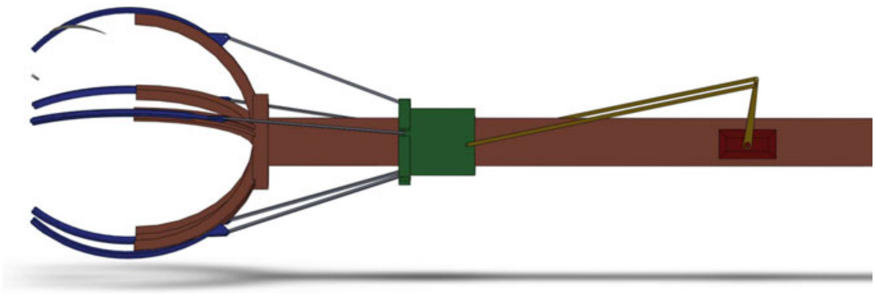

Fig. 8 Intermediate position of linear bearing (fruit just detached and semi-grasped position)

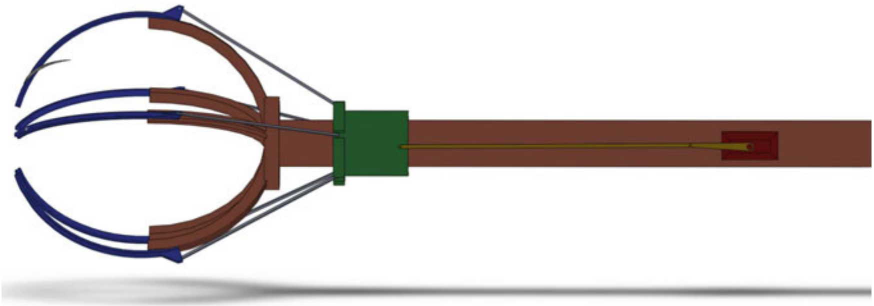

Fig. 9 Final position of linear bearing (fruit detached and fully grasped until drop-down)

peduncle to detach it from stem. Figure 8 shows the intermediate position while fruit has been identified by the vision system and motor has started pushing the linear slide bearing.

Figure 9 shows the final stage of fruit plucking manipulator, while the manipulator has closed the cup by pushing linear slide bearing fully. At this stage, fruit will be detached from the stem and will be grasped between the fingers of manipulator. The curved fingers of manipulator also ensure the appropriate grasping of fruit, without slippage mimicking the human grasping.

After successfully plucking the fruit, it will be dropped at desired location by the cultivator using robot or drone.

7 Conclusions

In this paper, a design of robotic fruit plucking manipulator with sliding blade for fruit plucking drones and robots has been proposed.

- This design will stand as least harmful and damage free for fruits.

- This design can achieve a comparatively higher success rate of fruit detachment from the stem than others.
- The cutting force required to detach fruit from the stem will be much lesser than other manipulators.
- This will certainly solve the problem of yield loss due to the mishandling of fruits by drones and robots.
- This can be used for mass harvesting applications where labor scarcity is found.

8 Future Scope

After further improvements in this design, robotic manipulator for fruit plucking can be validated by simulating using Gazebo environment and ROS (robot operating system), MATLAB. Also, after manufacturing prototype of the same, it can be tested in real environment. It can be integrated with robotic systems or fruit plucking drones for efficiency improvement.

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Analysis of Crack Dimensions During Crack Propagation Using Neural Network

Sumit Shoor, Dharma Teja Gopaluni, Wangchen Tamang, Pranay Prasad, Harpreet Singh, and Manpreet Singh

Nomenclature

ANN	Artificial neural network
ML	Machine learning
AI	Artificial intelligence
RMS	Root-mean-square
SNR	Signal-to-noise ratio
NN tool	Neural network tool

1 Introduction

Machine learning (ML) and artificial Intelligence (AI) are two emerging scientific technologies that are rapidly overtaking all previous industry technology. So, in order to probe further into this information, there are many ways in which numerous subparts are divided into distinct categories. To begin, we must consider why ML and AI are replacing old-school technology. The explanation is that ML systems are more efficient, less costly, and more adaptable due of this involvement-free quality. There are four types of machine learning approaches: supervised learning, unsupervised learning, semi-supervised learning, and reinforcement learning (RL) [1].

S. Shoor · D. T. Gopaluni · W. Tamang · P. Prasad · M. Singh (✉)
School of Mechanical Engineering, Lovely Professional University, Phagwara, India
e-mail: manpreet.20360@lpu.co.in

H. Singh
Vy Buss, Oslo, Norway

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Furthermore, deep learning is a subset of AI that includes artificial neural networks, and it functions similarly to neurons in the human brain. The ANN architecture consists of input layers, hidden layers, and output layers. These layers will respond in accordance with the data as inputs are provided in the input layers, and the hidden layers are constructed in the algorithm based on the number of hidden layers desired, with logic developed in that hidden layer to provide the correct output. Furthermore, there are two types of hidden layers: single layer neural networks and multi-layer layer neural networks. As the names suggest, they entirely represent the number of hidden layers in the system; the more hidden layers, the greater the accuracy [2–5].

Moreover, a new multi-class semi-supervised SVM approach has been proposed, and this method will help in identifying the top 'k' points in the datasets and to match with the nearest neighbors. The combination of support vector machine with a multi-class group-based semi-supervised learning approach improves intrusion classification performance. By utilizing sequence databases and sequential pattern analysis, the suggested method overcomes the delay in intrusion categorization [6–8].

In this work, the data obtained from the bearing have been subjected to the NN tool in MATLAB and used Levenberg–Marquardt backpropagation (trainlm). Although it requires more memory than other algorithms, trainlm is frequently the fastest backpropagation method in the toolbox and is usually encouraged as a first-choice supervised technique.

2 Experimentation

2.1 Data Extraction

First, the provided bearing with the seeded crack is run continuously for several hours to extract some of the characteristics that may be causing the crack to grow. RMS, crest factor, SNR, skewness, kurtosis, and Shannon entropy are the parameters in question. The data are provided in Table 1.

2.2 Application of Neural Network

Table 1 data will be imported into MATLAB, and a neural network model will be trained. Keeping the time duration constant, the rest of the parameters are trained independently to see which factor is more affected by crack propagation by comparing the projected data output to the actual data [2, 9–15]. The overall schematic NN tool module is shown in Fig. 1.

Table 1 Data retrieved from the bearing

Time duration in hours	RM S	Crest factor	SNR	Skewness	Kurtosis	Shannon entropy (10^7)	Total area	Width
0	8.347	7.1256	22.98	0.189	5.554	2.42	24.86	1.82
10	10.22	6.8215	20.77	0.168	6.492	3.59	24.86	1.82
20	8.087	6.2457	22.33	0.208	5.527	2.02	24.86	1.82
30	8.472	8.0384	21.7	0.184	5.749	2.27	24.86	1.82
40	8.485	7.0794	22.46	0.22	5.626	2.27	24.86	1.82
50	8.448	8.2828	20.71	0.228	5.913	2.26	24.8625	1.82
60	8.456	7.3888	23.4	0.229	5.549	2.26	24.865	1.82
70	8.449	6.5549	20.99	0.223	5.618	2.25	24.8675	1.82
80	8.365	7.2492	23.45	0.223	5.542	2.19	24.96	1.82
90	8.308	6.418	22.34	0.221	5.603	2.17	24.96	1.8286
100	8.251	7.0285	21.54	0.216	5.752	2.13	24.96	1.8373
120	8.3	6.4237	22.2	0.218	5.679	2.16	25.36	1.8953
140	8.601	6.7204	21.8	0.225	6.147	2.37	25.56	1.92
160	9.264	6.8881	20.35	0.168	5.521	2.8	26.0445	2.1
170	8.79	6.0588	20.29	0.18	5.728	2.48	26.4586	2.4766
180	7.68	13.357	23.6	0.119	8.537	2.03	26.978	3.1198
184	16.9	11.788	24.1	0.07	7.43	13.9	27.609	3.2798
188	8.1	14.3845	22.1	0.17	9.53	2.07	27.987	3.4399
192	7.97	11.439	22.9	0.04	7.67	1.98	28.275	3.6975
196	8.24	14.1009	24	0.11	11.6	2.19	28.345	4.0525

(continued)

Table 1 (continued)

Time duration in hours	RM S	Crest factor	SNR	Skewness	Kurtosis	Shannon entropy (10^7)	Total area	Width
200	25.02	10.2382	19.67	0.129	7.312	30.7	28.778	4.867
204	22	9.5045	19.4	0.09	7.53	28	28.83525	5.16
208	25.4	9.4644	22.4	0.11	7.15	20	28.8925	5.4545
212	25.7	12.754	19.5	0.16	8.63	26	28.94975	5.7482
216	24.9	8.8966	18.18	0.178	8.017	30.5	29.007	6.042
220	13.8	9.1122	24.3	0.12	7.09	7.27	28.885	7.0116
224	16	10.0815	21.2	0.16	7.63	15.2	28.945	7.0983
229	15.28	11.0412	23.31	0.078	8.1	10.2	29.15	7.231
232	19.2	11.2517	22.5	0.26	10.2	15.9	29.1725	7.341
239	16.28	7.774	21.91	0.141	6.48	11.7	29.202	7.531
248	19.21	9.1612	17.67	0.151	6.135	12.2	29.324	7.761
259	14.86	7.3411	18.42	0.1707	6.824	9.58	29.556	8.631
267.5	8.723	9.1705	21.7	0.14	4.967	2.66	29.564	8.987
274.5	9.15	8.3301	19.51	0.041	6.653	3.06	31.019	9.362
278.5	9.178	9.6329	21.2	0.115	6.682	13.26	33.372	9.761
284.5	9.603	10.247	19.47	0.014	7.288	3.09	36.518	10.401
285	9.114	10.4396	19.35	0.009	7.954	2.74	40.157	10.967

Furthermore, the overall area and width of the crack are considered goal data. Now, the ANN is trained using the trainlm algorithm for each parameter independently, and the expected output is simulated by feeding the algorithm sample data; the predicted total area and crack width are then compared to the actual data. This study is repeated for each parameter separately, and the ANN model with the lowest error in projected values is regarded to be the most influential factor in crack propagation.

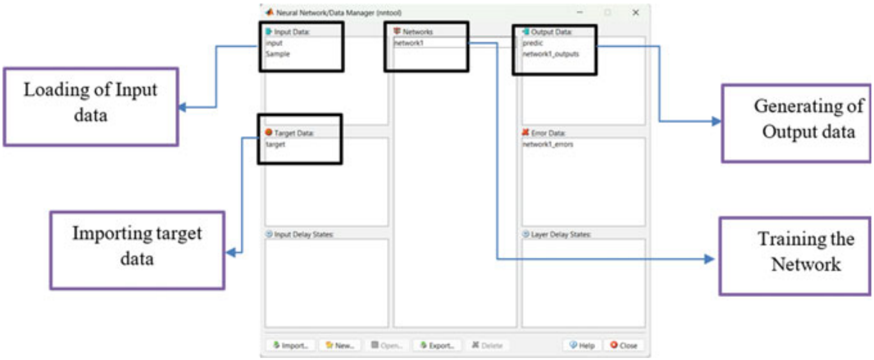

Fig. 1 NN tool module

Furthermore, the method provides a regression plot for the input and output data, which establishes a regression line between two parameters and aids in the visualization of their linear correlations. The regression plot is commonly characterized as R, the plot that is formed comes with a R value, which stands for regression value, and this value is regarded to be best and most accurate if R square equals 1 [16]. The NN training tool used is shown in Fig. 2.

3 Results and Discussions

3.1 Root-Mean-Square (RMS)

Using the RMS and time duration values as input parameters and the total area and breadth as targets, an ANN model was constructed, and values were forecasted using that model by providing some sample data as input. Table 2 shows the projected values as well as the actual data.

The predicted values are created using the ANN model, and the accuracy of the trained model is calculated using the actual values.

The trained model's accuracy is calculated by taking the average of all the values. The findings indicated that RMS as a single parameter had an accuracy of 94.2%. The accuracy was computed using the formula below [16]:

$$\text{Accuracy} = 1 - (\text{Predicted value} - \text{Actual value})/\text{Predicted value}$$

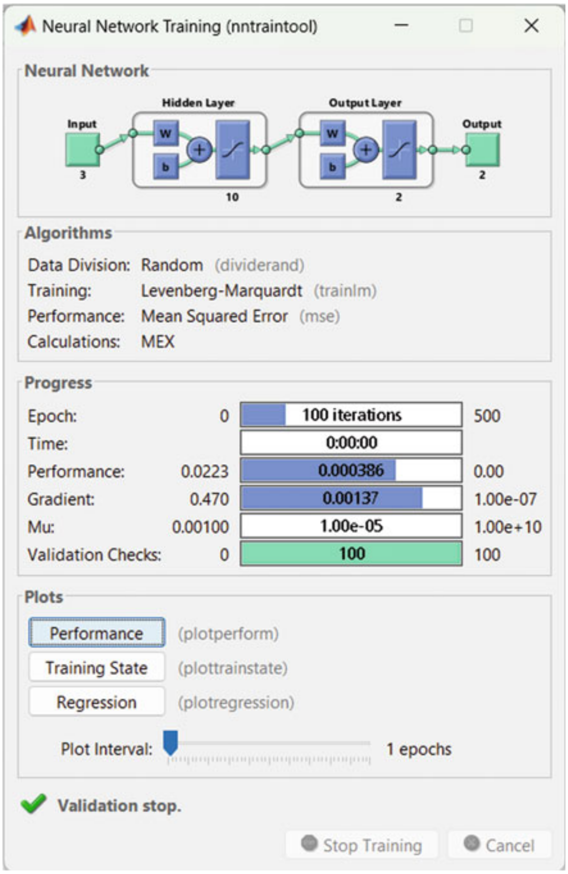

Fig. 2 NN training tool

3.2 Crest Factor

An ANN model was built with the crest factor and time duration values as input parameters and the total area and breadth as targets, and values were projected using that model by supplying some sample data as input. Table 3 displays both the predicted and actual numbers.

3.3 Remaining Parameters

The same procedure was followed for the remaining parameters, namely SNR, skewness, kurtosis, and Shannon entropy, and the predicted data, as well as the actual data's accuracy, were shown in Table 4.

Table 2 Analyzed data with RMS as input parameter

Input parameters		Actual/target values		Predicted values		Accuracy (in %)
Time duration in hours	RMS	Total area	Width	Total area	Width	
0	8.347	24.86	1.82	24.8600	1.82	100.0
10	10.22	24.86	1.82	24.8600	1.82	100.0
20	8.087	24.86	1.82	24.8600	1.82	100.0
30	8.472	24.86	1.82	24.8600	1.82	100.0
40	8.485	24.86	1.82	24.8600	1.82	100.0
50	8.448	24.8625	1.82	24.8601	1.82	100.0
60	8.456	24.865	1.82	24.8604	1.82	100.0
70	8.449	24.8675	1.82	24.8619	1.8200	100.0
80	8.365	24.96	1.82	24.8708	1.8200	99.8
90	8.308	24.96	1.8286	24.9076	1.8202	99.7
100	8.251	24.96	1.8373	25.0026	1.8249	99.6
120	8.3	25.36	1.8953	25.3488	1.8787	99.5
140	8.601	25.56	1.92	25.5771	1.9401	99.4
160	9.264	26.0445	2.1	26.0410	2.0878	99.7
170	8.79	26.4586	2.4766	26.2826	2.4391	98.9
180	7.68	26.978	3.1198	27.6182	3.0798	98.2
184	16.9	27.609	3.2798	24.8600	3.2777	94.4
188	8.1	27.987	3.4399	27.9953	3.4596	99.7
192	7.97	28.275	3.6975	28.2749	3.6800	99.8

(continued)

Table 2 (continued)

Input parameters		Actual/target values		Predicted values		Accuracy (in %)
Time duration in hours	RMS	Total area	Width	Total area	Width	
196	8.24	28.345	4.0525	28.1086	3.8432	96.9
200	25.02	28.778	4.867	24.86	4.8627	92.1
204	22	28.83525	5.16	24.86	5.1546	92.0
208	25.4	28.8925	5.4545	24.86	5.4346	91.7
212	25.7	28.94975	5.7482	24.86	5.7407	91.7
216	24.9	29.007	6.042	24.86	6.0431	91.6
220	13.8	28.885	7.0116	24.86	6.8938	91.1
224	16	28.945	7.0983	24.86	7.0906	91.7
229	15.28	29.15	7.231	24.86	7.2384	91.3
232	19.2	29.1725	7.341	24.86	7.5194	90.1
239	16.28	29.202	7.531	24.86	7.4396	90.7
248	19.21	29.324	7.761	24.86	7.7607	91.0
259	14.86	29.556	8.631	24.86	8.6296	90.5
267.5	8.723	29.564	8.987	24.86	8.9862	90.5
274.5	9.15	31.019	9.362	24.86	9.2226	86.9
278.5	9.178	33.372	9.761	24.86	9.7644	82.9
284.5	9.603	36.518	10.401	24.86	10.3986	76.5
285	9.114	40.157	10.967	24.86	10.9600	69.2

Along with the accuracy, regression graphs for all parameters have been plotted and are shown in Figs. 3, 4, 5, 6, 7, and 8.

According to the preceding data, the SNR was 99.2%, skewness was 98.6%, kurtosis was 97.1%, and Shannon entropy was 97.8% accurate.

Table 3 Analyzed data with crest factor as input parameter

Input parameters		Actual/target values		Predicted values		Accuracy (in %)
Time duration in hours	Crest factor	Total area	Width	Total area	Width	
0	7.1256	24.86	1.82	24.8600	1.82	100.0
10	6.8215	24.86	1.82	24.8600	1.82	100.0
20	6.2457	24.86	1.82	24.8600	1.82	100.0
30	8.0384	24.86	1.82	24.8600	1.82	100.0
40	7.0794	24.86	1.82	24.8600	1.82	100.0
50	8.2828	24.8625	1.82	24.8600	1.82	100.0
60	7.3888	24.865	1.82	24.8600	1.82	100.0
70	6.5549	24.8675	1.82	24.8600	1.8200	100.0
80	7.2492	24.96	1.82	24.8600	1.8200	99.8
90	6.418	24.96	1.8286	25.6415	1.8200	98.4
100	7.0285	24.96	1.8373	24.9593	1.8200	99.5
120	6.4237	25.36	1.8953	25.7792	1.8200	97.1
140	6.7204	25.56	1.92	25.8987	1.8200	96.6
160	6.8881	26.0445	2.1	26.0445	1.8200	92.3
170	6.0588	26.4586	2.4766	26.4577	1.8200	82.0
180	13.357	26.978	3.1198	24.8600	3.1218	95.7
184	11.788	27.609	3.2798	24.8600	3.2773	94.4
188	14.3845	27.987	3.4399	24.8600	3.3777	92.8
192	11.439	28.275	3.6975	24.8600	3.6949	93.1
196	14.1009	28.345	4.0525	24.8600	4.0541	93.0
200	10.2382	28.778	4.867	28.7983074	4.9050	99.6
204	9.5045	28.83525	5.16	28.85434946	5.1448	99.8
208	9.4644	28.8925	5.4545	28.89521537	5.4927	99.6
212	12.754	28.94975	5.7482	24.86	5.7404	91.7
216	8.8966	29.007	6.042	28.96290978	6.0790	99.6
220	9.1122	28.885	7.0116	29.00115216	6.4209	95.2
224	10.0815	28.945	7.0983	29.04998962	6.8310	97.9

(continued)

Table 3 (continued)

Input parameters		Actual/target values		Predicted values		Accuracy (in %)
Time duration in hours	Crest factor	Total area	Width	Total area	Width	
229	11.0412	29.15	7.231	29.10491902	7.2469	99.8
232	11.2517	29.1725	7.341	29.12729376	7.4323	99.3
239	7.774	29.202	7.531	29.18287349	7.5263	99.9
248	9.1612	29.324	7.761	29.20599516	8.0095	98.2
259	7.3411	29.556	8.631	29.5600133	8.6280	100.0
267.5	9.1705	29.564	8.987	29.69694264	8.7809	98.6
274.5	8.3301	31.019	9.362	31.01305386	9.3511	99.9
278.5	9.6329	33.372	9.761	32.19229614	9.7187	98.0
284.5	10.247	36.518	10.401	36.50258921	10.4959	99.5
285	10.4396	40.157	10.967	36.82257261	10.5398	93.4

By repeating the accuracy calculation method from the previous stage, the crest factor exhibited 97.4% accuracy

Table 4 Accuracy percentage of remaining parameters

S. No.	Input parameters	Accuracy (in %)
1	SNR	99.2
2	Skewness	98.6
3	Kurtosis	97.1
4	Shannon entropy (10^7)	97.8

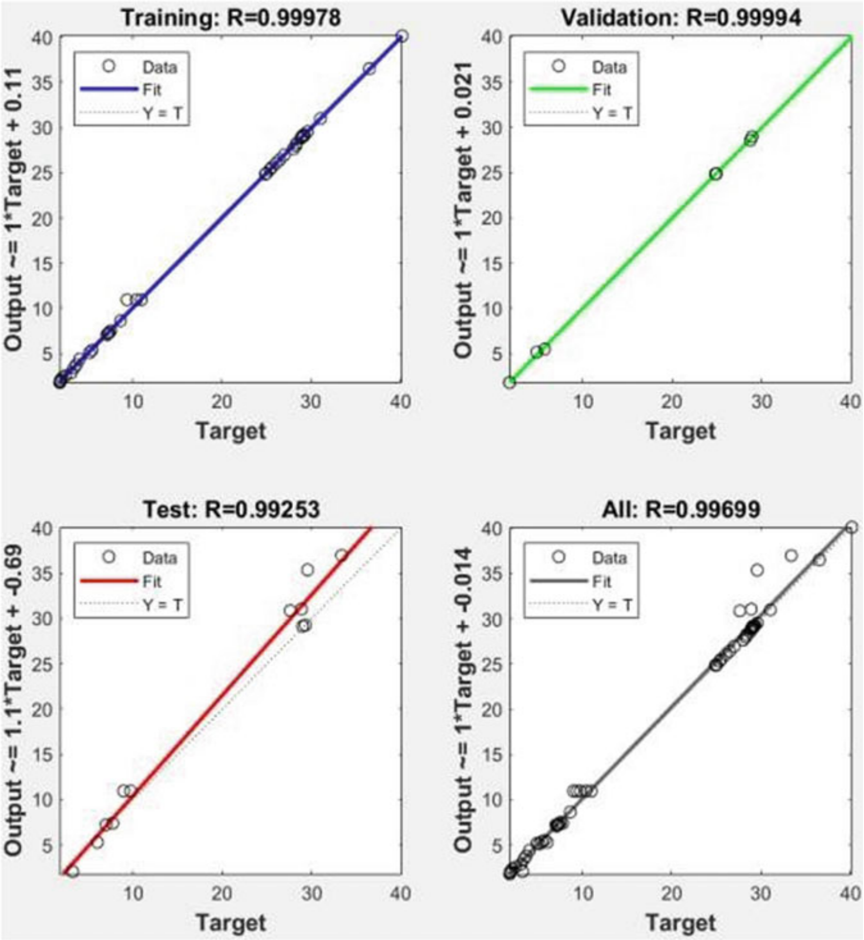

Fig. 3 Regression plot for RMS

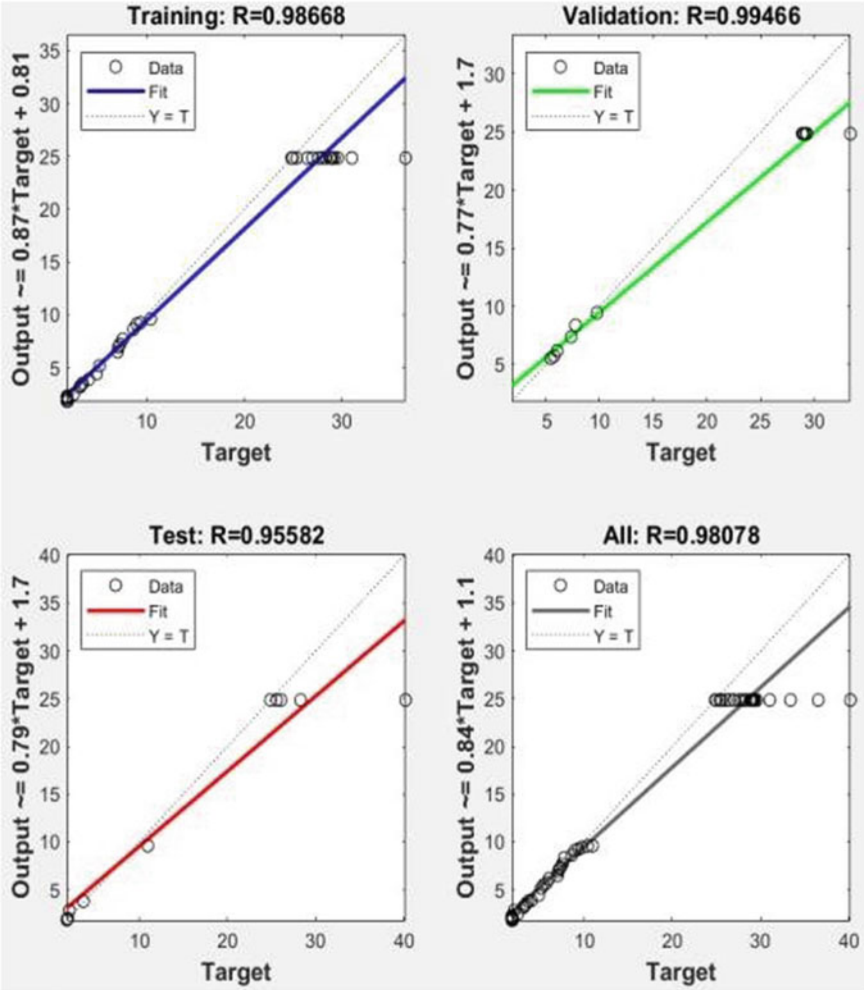

Fig. 4 Regression plot for crest factor

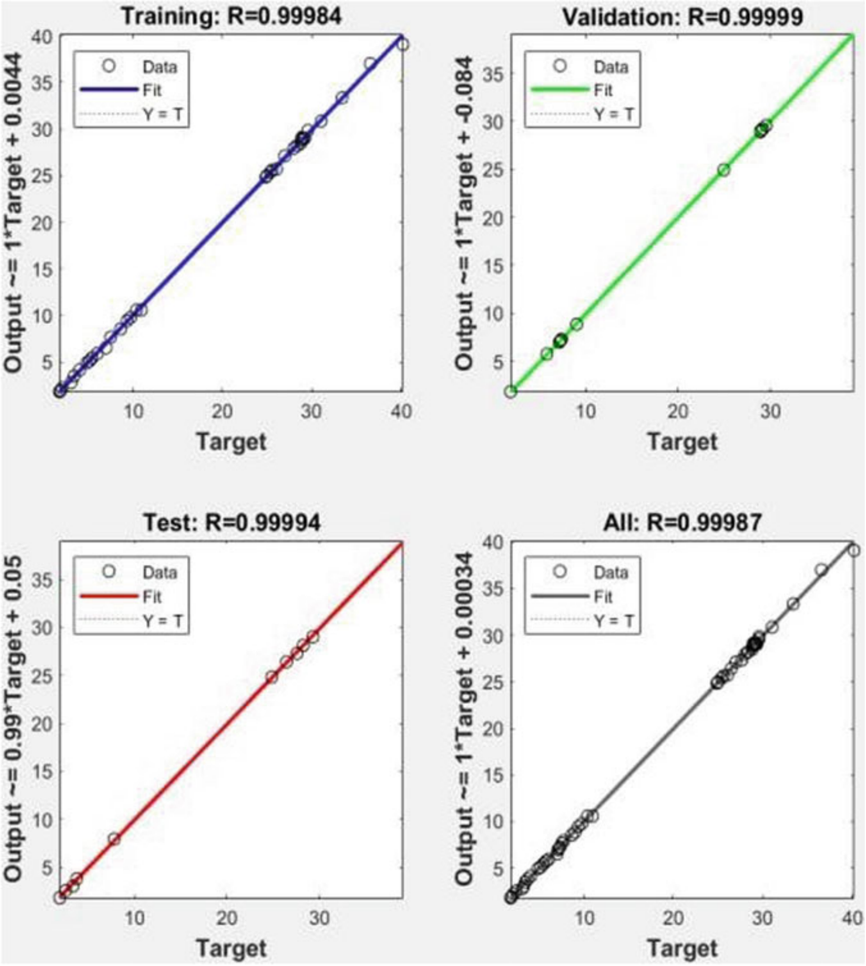

Fig. 5 Regression plot for SNR

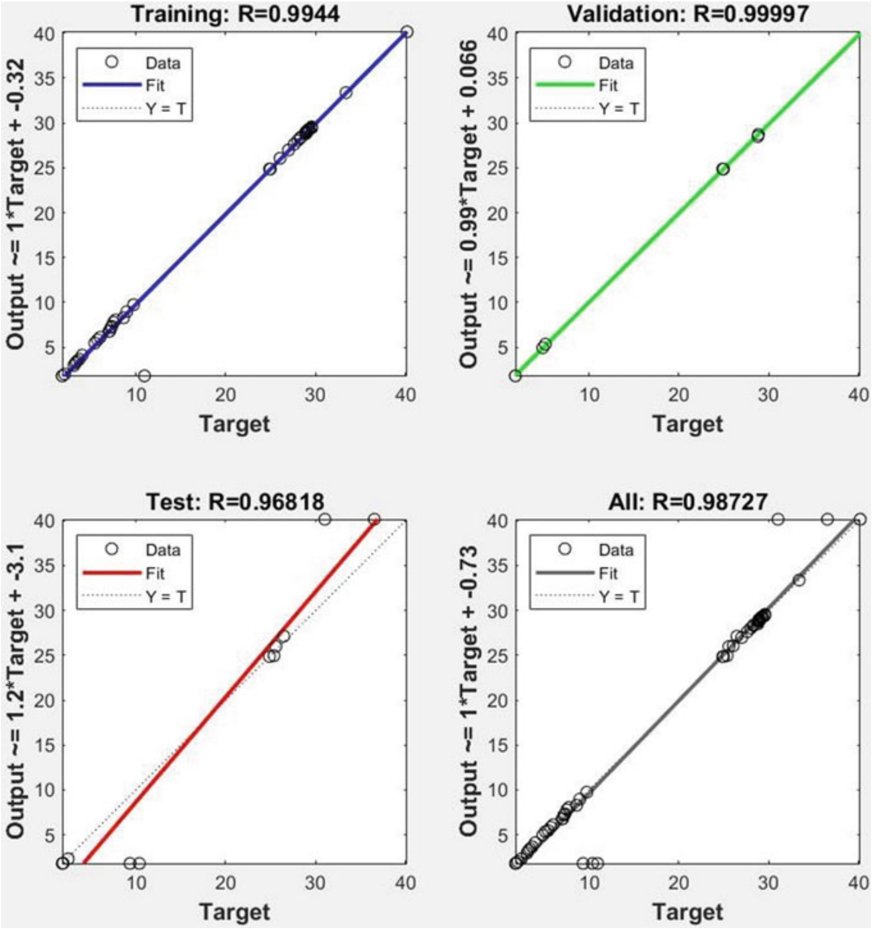

Fig. 6 Regression plot for skewness

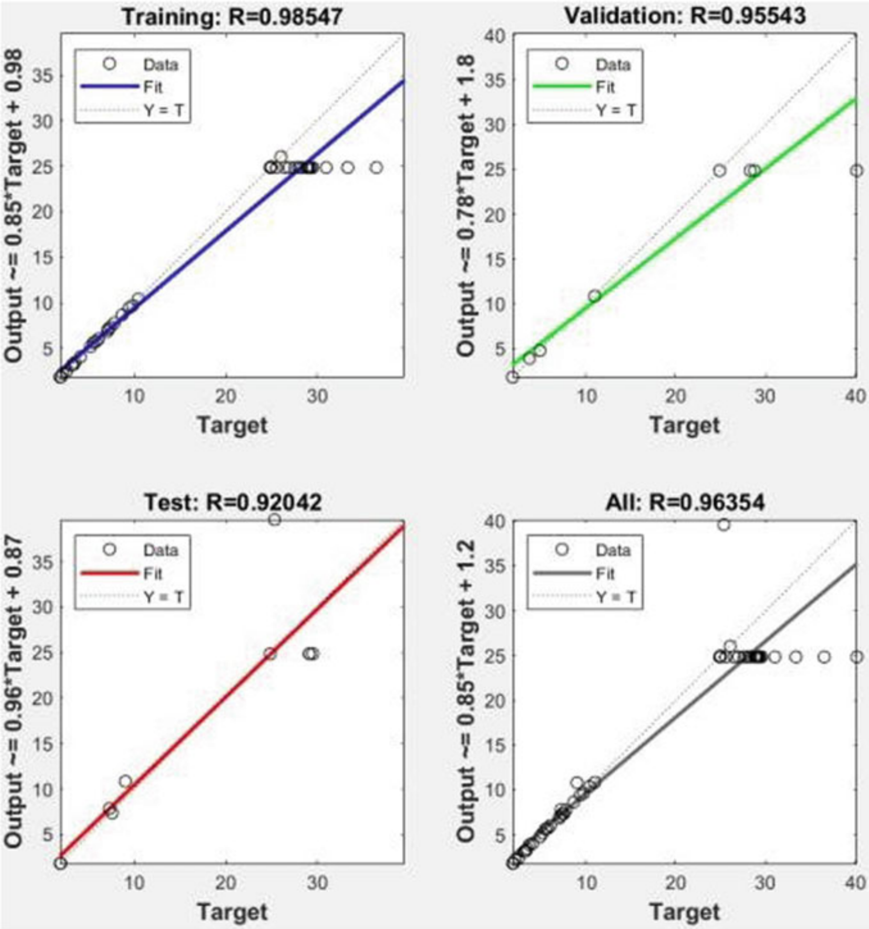

Fig. 7 Regression plot for kurtosis

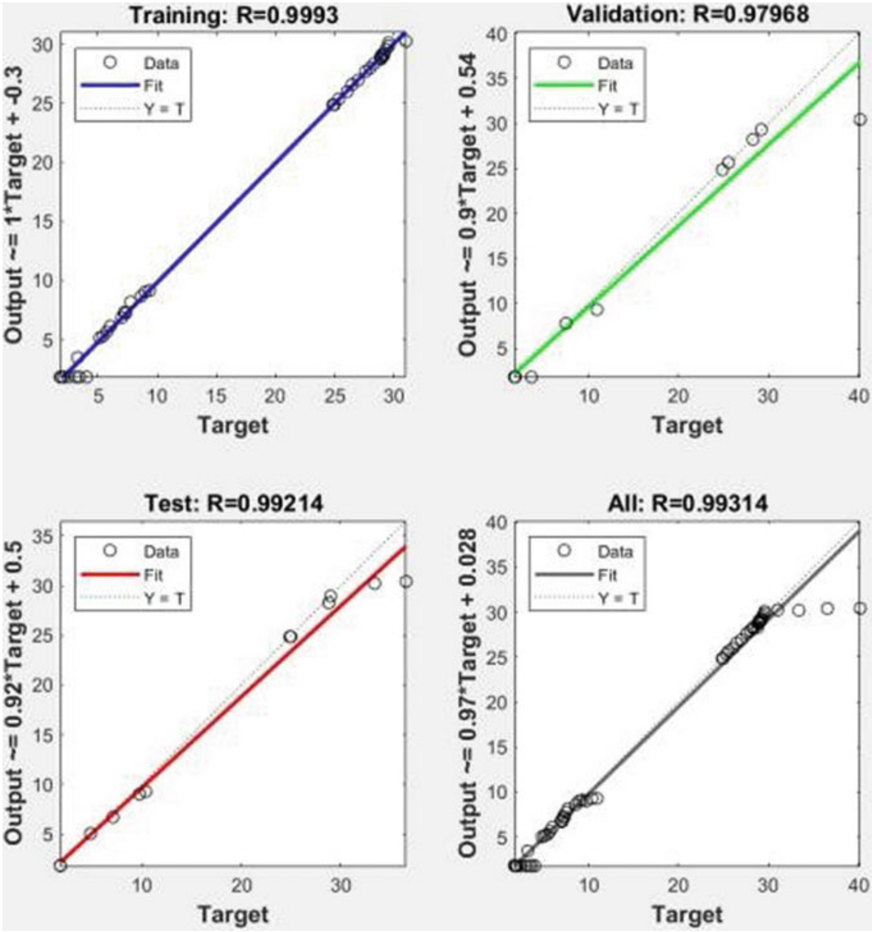

Fig. 8 Regression plot for Shannon entropy

4 Conclusions

To summarize, the ANN model performed admirably in predicting the data with more accuracy. Although there was some variation for each parameter, the sound-to-noise ratio was 99.2% accurate in forecasting data in bearing crack propagation. As a result, we infer that the SNR, as a single parameter, demonstrates the greatest dependence in bearing crack propagation. The findings are dependent on a single parameter, but if we used dual or triple parameters to construct the output, it is possible that the results would be more accurate.

Furthermore, the work will be expanded to examine several parameters at the same time to make predictions, so that the work will be more beneficial in future to know the exact forecast from the inputs.

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Reconfigurable Manufacturing System Generic Design Framework for System-Level Design

Rutuja Shivdas and Sagar Sapkal

Nomenclature

RMS	Reconfigurable manufacturing system
NSF	National Scientific Foundation
ERC	Engineering Research Center
RMT	Reconfigurable machine tool
OC	Operation cluster

1 Introduction

Manufacturing has evolved significantly over the last two centuries. Manufacturing paradigm changes are classified as Industry X.0 industrial revolutions. Manufacturing paradigm craft production mentioned as Industry 1.0 renovated to mass production period which brings up Industry 2.0 to mass customization and then again to personalization. The craft production period has been categorized by very high product variety and very low volume; most of the products are agricultural. The mass production period has been characterized by stable market demand. In the 1980s, mass

R. Shivdas (✉) · S. Sapkal
Department of Mechanical Engineering, Walchand College of Engineering, Vishrambag, Sangli, Maharashtra 416415, India
e-mail: rutujashivdas7@gmail.com

S. Sapkal
e-mail: sagar.sapkal@walchandsangli.ac.in

R. Shivdas
Department of Mechanical Engineering, Dr. D. Y. Patil Institute of Engineeering, Management & Research, Akurdi, Pune, Maharashtra 411044, India

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customization was familiarized. It is a society-driven paradigm. Development of flexible automation is possible due to the application of computers into industrial operations, and this period brings up Industry 3.0. Global manufacturing refers to Industry 4.0. Globalization increases the individual consumption of products and continues to grow rapidly, which encourages sustainability concerns [1]. Researchers at the National Scientific Foundation Engineering Research Center (NSF/ERC) for reconfigurable manufacturing system (RMS) issued a patent for RMS design [2]. RMS is proposed to process a considered part family. This customized flexibility of the reconfigurable machine tool (RMT) makes them low priced in comparison with general-purpose machines[3]. According to the definition of RMS, "It is designed from the outset for a quick change in structure, also in hardware and software components, to quickly adapt manufacturing capacity and functionality inside a part family in response to sudden fluctuations in the market or regulatory requirements [4]."

RMS has six core reconfigurable characteristics. These characteristics of RMS are empowering a system to change continually for a lifetime in accordance with fluctuations in the market environment, consumer demand, and process technology. Hence, RMS can reliably decrease its lifetime cost. Customization, convertibility, scalability, modularity, and integrability are quantitative reconfigurability characteristics while diagnosability is a qualitative/quantitative characteristic [2].

RMS is modular in structure. The basic and auxiliary modules are assembled to form the reconfigurable machines. The same basic module is used to create several RMT configurations according to production specifications by exchanging auxiliary modules [3]. The RMS consists of material handling systems, control, and communications, as well as reconfigurable workstations. In the RMS design technique, system-level design is the initial step in which the entire system is planned such that subsystems can be easily and economically reconfigured in parallel, serial, or hybrid configurations which supports machine-level design [5]. The actions that are carried out inside the production system's boundaries but at a significantly higher level than machines are referred to as system-level reconfiguration efforts. Machine-level reconfiguration effort refers to actions taken within the limitations of the manufacturing system and entirely within the capabilities of the machine [6]. System-level design consequently is the basis for manufacturing system design. RMS design is not supported by traditional manufacturing system design methodologies; hence, a systematic RMS design process is essential. In this study, work is done to propose a generic design framework for RMS that takes system-level design into account.

2 Literature Review

An extensive literature review that addresses system-level RMS design is included in this section. Bortolini et al. [7] investigated the significance of RMS within the Industry 4.0 framework and explored next-generation manufacturing systems. They examined applied research and field application as one of the key new research trends for effective RMS implementation, which involves part family formation, layout design, configuration design, machine selection, planning, and scheduling. In this work, the literature review focuses on significant theories and practices presented to explore methodologies used to solve system-level design problems such as configuration design, machine selection, and layout design for RMS.

Tillbury and Kota [4] mentioned that in the year 1999, NSF/ERC issued an RMT design patent and illustrated the RMS design principles. Katz and Moon [8] illustrated the approach for designing an RMT. They presented the design process of the virtual arch RMT developed in view of a part family of products with inclined surfaces. Aguilar et al. [9] proposed a synthesized machine tool product development methodology and modeled a new lathe-mill RMT using the proposed methodology.

2.1 RMS Performance Measures

Koren and Wang [10] demonstrated GA for optimization with the total number of equipment as the optimization goal and introduced a scalability planning method for rearranging a real-world manufacturing system. Goyal et al. [11] established a method for quantifying operational capability and machine reconfigurability measures to evaluate an RMT's responsiveness. Youssef and ElMaraghy [12] concentrated on the selection of configurations at the system level. They constructed a metric to assess the degree of reconfiguration smoothness to determine a comparative assessment of the anticipated expenditure, effort, and time needed to reconfigure from one configuration to another. Metric evaluates the smoothness of system-, machine-, and market-level reconfigurations.

2.2 RMS Configuration

Dou et al. [13] presented a method for designing single-product flow-line configurations that consider the goal to reduce capital costs of configurations constrained to investment limits, space restrictions, capacity constraints, and precedence constraints within tasks. Hasan et al. [14] focused on choosing the best RMS configuration that will satisfy numerous part family order requirements. The goal is to execute orders for part families on an RMS configuration while increasing the estimated benefit earned by the manufacturer. Ashraf and Hasan [15] executed research for the configuration selection decision, and a multi-objective problem is formulated for a reconfigurable serial product flow line that is integrated with RMTs. Sabioni et al. (2021) [16] summarized the research on RMS configuration in terms of configuration level, and optimization methods for simulating and resolving RMS configuration-related issues.

2.3 Machine and Layout Selection for Process Plan Generation in RMS

Yamada et al. [17] offered an RMS layout optimization. With the use of a particle swarm optimization technique, they took into account the goal of attaining the shortest possible manufacturing time for manufacturing systems and the arrangement of transportable robots. Abdi [18] developed an analytical hierarchy process-dependent model which considers both qualitative and quantitative factors for cost, reconfigurability, quality, and reliability when choosing layout configurations for an RMS. Maganha et al. [19] focus on reconfigurable layouts and review the literature on RMS layout design. Touzouta and Benyoucef [20] addressed three hybrid heuristics, namely the repetitive iterated local search on single-unit process plan heuristic, single-unit process plan heuristic, and archive-based iterated local search heuristic, which are proposed and compared to address the multi-unit process plan, multi-objective single-product process plan. Arnarson et al. [21] proposed a mathematical model using optimization and Industry 4.0 technologies for the smart layout design of a platform-based RMS.

2.4 Part Family

RMS intends to limit its adaptability to the families that are identified to be part of it. Part clustering is therefore essential to the effective execution of RMS implementation. Galan et al. [22] focused on system-level issues that accelerated production and maintain product quality while producing goods in the precise quantity needed and suggested Jaccard's coefficient-based part family formation methodology. Goyal et al. [23] established the longest common sequence-shortest composite subsequence-dependent bypassing moves and idle machines similarity coefficient. Wang et al. [24] worked as an extension of Goyal et al. [23] part family formation methodology. Huang and Yan [25] focused to improve the work of Wang et al. [24]. Shivdas and Sapkal [26] established an approach to group parts into families while taking into consideration RMS characteristics by proposing a composite similarity metric.

3 System-Level Design

System-level design of RMS covers configuration design and system layout design. The design of handling subsystem storage, subsystem design, and added value subsystem design are all included in the layout design. Added value refers to the component of the manufacturing systems that contributes value to the raw material, such as the assembly, and machining systems. Overall, system-level design activities involve modifying the material flow path, relocating the machines within the system, and adding, removing, or adjusting the machines. Removing, adding, or adjusting machine modules and operation clusters are machine-level activities [27].

In this section, the generic design framework for RMS is presented considering system-level design. Figure 1 shows phases of the RMS generic design framework. The detail about each phase is explained in the next section.

- Determining the requirement for reconfigurability is the first step in RMS design. Identification of change of drivers of the system is carried out in this phase. The

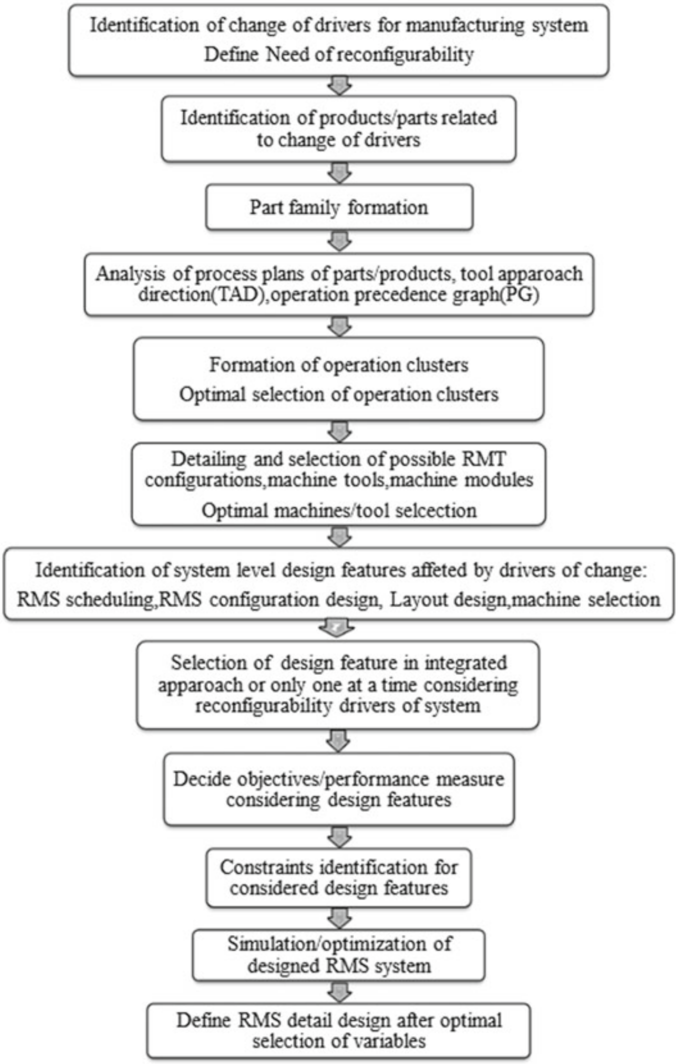

Fig. 1 RMS generic design framework considering system-level design

development of new products, the requirement for product customization, the relocation of manufacturing facilities, and other factors are some of the factors that are driving the requirement for reconfigurability [27].

- The parts/products of the system that are responsible for change are analyzed and selected for further exploration.
- In the next phase, part family formation is carried out as it is one of the important characteristics of RMS. In some recent literature, Wang et al. [25], Shivdas, and Sapkal [26] developed a methodology to cluster parts in families while considering RMS properties in composite similarity metric and proposed a composite similarity metric for the part family formation of RMS.
- Analysis of tool approach direction, process plans, and generation of operation precedence graph carried out depending upon the optimal selection of operation clusters (OC) carried out. Shabaka and Elmaraghy [28] outlined in detail an approach to generate machine configuration through the creation of operation clusters (OCs).
- OCs are further applied in detailing and selecting possible RMT configurations, machine tools, machine modules, and optimal machines/tool selection.
- The next phases in the design framework give details about system-level design features selection and their optimization to achieve optimal RMS design. System-level design features of RMS comprise configuration design, RMS scheduling, RMS layout design, and machine selection and their optimization. This paper's literature review section summarizes research findings that take configuration, layout design, and machine selection into consideration.
- In the final stages, RMS design work is carried out in an integrated approach considering two or more system-level design features at a time or a system can be designed considering one design feature. Then, the analysis of the designed RMS is carried out by evaluating the considered performance measures of the system.

4 Conclusion

RMS characteristics have the potential to act as a solution for challenges faced by industries due to changes in manufacturing systems. However, compared to traditional manufacturing systems, designing the RMS provides a substantial difficulty because it must be built to produce a wide range of variants and product generations efficiently over the period of its life. In designing RMS systems and putting them into practice with consideration of customized part families, the general design framework which has been presented in this paper will be significant. Based on the analysis of design processes, there is currently a dearth of research on how to effectively address RMS system-level design challenges in practice. It may be challenging to implement and test specific theories in the industrial case studies context, such as the design of reconfigurable machinery, production planning, and the design of reconfigurable processes, all of which currently present significant research challenges. It would be interesting to carry out further research in future to analyze how various companies implement the proposed framework and develop reconfigurable manufacturing systems.

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Musculoskeletal Risks Assessment in Bus Body's Roof Stick Manufacturing

Mangesh Joshi

1 Introduction

Work-related musculoskeletal disorders (WMSDs) refer to a group of painful or disabling conditions that affect the muscles, tendons, nerves, and joints caused by the work environment or work-related activities. WMSDs can be caused by repetitive motions, awkward postures, heavy lifting, forceful movements, or other physical stresses that are common in certain occupations. Common examples of WMSDs include carpal tunnel syndrome, tendonitis, lower back pain, and neck and shoulder pain. WMSDs are a significant occupational health and safety issue and can result in lost productivity, increased absenteeism, and increased healthcare costs [1, 2].

REBA, RULA, and OWAS are all tools used to assess ergonomic risk factors in the workplace. REBA assesses the entire body posture during a job task and evaluates physical and postural factors associated with WMSDs. RULA focuses specifically on the upper extremities, including the neck, shoulders, arms, wrists, and hands, and evaluates the risk factors associated with tasks that require repetitive motion, forceful exertion, and awkward postures. OWAS assesses body postures and movements and classifies them into one of six categories based on the level of physical strain placed on the worker's body. The assessment is based on a systematic observation of the worker's posture and movement during a specific job task.

All three tools can be used to identify potential ergonomic hazards and determine appropriate interventions to reduce the risk of WMSDs. However, it is important to note that no single tool can provide a comprehensive assessment of all ergonomic risk factors, and a combination of tools and methods is typically used to develop an effective ergonomic risk management program.

Ergonomic assessments are important in the automobile sector as the work in this industry often involves manual labor and repetitive motions, which can lead

M. Joshi (✉)
Shri Ramdeobaba College of Engineering and Management, Nagpur, MH 440013, India
e-mail: joshimp@rknec.edu

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to WMSDs if not managed properly. Here are some key steps for conducting an ergonomic assessment in the automobile sector:

- Identify job tasks: Identify the specific job tasks that are most likely to cause ergonomic hazards, such as lifting heavy parts, working in awkward postures, or performing repetitive motions.
- Assess the risk factors: Use tools like REBA, RULA, and OWAS to evaluate the ergonomic risk factors associated with the identified job tasks.
- Determine appropriate interventions: Based on the assessment results, determine appropriate interventions to reduce the risk of WMSDs. This may include modifying the work environment or job tasks, providing ergonomic equipment or tools, or implementing training programs for workers.
- Implement and evaluate interventions: Implement the interventions and evaluate their effectiveness. This may involve monitoring worker health and safety, collecting feedback from workers, and modifying interventions as needed.
- Continuously monitor and improve: Ergonomic assessments should be an ongoing process, with regular monitoring and review to identify and address new or changing ergonomic hazards.

Overall, conducting an ergonomic assessment in the automobile sector can help to prevent WMSDs and improve worker health and safety. It is important to involve workers in the assessment process and to implement interventions in a collaborative and supportive manner to ensure their effectiveness and sustainability [3–6].

1.1 Study Objectives

This study has been carried out keeping two objectives in focus:

- To investigate ergonomic risks involved in roof stick manufacturing activity.
- Understanding the correlation between the outputs of each method.

2 Literature Review

A literature review was conducted to determine the industries that have undergone ergonomic assessments. Authors [7] discussed the use of surface electromyography techniques to identify ergonomic risks in screen printing tasks, revealing that prolonged monotonous and repeated bending tasks in a printing environment increase the risk of lower back muscle fatigue. In carpet alignment tasks, authors [8] implemented the strain index and found a need for urgent corrective action. Author [9] applied the RULA method in CATIA and found high risk in carpet cleaning activity. Using REBA and RULA, author [10] investigated the risk factors of WMSDs and postural discomfort among welders working in unorganized manufacturing units, with the Nordic musculoskeletal disorder questionnaire used to check agreement

Table 1 Sample articles published in automobile sector

Method	Refs.	Findings
OWAS	[12]	Medium risk level was observed
	[13]	Tested on virtual environment
	[14]	Medium-to-high risk was observed
RULA	[15]	Extremely high risks and the changes need to be done immediately
	[16]	The workers were under moderate-to-high risk of WMSDs
	[12]	Medium risk level of occurrence of musculoskeletal disorders
	[13]	Tested on virtual environment
	[17]	The workers were under moderate-to-high risk of WMSDs
REBA	[18]	The prevalence of WMSDs in the back and the waist was high
	[13]	Tested on virtual environment
	[17]	The workers were under moderate-to-high risk of WMSDs

of results with factual risk data. RULA was also implemented to evaluate muscle force and postures [11], resulting in a reduction of the RULA score from 7 to 3 in the bar cutting process in construction. Table 1 tabulates a few cases of work-related to ergonomic risks assessment in the automobile sector, including roof stick manufacturing.

3 Study Design

3.1 Study Population

A total of nine dedicated skilled workers, performing various operations involved in roof stick manufacturing activity comprising of seven tasks, are selected. All are male workers with mean age of 35 years and standard deviation of 7.6 years. Each worker performs operation assigned to him continuously for two hours without break. The study is repeated for three consecutive days to study repeatability of the results obtained. In the observation, the variation in postures by the same worker on different occasions was documented. A posture with high frequency of occurrence and probable risk of causing MSDs is selected from each of the seven tasks. The workers are observed and filmed during their work. Pictures were taken by standstill camera positioned approximately parallel to the operator to avoid misalignment errors in measurement of exact angle.

Table 2 Exposure factors considered in OWAS, REBA, and RULA

Technique	Posture	Load/ force	Movement frequency	Coupling
OWAS	Y	Y	–	–
RULA	Y	Y	Y	–
REBA	Y	Y	Y	Y

Table 3 Action categories, method scores, and conclusion

Category	OWAS	RULA	REBA	Conclusion
AC1	1	1–2	1–3	*OK situation*
AC2	2	3–4	4–7	**Study for a change**
AC3	3	5–6	8–10	Action for a change
AC4	4	> 7	11–15	***Urgent change***

3.2 Study Methods

Many posture assessment methods are available in the literature for identification of MSD risk. There are various methods used to assess ergonomic risks, including checklists, interviews, discussions, surveys, and questionnaires. These methods may assess the whole body, only the upper extremities, or different parts of the body.

The manufacturing of roof sticks involves the use of the full body. In order to assess ergonomic risks under varying field conditions and utilizing a video recording system, OWAS, RULA, and REBA were compared. Table 2 presents the different risk exposure parameters associated with these three methods [19–22].

The postural angle classification in OWAS, REBA and RULA differs from each other, which can impact the results obtained from each method. Table 3 shows the scores involved in various action categories.

3.3 Statistical Analysis

Statistical analysis was performed in Microsoft Excel Version 2016. Spearman's correlation coefficient is used as statistical measure of the strength of relationship between paired data. The value of Spearman's correlation coefficient and the interpretation of relationship are given in Table 4. The value less than 0.39 indicates weak relationship. The value between 0.40 and 0.59 indicates moderate relationship, and the value between 0.80 and 1.0 indicates very strong relationship.

Table 4 Spearman's correlation coefficient interpretation

Range	Value	Relationship
1	0.00–0.19	Very weak
2	0.20–0.39	Weak
3	0.40–0.59	Moderate
4	0.60–0.079	Strong
5	0.80–1.0	Very strong

4 Results and Discussion

In this study, seven different work elements involved in roof stick manufacturing were examined.

4.1 Comparisons of OWAS and RULA

Figure 1 displays the action category levels of OWAS/RULA for seven work elements, indicating the frequency of OWAS action categories against RULA action levels (as presented in Tables 5 and 7). The Spearman's correlation coefficient rank test demonstrated a weak relationship between the outputs, with $r_s = 0.357$. As depicted in Fig. 1, OWAS generally underestimated postural discomfort for all the involved postures when compared to RULA. Specifically, RULA categorized 0% postures in action category AC1, 42.86% postures in AC2, and 57.14% in AC3. Conversely, OWAS classified 57.14% postures in action category AC1 and 42.86% in AC2 (as shown in Table 8).

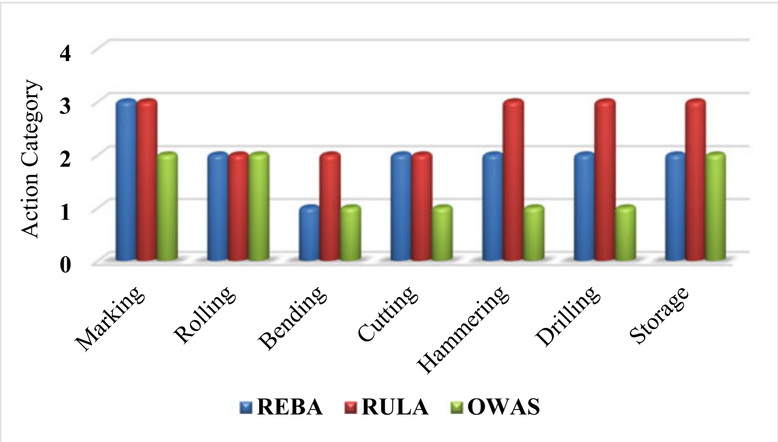

Fig. 1 Comparison of results

Table 5 Results of OWAS assessment

Activity	Back	Upper limb	Lower limb	Force/load	Action category
Marking	2	1	1	1	II
Rolling	2	1	1	1	II
Bending	1	1	1	1	I
Cutting	1	1	2	1	I
Hammer	1	3	7	1	I
Drilling	1	2	1	1	I
Storage	2	1	1	1	II

Table 6 Results of REBA assessment

Activity	Score A	Score B	Score C	Act. score	REBA score
Marking	7	3	7	1	8
Rolling	6	3	6	1	7
Bending	1	2	1	1	2
Cutting	4	3	4	1	5
Hammer	4	4	4	1	5
Drilling	4	6	5	1	6
Storage	6	3	6	0	6

4.2 Comparisons of OWAS and REBA

The frequency of OWAS and REBA action categories for seven work elements is presented in Fig. 1, along with the corresponding results in Tables 5 and 6. The Spearman's correlation coefficient rank test indicates a moderate relationship between the two methods, with a coefficient of rs = 0.553. Similar to the comparison with RULA, OWAS tends to underestimate postural discomfort compared to REBA for all postures as shown in Fig. 1. REBA categorized 14.29% of postures in the action category AC1, 71.43% in AC2, and the remaining in AC3. Meanwhile, OWAS classified 57.14% of postures in action category AC1 and the remaining 42.86% in AC2, as presented in Table 8.

4.3 Comparisons of REBA and RULA

According to the Spearman's correlation coefficient rank test, there is a moderate relationship between the outputs of REBA and RULA with $rs = 0.589$ (Tables 6 and 7). However, compared to RULA, REBA generally underestimated postural discomfort for all the involved postures. RULA categorized 0% of postures in action

Table 7 Results of the RULA assessment

Activity	Score A	Score B	RULA score
Marking	3	5	5
Rolling	2	5	4
Bending	2	5	4
Cutting	4	3	4
Hammer	4	5	5
Drilling	4	4	5
Storage	4	5	6

Table 8 Posture classification percentage as per action categories

	REBA	RULA	OWAS
AC1	14.29	0.00	57.14
AC2	71.43	42.86	42.86
AC3	14.29	57.14	0.00
AC4	0.00	0.00	0.00

category AC1, 42.86% of postures in AC2, and a majority of the postures (57.14%) classified into AC3. On the other hand, REBA classified 14.29% of postures in action category AC1, 71.43% of postures in AC2, and only 14.29% in AC3 (Table 8).

The present study compared OWAS, REBA, and RULA methods of posture assessment for the roof stick manufacturing activity in an automobile reconditioning organization. Correlation between methods is provided in Table 9. The results showed that RULA method tended to overestimate postural load scores, followed by REBA and OWAS. While each method has its own advantages and limitations, researchers should be aware of their applicability. OWAS, REBA, and RULA have limitations related to postural classification, load limit ranges, and leg classification. Moreover, OWAS treats back posture with 90° bend the same as 20° bend, which raises questions about its sensitivity. However, the validity of OWAS has been proven by many researchers. On the other hand, RULA method has only two leg categories compared to seven in OWAS and four in REBA, which is also questionable. Therefore, it is crucial to understand the limitations of each method before applying it to avoid obtaining random scores that are unrelated.

The three posture assessment methods (OWAS, REBA, and RULA) used in this study are all based on observational assessments, which are subjective and only address three risk factors: posture, force, and repetition. The authors highlighted

Table 9 Results of Spearman's correlation

Method	r_s	Relationship
REBA–RULA	0.589	Moderate
RULA–OWAS	0.357	Weak
OWAS–REBA	0.553	Moderate

that REBA assigns equal weights to factors such as twisting, lateral bending, and abduction, regardless of their degree (e.g., 5° or 20° of twisting). It is important for researchers to understand the limitations of each method before using it; as otherwise, the method may produce random scores that are not relevant.

5 Conclusion, Limitation, and Future Scope

In this study, ergonomic intervention was implemented to address the risk of work-related musculoskeletal disorders (WMSDs) in nine workers engaged in roof stick manufacturing activity at a bus body building and reconditioning plant with seven elemental work steps. The OWAS, RULA, and REBA methods were used to assess posture, and their classification schemes were compared based on action categories. The number of action categories for each method was standardized. The results showed that the RULA method overestimated postural load scores compared to REBA and OWAS methods.

The main constraint of this study is the relatively small sample size available. However, the study can be extended to other organizations or developed countries to gain further insights. Future studies could also explore the relationship between physical workload associated with work postures and corresponding energy expenditure values, which could provide valuable information for designing workstations that minimize the risk of WMSDs.

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Design and Modification of Engine Piston—Review

Ishan Thakur, Amrinder Singh Johal, and Deepak Kapila

1 Introduction

A piston is a reciprocating component of an internal combustion engine that is housed within a cylinder. It plays a crucial role in the operation of the engine. It aids in the conversion of heat energy from combustion to mechanical energy by going through four stages: suction (intake of air–fuel mixture), compression (compression of the mixture), expansion (burning of the mixture), and exhaust (removal of gas and residuals). The piston contains several important components, such as piston rings, wrist pins, and connecting rods. The piston rings to create a seal that helps keep the air–fuel mixture within the cylinder, as well as reduce friction between the piston and the cylinder walls. The connecting rod is connected to the crankshaft and transfers the up-and-down motion of the piston to the crankshaft, which then converts it to rotational motion. The wrist pin is connected to the piston and the connecting rod and helps to keep the piston aligned in the cylinder. The force generated from the expansion of gas in the cylinder is transferred from the piston to the crankshaft with the help of the connecting rod, which further provides rotational momentum to the flywheel. The piston should demonstrate qualities, such as high resistance to gas pressure, low weight, low NVH (noise, vibration, and harshness), prevention of gas leakage, and strength to maintain shape under high temperatures and heavy loads.

I. Thakur (✉)
Automobile Engineering, Chandigarh University, Gharuan, Punjab 140413, India
e-mail: ishanthakur02@gmail.com

A. S. Johal
Mechanical Engineering, Chandigarh University, Gharuan, Punjab 140413, India
e-mail: amrindersingh.me@cumail.in

D. Kapila
Electronic Engineering, Chandigarh University, Gharuan, Punjab 140413, India
e-mail: deepak.e1539@cumail.in

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Recently, the auto industry is worried about the longevity of pistons and is actively researching ways to prevent piston failures caused by the forces of combustion, thermal load, and high-frequency vibrations, as well as friction. An unmixed fuel, over-revving of the engine, and/or detonation, commonly cause these issues.

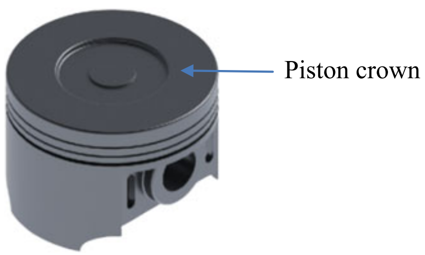
1.1 Piston Crowns

Piston crowns are essential components of an engine's combustion chamber, playing a critical role in optimising the combustion process, directing the flow of fuel and air, and cooling the piston. Figure 1 shows the piston crown. There are several types of piston crowns used in different applications, each with its unique advantages.

- The **open-chamber** type is the most commonly used in high-performance engines, utilising a wide chamber that allows for more efficient combustion and greater cylinder pressure. This design also directs fuel and airflow for more efficient combustion.
- The **closed-chamber** type is designed with a small chamber that limits the flow of fuel and air, resulting in a slower, more efficient combustion process. This design is generally used in engines that require less power and have lower compression ratios.
- The **semi-hemispherical** design utilises a larger chamber than the open-chamber design and features a curved surface to direct the flow of fuel and air for more efficient combustion. This design is generally used in engines that require more power and have higher compression ratios.
- The **flattop** design has a flat surface that directs fuel and airflow for a faster and more efficient combustion process. This design is generally used in engines requiring the highest levels of power and compression ratios.
- The **dome-top** design utilises a dome-shaped surface that directs fuel and airflow for a slower, more efficient combustion process. This design is generally used in engines that require less power and have lower compression ratios.

No matter what type of piston crown is used, it is essential to ensure that it is properly installed and maintained to maximise performance and fuel economy.

Fig. 1 Piston crown



1.2 Material Used

Pistons are used in a wide variety of applications, from automotive engines to pumps and compressors. The materials used to make pistons must be carefully chosen based on the requirements of the application, and must meet a variety of criteria including strength, durability, heat resistance, and cost. The most common material used to make pistons is cast iron. This material is strong, durable, and relatively inexpensive. It is also resistant to corrosion and can withstand high temperatures. Because of its strength and durability, cast iron is ideal for use in motor engines, where it is subject to high pressures and temperatures. Aluminium is also a popular choice for pistons. It is lightweight, which helps improve fuel economy, and it is corrosion-resistant. It can also withstand high temperatures, though it is not as strong as cast iron. Its main advantage is that it is much less expensive than cast iron, which can make it a good choice for applications that don't require a lot of strength. Forged steel is also used for pistons. It is stronger than cast iron or aluminium and can withstand higher temperatures. It is also more expensive than other materials, so it is typically reserved for applications that require a lot of strength. Finally, composite materials such as carbon fibre and Kevlar are also used for pistons. These materials are lightweight and strong and can be tailored to the specific requirements of the application. They are also more expensive than other materials but can be a good choice when strength and heat resistance are important. In conclusion, there is a variety of materials used to make pistons, depending on the specific requirements of the application. Cast iron is the most common choice, but aluminium, forged steel, and composite materials can also be used. All of these materials have advantages and disadvantages, so the material used should be carefully chosen based on the specific requirements of the application.

The following table consists of the properties of various materials used (Table 1).

2 Literature Review

Ultra-high tensile strength steels, aluminium and magnesium alloys, polymers, and carbon fibre reinforced composite materials were used in Krishnan et al.'s study of lightweight materials. Al 6061, a novel aluminium composite matrix with silicon carbide particles that has the same overall performance with just slight differences in characteristics, was developed to extend the piston's lifespan. Then, using Autodesk Inventor software, a parametric piston model was created in 3-D with a 2:3 aluminium to silicon carbide ratio [4].

Rao et al. utilised Unigraphics to evaluate a piston model's performance. They used a piston made of aluminium-based MMC containing 5, 10, 15, and wt. % and fly ash particles measuring 53 μm to demonstrate their findings. The component was machined to the required shape after the stir-casting procedure produced it with the necessary complexity and form. The outcomes showed that the modified piston model

Table 1 Materials used to manufacture piston

Properties	AlA2618 [2]	AlGHY1250 [3]	AlGHS1300 [2]	AlA356 T6 [1]	Al6061	Ti6Al4V [2]	Al2024
Poisson's Ratio	0.33	0.3	0.3	0.33	0.33	0.33	0.33
YoungModulus (GPa)	74.5	83	98	72.4	69	113.8	73.1
Thermalconductivity (W/m°C)	147	135	120	150	170	7.3	140
Density (Kg/m^3)	2767.9	2880	2780	2600	2700	4430	2800
Ultimatetensile strength (MPa)	480	1250	1300	234	310	950	469

outperformed the base model in terms of performance. This model's dependability was increased by lowering stresses and minimising the weight of the piston. Results demonstrated how the hardness, wear, and friction of the piston changed from the original version to the modified one [5].

Design and study of a piston head utilising an aluminium alloy were carried out by Suralikerimath et al. prior to being imported into ANSYS 14.5 from CATIA V5R20, the model was converted to a STEP file. The programme had already specified all of the aluminium alloy's material characteristics, and the model had been meshing for FEM analysis. The thermal stress caused in different areas of the piston head was calculated using thermal analysis [6].

Viswanath carried out a study to look into and examine the piston's stress distribution. Ti-6Al-4V, Al alloy 4032, Copper, and Al alloy 2024 were the four materials he created and examined for the structural and thermal examination of the piston. The piston head was subjected to a pressure of 13.6 MPa and a temperature of 1500 degrees Celsius. The piston's stress distribution was determined employing a finite element analysis approach, and the mesh was optimised to lessen stress concentrations in the piston head, skirt, and sleeve [7].

Sundaram et al. used CREO to carry out a 3-D Model study and ANSYS 14.5 to carry out a CAE analysis. The thermal analysis of the piston was conducted using three different materials (Al with 10%, 20%, and 30% SiC). The ANSYS study revealed that for both steady-state and transient thermal assessments, Al with 10% SiC exhibited the greatest temperature distribution. Al with 10% SiC is, therefore, the best material for the piston, it may be inferred [8].

With the use of CAE tools, Vibhandik et al. carried out a design study and optimisation of a piston and the deformation of its thermal stresses. They chose a diesel engine vehicle's IC engine piston from TATA Motors. An optimised piston constructed of aluminium and titanium alloys was compared to a standard diesel piston using a thermal study. This analysis's goal was to extend the piston's life by decreasing the stress concentration on its upper end. After doing the investigation, they came to the conclusion that titanium had superior thermal characteristics and might enhance piston performance, but it was expensive for large-scale applications and could only be employed in unique circumstances [9].

Rai, in this work, a piston and piston ring for a single-cylinder, four-stroke petrol engine were created using the CATIA V5R20 software. After that, ANSYS 14.5 software was used to import the design and perform structural and thermal analysis. The piston was made of three distinct materials, whilst the piston ring was made of two different materials. The analysis's findings were contrasted in order to choose the best design [10].

Research was undertaken by Plamenov et al. to assess the effects of several piston design parameters (such as piston top land height and barrel thickness) on the stress and deformation produced. The impact of barrel thickness on stress generation was finally discovered using optimisation studies and the ANSYS FEA programme [11].

Bhagat et al.. During use, piston skirts may distort, eventually leading to fractures at the top of the piston head. This is brought on by the stress concentration brought on by the piston's lack of adequate rigidity. A mathematical model that considers the deformation of the piston crown as well as the quality of the piston and piston skirt was developed to lessen this stress concentration. The maximum stress could be reduced from 228 to 89 MPa, and the maximum deformation could be decreased from 0.419 to 0.434 mm by using finite element analysis (FEA) [12].

By Mukkawar et al. a piston from a four-stroke single-cylinder engine of a Bajaj Pulsar 220 cc motorbike was used to evaluate the stress distribution of two distinct Al alloys using CAE tools. The outcomes showed that the AL-GHY 1250 piston's deformation was significantly less than that of the traditional piston. The study also showed that employing this alloy might reduce mass whilst maintaining the same level of safety, with the factor of safety rising to 27%. In comparison, it was discovered that the Al-GHY 1250 material performed better than Al-2618 [13].

3 Result

Based on these studies, we can infer that a composite piston comprised of aluminium 6061 and aluminium silicon carbide or aluminium with 10% SiC is a good material for pistons because of its superior stress distribution, lower stress concentration and deformation, and improved temperature distribution. Moreover, updated piston models with aluminium-based MMC can provide greater performance by decreasing strains and reducing piston weight. Nevertheless, additional considerations like cost, availability, and special application requirements may influence material selection.

4 Future Scope

The research projects covered in this article are focused on designing and analysing pistons using a variety of materials and computing tools. Materials including ultra-high tensile strength steels, alloys of aluminium and magnesium, polymers, and composite materials reinforced with carbon fibres were also investigated. The piston's reliability, performance, resistance to thermal stress, and weight reduction are all goals of the study. The study evaluated stress distributions and optimised the mesh to reduce stress concentrations in the piston head, skirt, and sleeve using finite element analysis approaches and tools from Autodesk Inventor, Unigraphics, CATIA V5R20, ANSYS 14.5, and CREO. The study shown that altering the piston's performance and reliability may have a significant influence, which has implications for the automotive and engineering industries.

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Effect of Dynamic Misalignment on the Stiffness Characteristics of a Double-Row Self-Aligning Rolling-Element Bearing

Vivek Parmar, Subodh Kumar, Varun Sharma, and S. P. Harsha

Nomenclature

$F = [F_x, F_y, F_z]^T$	Applied force vector
$F_{stiff} = \left[F_{rx} F_{ry} F_{rz}\right]$	Contact stiffness force vector
$f_R = \left[f_{rx}, f_{ry}, f_{rz}\right]$	Contact force vector
K	Load–deflection factor
$[K_b]$	Self-aligning bearing's stiffness matrix
(k_{ix}, k_{iy})	Stiffness for radial directions
k_j^i, C_j^i	Stiffness and damping for the rolling-elements
M_x, M_y	External moment about X and Y axis due to misalignment
m_o, m_{i+s}	Mass of outer and collective mass of inner and outer race, respectively
N_b	Number of balls single row of bearing
Q_j^i	Contact force
ϕ	Angle of raceway misalignment
θ_j^i	Azimuthal angle for of the jth rolling-element in ith row
ω_c	The rotational frequency of cage
α_j^i	Contact angle

V. Parmar · S. Kumar
Department of Mechanical Engineering, DIT Uiversity, DehradunUttarakhand 248009, India

V. Parmar (✉)
BAJAJ ENGINEERING SKILLS TRAINING (BEST) CENTRE, Banasthali Vidyapith, Banasthali, Rajasthan, India
e-mail: vivekparmar@banasthali.in

V. Sharma
Department of Industrial and Production Engineering, Dr B R Ambedkar National Institute of Technology, Jalandhar 144027, India

S. P. Harsha
Advanded Vibration and Noise Control Lab, MIED, IIT Roorkee, Roorkee, , Uttarakhand 247667, India

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1 Introduction

Spherical rolling-element bearings find a number of applications in rotating machinery especially where there is requirement of negating the dynamic misalignment. Typically, the double-row self-aligning bearings, which are a category of a spherical bearing, can counter a misalignment of 1^0 to 3^0. During misalignment, the load and deflection characteristics of a bearing differ from that of an aligned one. Moreover, the system's dynamics is also characterized by the stiffness variations during operations. These stiffness variations can be understood by developing a mathematical model for the bearing and thus analyzing the simulated response for different dynamic conditions.

Lim and Singh [1] analyzed the stiffness characteristics of a rotor-bearing by formulating a 6×6 stiffness matrix for various loaded conditions. Yet, some coefficients were experimentally verified, but majority of them were analyzed numerically. They also demonstrated its superiority over other models by incorporating the proposed method with other methods. In one of other studies, they analyzed the dynamics of geared-rotor system. Royston and Basdogant [2] applied the theory by Lim & Singh to characterize the dynamics of spherical rolling-element bearing supported by experimental validation. It was observed that the stiffness coefficients depend on the axial-loads. Harsha et al. [3] analyzed nonlinear vibrations of a rolling-element bearing through a parametric study considering speed, load, waviness clearance etc. Harsha and Kankar [4] also performed an analysis for the stability of a rotor bearing system with variation in waviness parameters and number of balls. Gunduz et al. [5] analyzed the modal response of angular contact bearing subjected to bearing preloads. A stiffness matrix of order 5 was developed for the same bearing for given displacements and mean load. Also, the experimental investigations were found to be in accordance with the numerical simulations. Zhuo et al. [6, 7] analyzed the dynamic behavior of a spherical double-row ball bearing for variations in speed, load and clearance etc. using a mathematical model. Patil et al. [8] also developed model to examine the acoustic emissions of a rolling-element bearing. They later proposed another method to relate the radial-load-zone with the signal impulse [9]. Parmar et al. [9–12] also presented a model to study the dynamic behavior of a self-aligning bearing for various parameters, waviness, localized defects and misalignment.

As per the author's knowledge, so far, a few studies have been performed to analyze the dynamics of a self-aligning ball bearing, but a very few of them have focused on characterizing the bearing's stiffness during misalignment of the raceways. This paper attempts to analyze these stiffness variations during different load, speed and misalignment conditions. A mathematical model has been presented for the same purpose and the numerical simulations have been shown in the results and discussion section.

2 Dynamic Model

Figure 1 shows the moments and contact loads on the bearing's inner-race while misalignment of the raceways. A multibody model, as used in the study [10], has been used here to analyze the stiffness variations in the bearing for aligned and misaligned conditions. Hertzian contact stress theory is used to calculate the contact loads and further, the equations of motion are derived based on the force–displacement relations, as shown in Eq. 1. The stiffness of the system in all three directions (x, y, z) has been derived in Eq. 2. There are two sets of governing equations, i.e. Eqs. 3 and 4. The first equation governs the three-dimensional motion of the shaft under the effect of loads while in motion. On the other hand, Eq. 4 characterizes the wobbly rotational motion of the inner-race about the radial axis. The spring and damper multibody model has been shown in Fig. 2.

The bearing resisting force vector ($\mathbf{F_{stiff}}$) in all directions can be represented as

$$\mathbf{F_{stiff}} = \begin{Bmatrix} F_{rx} \\ F_{ry} \\ F_{rz} \end{Bmatrix} = \sum_{i=1}^{2}\sum_{j=0}^{N_b} K\left(\delta_j^i(\theta)\right)^{3/2} \times \begin{Bmatrix} \cos\left(\alpha_j^i\right)\sin\left(\theta_j^i\right) \\ \cos\left(\alpha_j^i\right)\cos\left(\theta_j^i\right) \\ \left((-1)^i \sin\left(\alpha_j^i\right)\right) \end{Bmatrix} \tag{1}$$

The bearing stiffness and damping matrix ($\mathbf{K_b}$) can be expressed as

$$K_b = \begin{bmatrix} k_x & 0 & 0 \\ 0 & k_y & 0 \\ 0 & 0 & k_z \end{bmatrix} = \begin{bmatrix} (F_{rx}/\delta_{xs}) & 0 & 0 \\ 0 & \left(F_{ry}/\delta_{ys}\right) & 0 \\ 0 & 0 & (F_{rz}/\delta_{zs}) \end{bmatrix} \tag{2}$$

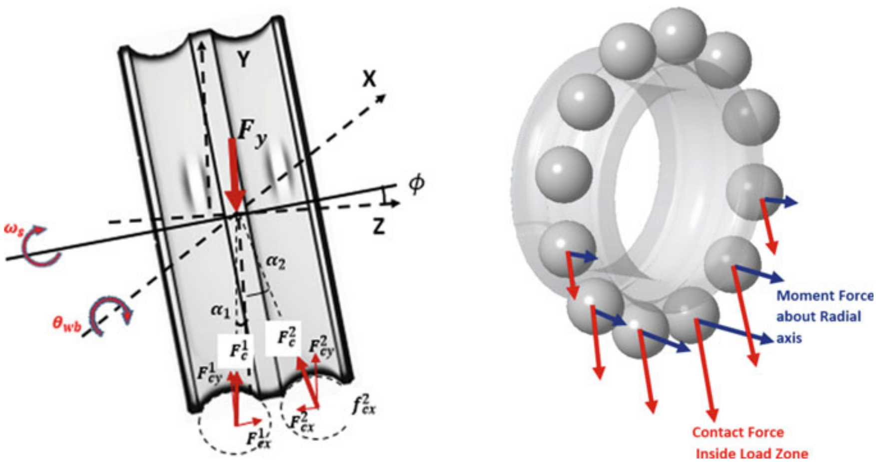

Fig. 1 A self-aligning ball bearing with two rows of rolling-elements under dynamic misalignment. Inner-race under the effect of contact force and moments during misalignment

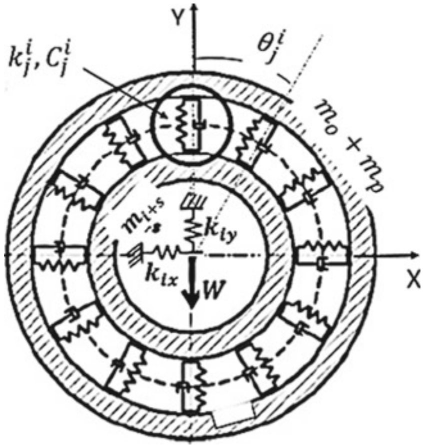

Fig. 2 Multibody model of the bearing using spring and dampers

2.1 For IR-Shaft Linear Motion

$$\left[\boldsymbol{F}^{IR+Shaft}_{inertia} + \boldsymbol{F}^{bearing}_{contact-damp} + \boldsymbol{F}^{bearing}_{contact-stiff}\right] = \boldsymbol{F}^{shaft}_{applied} \tag{3}$$

$$m_{i+s}\left(\ddot{\delta}_{xs}\right) + c_x\left(\dot{\delta}_{xs}\right) + k_x(\delta_{xs}) = F_x \tag{3a}$$

$$m_{i+s}\left(\ddot{\delta}_{ys}\right) + c_y\left(\dot{\delta}_{ys}\right) + k_y\left(\delta_{ys}\right) = F_y \tag{3b}$$

$$m_{i+s}\left(\ddot{\delta}_{zs}\right) + c_z\left(\dot{\delta}_{zs}\right) + k_z(\delta_{zs}) = F_z \tag{3c}$$

2.2 For IR-Shaft Angular Motion

$$\left[\boldsymbol{M}^{IR}_{inertia}\right] + \left[\boldsymbol{M}^{shaft-IR}_{stiff}\right] = \boldsymbol{M}^{IR}_{applied} \tag{4}$$

$$J\left(\ddot{\theta}_{xo}\right) - 4k_{ix}L^2\theta_{xo} = M_X \tag{4a}$$

$$J\left(\ddot{\theta}_{yo}\right) - 4k_{iy}L^2\theta_{yo} = M_Y \tag{4b}$$

The misaligned model of the shaft-bearing system has been shown in Fig. 3. Here, the constant for viscous damping ‘c’ is chosen so as to adjust the damping to become $0.25 - 2.5 \times 10^{-5}$ times linearized stiffness. Also, equations of motion have already been shown above in Eqs. 3 and 4. These are ordinary differential equations and thus

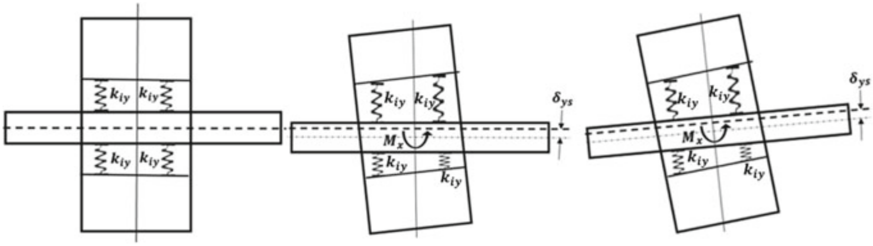

Fig. 3 Shaft and inner-race orientations in a shaft-bearing system i.e. perfectly aligned, only inner-race misaligned and both shaft and inner-race misaligned, respectively

have been numerically solved using the ODE-45 function of MATLAB, which uses the 4th order Range-Kutta method.

3 Results and Discussions

The effect of parameters like radial-load, axial-load and misalignment angle on the magnitude of stiffness coefficients is analyzed in this section. An external load vector of **F = [10 50 5] N** is applied to the shaft and the system was analyzed for variation in misalignment angles. Figure 4 shows that with an increase in radial-load, the stiffness coefficient value increases. Although the increase in K_{xx} is higher as compared to K_{yy} & K_{zz} values. Figure 5 shows the variation in radial and axial stiffness coefficient values with increase in radial-load.

An increase in axial-load is observed to decrease in radial and axial stiffness values. This is due to the fact that due to axial-load, one row of the rolling-elements is pushed toward the center-plane, while the other is pushed toward the end of the outer-sphere. Due to this fact, one row carries more load than the other, thus reducing

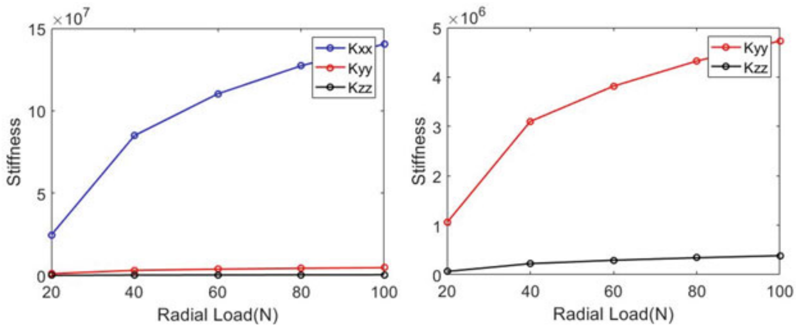

Fig. 4 Variation in stiffness coefficients due to increase in radial-load

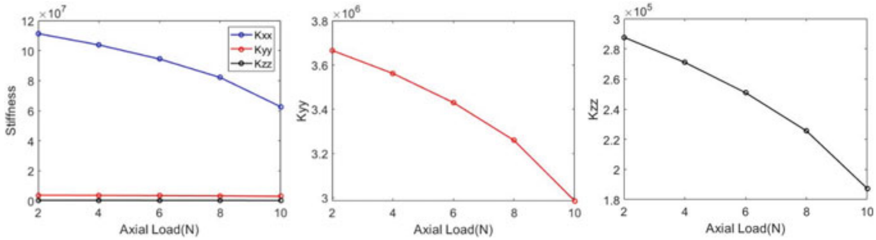

Fig. 5 Variation in stiffness coefficients due to increase in axial-load

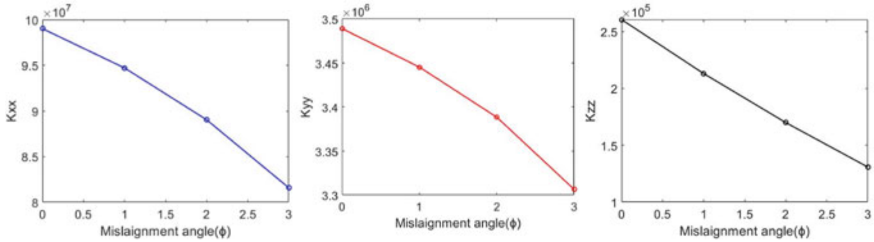

Fig. 6 Variation in stiffness coefficients due to increase in misalignment angle

the overall bearing stiffness. Figure 5 shows the variation of K_{xx}, K_{yy} and K_{zz} with increase in axial-load.

An increase in misalignment angle is also found to decrease the stiffness of the bearing (Fig. 6). In the above section, it was shown that due to the misalignment of the inner-race, the load carried by both the rows varies, due to which, one row carries more load than the other. From the results, it is observed that all the stiffness coefficients have a decreasing trend with the increase in bearing misalignment angle.

Figure 7 shows the frequency spectrum and the modulated time signal of a spherical bearing with misaligned raceways. The cage frequency appearing in the spectrum can be seen modulating the time wave form. Thus, it can be concluded that the misalignment of the raceways modulates the cage frequency as the cage rotates in an unpredictable manner, i.e. wobbly motion thus characterizing the misalignment.

The variation of stiffness coefficients with time for aligned and misaligned condition is shown in Fig. 8. The time duration for each stiffness coefficient is chosen to be same and is almost about 1 to 2 ball pass periods. The effect of misalignment on the time-variation of stiffness can be observed from these results. It can be clearly observed that the variation in misalignment alters the pattern of variation in stiffness coefficient with time.

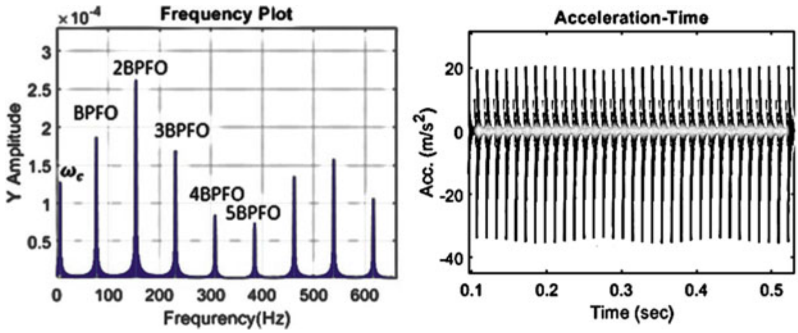

Fig. 7 Frequency spectra and modulated time series of a spherical bearing under misalignment showing modulations by the cage frequency

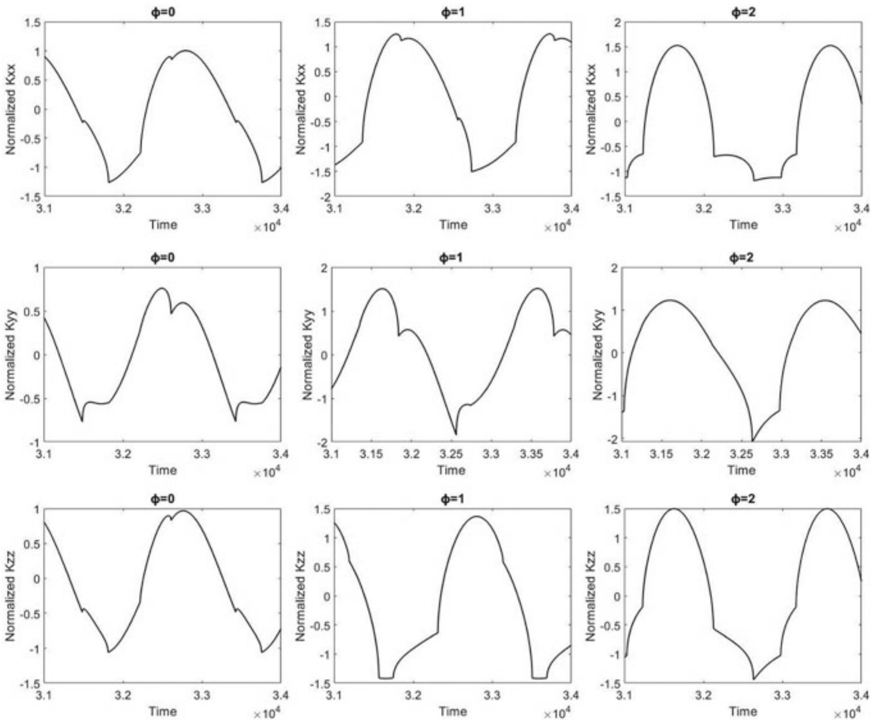

Fig. 8 Variation of stiffness coefficients ($K_{xx}, K_{yy}\&K_{zz}$) with time for various aligned and misaligned positions

4 Conclusion

1. It is observed that the value of bearing stiffness increases with the increase in radial-load, while it decreases with the increase in axial-load.
2. The bearing stiffness is observed to decrease with the increase in misalignment angle. The misalignment alters the orientation of the bearing, thereby reducing the stiffness.
3. The cage frequency is found to be modulating the time waveform of the bearing during misalignment. This shows that the cage of the bearing rotates in an abnormal way (wobbly motion) during misalignment.
4. From the time-varying characteristics of the stiffness, it is observed that the change in misalignment also changes the time-pattern of the stiffness variations.

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Design Simulation for Chassis of Electric Solar Vehicle

Neetu Verma, Krishan Kumar, and O. P. Mishra

1 Introduction

Sun mobile was world's first ever solar powered automotive vehicle, demonstrated at the General Motors Power auto show held in Chicago, Illinois for the first time. In 1981, Hans Tholstrup and Larry Perkins built a solar powered race car. In 1982, the pair became the first to cross a continent in a solar car, from Perth to Sydney, Australia. For racing purposes, the tadpole three-wheel designs were also famous for a solar vehicle considering the lightness in weight of the vehicle and the ease in usage of the electric hub motor in the vehicle. The application of CAD/FEA packages can be observed through discussing research done by various researchers. Yadav et al. [1] compared the fatigue performance of two competing manufacturing technologies. Computer aided modeling and optimization analysis [2] of crankshaft was done for two automotive crankshafts, namely, AISI-4140 alloy steel (EN19C) and ASTM A536 100-70-03 (GGG7O). A dynamic simulation was conducted on two crankshafts, AISI-4140 alloy steel (EN 19C) and ASTM A536 100-70-03 (GGG7O) four stroke engines. A finite element analysis was carried out to obtain the variation of stress magnitude at critical locations and was verified by simulations in ANSYS. Amandeep [3] analyzed for optimized design of brake pedal linkage. Finite element analysis through ANSYS was done and observed realistic analysis environment. Stress-prone areas were concentrated and stress-free volume of the material from the linkage assembly has been targeted. Keeping in view the design concepts of mechanical components, the stress-free volume has been removed for material saving

N. Verma (✉)
Department of Computer Science and Engineering, Deenbandhu Chhotu Ram University of Science and Technology, Murthal, Sonipat, India
e-mail: falseverma21neetu@gmail.com

K. Kumar · O. P. Mishra
Department of Mechanical Engineering, J. C. Bose University of Science and Technology, YMCA, Faridabad, India

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without compromising to endurance. The prime objective of this work is material saving and related material cost minimization. Oladebeye et al. [4] fabricated a cassava mash sieving machine with lump breaking device after designing through CAD approach. Khiabani et al. [5] studied about residual stresses in thick plates through CAE. Stresses and distortion were observed and compared to experimental outcomes and analytical calculations. Kumar et al. [6] performed design simulation for a wing better air worthy, which will offer a better lift and reduced drag. They concentrated over design and analysis for an optimum airfoil wing profile. NACA-6415 has been considered as base airfoil and JAVAFOIL was used to simulate the airfoil. The relationship of Angle of attack with coefficients of lift and drag has been observed. Soliman et al. [7] modeled for micro MEMS for a mobile microprocessor complex shape through CAE. Fatigue and impact conditions were performed on the Ball Grid Array Integrated Circuit using FEA tools. Kumar et al. [8] performed CAE analysis to predict the fatigue life of leaf springs. The fatigue analysis of parabolic leaf spring by three different methods was observed. Fatigue life of parabolic leaf spring was determined as per SAE spring design manually and experimentally by testing on full-scale fatigue testing machine. ANSYS is used for CAE solution for the prediction of leaf springs fatigue life considering stress theory. Life estimated by all three modes is then compared. Meguid et al. [9] performed FEA, prototyping and testing of a novel morphing wing system aerial vehicle. An adjustable camber morphing wing was designed. The design enabled the airfoil shape of wing to be precisely morphed to the target outline. Through aerodynamics and FEA, the flexible rib assembly performance and structural integrity are observed. Chassis of the car is the most important structural part that is responsible for driver safety as well as for better control of the vehicle. Triangulated structures were mostly preferred, which can bear the force without deflecting themselves. Chassis rigidity, weight to strength ratio are very important aspects to be kept in mind while designing chassis, especially for a solar electric vehicle i.e. high power to area occupied or weight ratio for the panels which will accommodate the vehicle. A higher strength to weight ratio for the roll cage [10] is tried to achieve by using chromyl pipes for making the chassis. In present work, an attempt is made to design a chassis with much space for solar panels, two passengers. CAE package, i.e. Hypermesh V13.0, has been used to perform the analysis [11, 12] of the roll cage, which is designed in CATIA V5. Static analysis of the chassis has been done for front impact, rear impact and side impact. Chassis is a French term and was initially used to denote the frame parts or basic structure of the vehicle and considered as back bone of vehicle. The components of the vehicle like power plant, transmission system, axles, wheels and tyres, suspension, controlling systems like braking, steering and electrical systems are to be mounted on the chassis frame as in Figs. 1 and 2.

Chassis has to withstand all the stresses while in static and dynamic conditions. Design and analysis through AE tools reduced the time of iteration and experimentation, thus saving a large capital which needs to be invested.

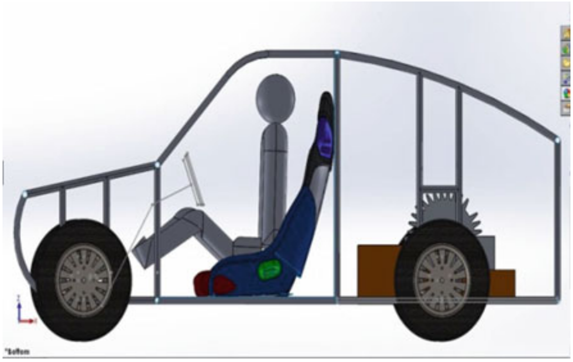

Fig. 1 Graphical layout of solar car

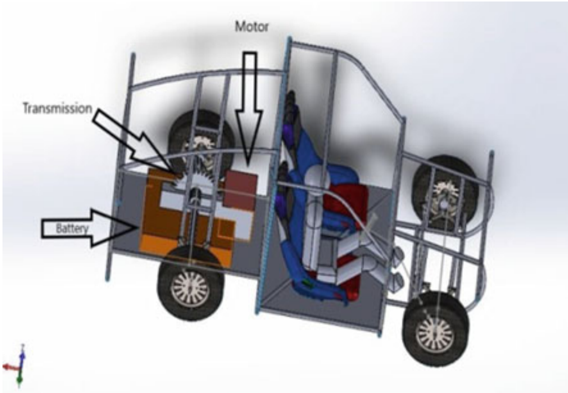

Fig. 2 Detailed graphic of solar car

2 Simulation

2.1 Material Selection

For this analysis work, three materials have been selected considering various parameters like percentage of carbon, tensile strength of material, Young's modulus, compressive strength, Poisson's ratio, Density etc. which are AISI 1018, AISI 1020, AISI 4130. Table 1 is showing carbon content of material's and mechanical properties (1) of AISI 1018, AISI 1020, AISI 4130.

AISI 4130 (chromyl) was selected because of having higher tensile strength, the strength after quench increased up to 835 N/mm^2.

Table 1 Material properties

S. No.	Properties	AISI 1018	AISI 1020	AISI 4130
1	Carbon content (%)	0.14	0.18	0.28
2	Poisson's ratio	0.3	0.3	0.3
3	Young's modulus (GPA)	205	205	205
4	Tensile strength (MPA)	370	350	460

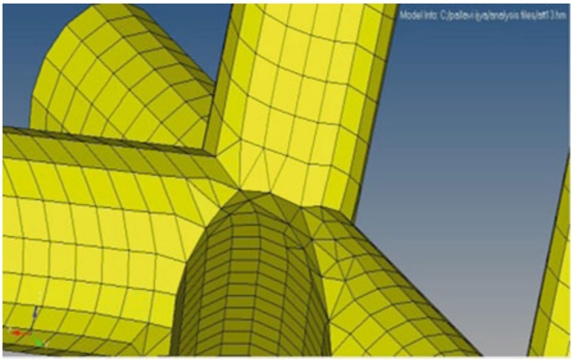

Fig. 3 FE Meshing at joint

2.2 Meshing

Meshing is process of dividing the whole geometry in very infinitesimally small pieces, so that we can analyze each small element separately in order to increase the accuracy of the process. A net like structure is created, so that infinite degree of freedom of model is reduced to finite degree of freedom of system. Creating a mesh in hypermesh is a longer process compared to meshing in ANSYS. A mid surface is created, in which cross-section of the pipe is equal to the mean of the outer and inner diameter of pipe. Before meshing, the geometry is checked for shared and suppressed edges. Proper trimming of joints is done at each junction manually. A mesh size of 5 mm is selected, the AUTOMESH panel is selected with mixed type of mesh as in Figs. 3, 4, 5 and 6. Warpage, Jacobian and aspect ratio are checked many times in order to check the quality of mesh and work on improving it.

2.3 Impact Analysis

The roll cage is a 35 kg chromyl (AISI4130) frame, which is welded using ER70S2 filler rod and TIG welded. AISI 4130 has high carbon percentage. It needs to be welded with TIG which has inert gas that shields the arc, so that aluminum does not react with air to create a brittle layer of alumina on the surface of the pipe, which otherwise to make the surface difficult to be welded. Front, back and side

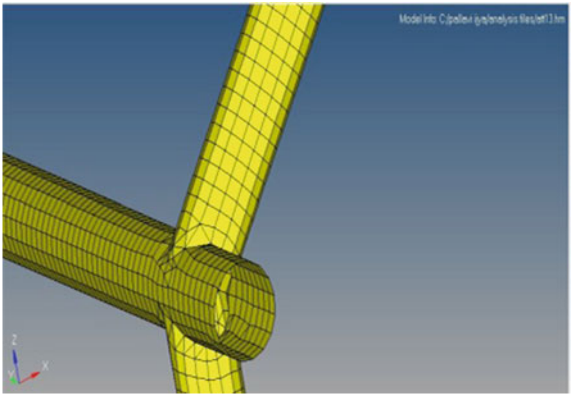

Fig. 4 FE Meshing in pipes

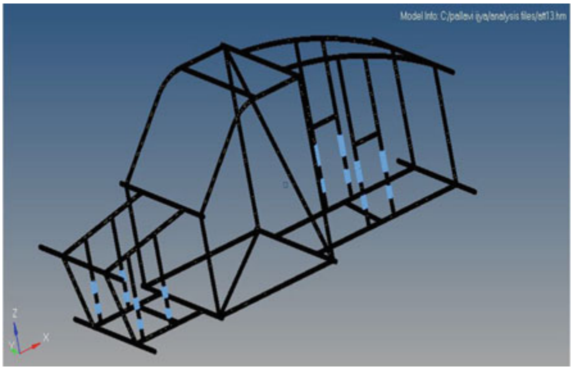

Fig. 5 FE meshing of roll cage

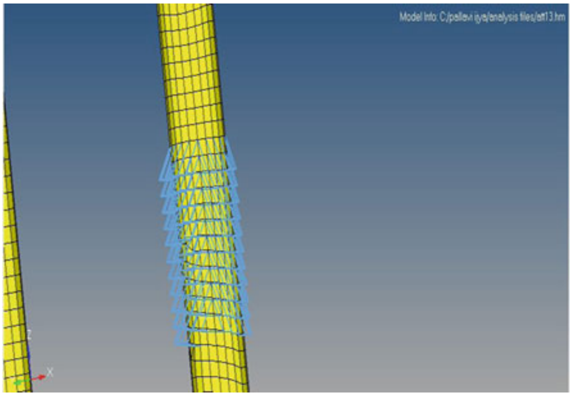

Fig. 6 Meshing at front suspension

collisions have been tested for the vehicle to perform the impact analysis under below mentioned force intensities in table. Table 2 is showing various force intensities on basis of analytical calculations performed through below equations.

Using impulse momentum equation:

Force * time = mass of vehicle* (final velocity-initial velocity).

Gravitational Force * Mass of vehicle = Force (calculated from previous equation).

The max velocity of vehicle is assumed to be 35 km/h.

Mass of the vehicle is taken- 250 kg (With driver).

Time for front impact, rear impact on experimental basis is taken as 0.2 s.

Time for side impact is taken as 0.3 s.

In hypermesh, MPCLL steps are carried out which are basically setting up one by one the material, properties, components, load steps and load collectors. Following have been fixed,

Material-MAT1;

Property-PSHELL;

Load collector-EIGRL

In analysis panel, type of load, points of action for loading, constraints etc. are to be considered as boundary conditions of the system under consideration and magnitude of force per unit node is to be defined. Some of the constraints for front, side and rear impact analysis are mentioned as below in Table 3.

Table 2 Force application on frame

Force type	Force intensity (N)	Equivalent gravitational force (G)
Front impact	13,875	5.5
Side impact	9250	3.5
Rear impact	13,875	5.5

Table 3 Boundary conditions

Boundary conditions	Front impact	Rear impact	Side impact
Force applied on	Front nose which comes in contact in impact from front	Rear part which comes in contact on impact	Side impact members
Fixed support (front suspension points)	Constraint d.o.f 2 (y axis)	Constraint all three d.o.f	Lower points all three d.o.f constraint
Fixed support (rear suspension points)	All d.o.f constrained	Constraint d.o.f 2 (y axis)	Lower points all three d.o.f constraint

3 Results and Discussions

After setting up all loading and boundary conditions, linear static analysis is carried out to observe the outcomes like stresses and deflections against different loadings conditions. For this analysis, front and side impacts have been performed w.r.t mentioned loadings. Figure 7 is showing graphical representation of stresses induced during front impact, while Fig. 8 is representing deformation contours produced in front impact analysis.

On same pattern as for front impact analysis, side impact analysis has been performed. Figure 9 is showing graphical representation of stresses induced during

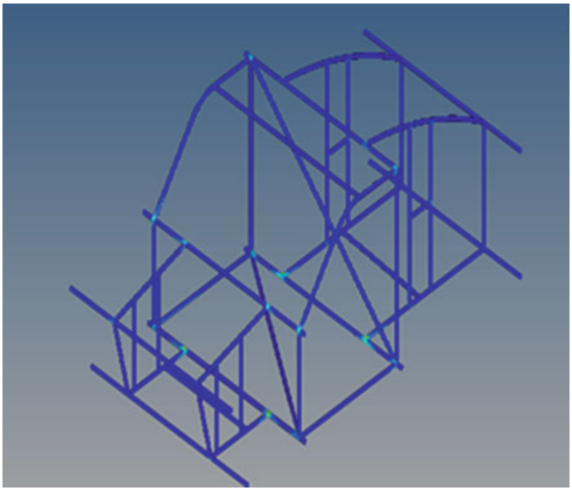

Fig. 7 Front impact stress

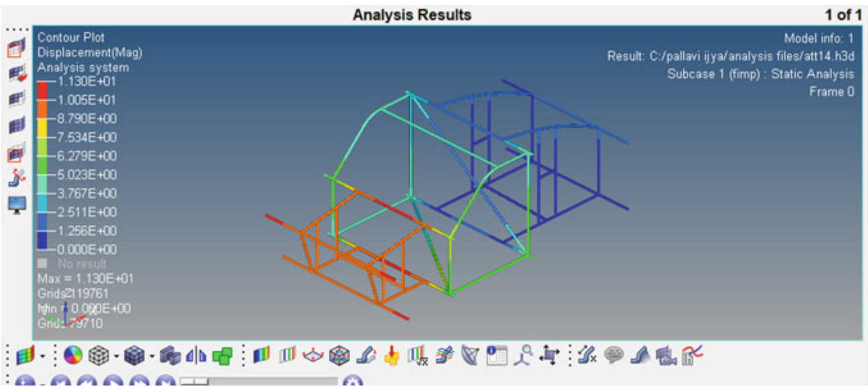

Fig. 8 Front impact deformation

side impact, while Fig. 10 is representing deformation contours produced in side impact analysis.

A comparative analysis has been done for both front and side impacts on basis of stress and deformation results obtained from the CAE analysis. Table 4 is showing all the results obtained through simulations, i.e. front and side impacts.

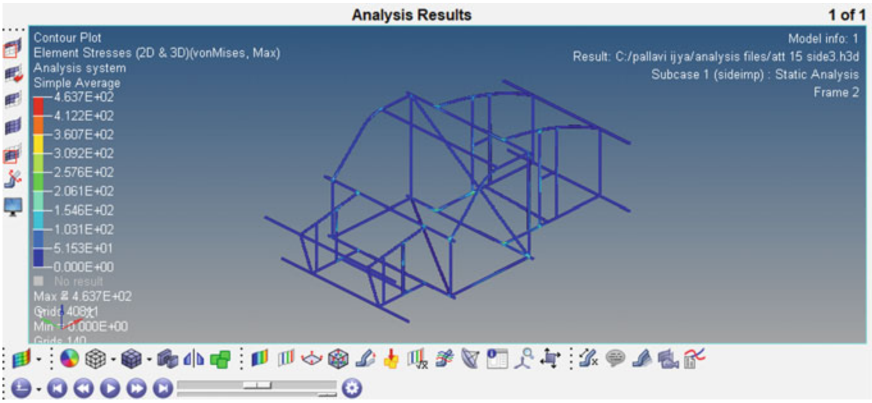

Fig. 9 Side impact stress

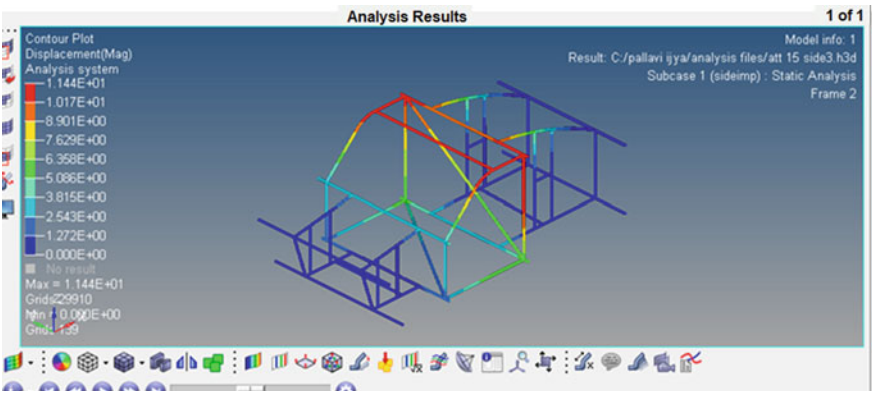

Fig. 10 Side impact deformation

Table 4 Comparative analysis

Impact type	Max. stress (MPa)	Max. displacement (mm)	FOS
Front	371	11.3	1.24
Side	353.84	11.4	1.3

4 Conclusion

The results were observed through finite element analysis of solar vehicle chassis carried out on Hypermesh V13.0. For different impact simulations, following have been observed;

1. Factor of safety comes out to be between 1.0 and 1.5, which is a suitable range for these kind structures i.e. FOS is 1.24 in front impact and 1.3 in side impact.
2. The stresses observed through different impact conditions, i.e. front and side, are in safe limits w.r.t. FOS.
3. The mesh size of 5 mm is found to be optimum as all outcomes are in safe zone.
4. Displacement produced in both impact conditions is observed to be close to each other.

Observing all these outcomes within safe conditions design is considered as safe & optimum.

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A Proposed Hybrid Clustering Approach for Cell Formation of Gear Box Manufacturing

Anand S. Shivade and Sagar U. Sapkal

1 Introduction

Group Technology (GT) is a well-known manufacturing concept due to a beneficial impact on batch type manufacturing. Families are created from related parts and associated machines, enabling some or all families of parts to be finished on a single machine group. Finding families of parts and group of machines is the process of cell generation. In batch type manufacturing, the volume of certain components might not be sufficient to support a dedicated production line. As an alternative, it might be possible to effectively use a machine cell by using the complete volume of a related part families. As a result, for every part families, a suitable machine cell is found that will almost entirely fulfill the requirements for processing of each part family that is allocated to it. Part families can be built from start to finish within the same cell. It has been proven that a CMS can reduce work at the processing level, resulting in shorter production times while providing flexibility for new products. In this study, three cell generation clustering methods are examined to find the most successful approach. The well-known performance measures are used to evaluate Rank Order Clustering-2 (ROC-2) and Void-Based Approach (VBA) and proposed hybrid algorithm. The most efficient method is chosen and recommended for gear box manufacturing industry.

A. S. Shivade (✉) · S. U. Sapkal
Mechanical Engineering Department, Walchand College of Engineering, Sangli, Maharashtra 416415, India
e-mail: shivadeanand@yahoo.in

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2 Literature Review

Extensive research has been conducted in this field, and various clustering methods have been developed. Eliguzel and Ozceylan [1] presented case study of gym center for redesigning layout having 33 sports equipment i.e. machines and 10 activity program i.e. parts. Distance of each program is calculated and clustering methods viz. ROC and average linkage clustering are applied. Results show that utilization of space increased by 30% and machines distance is reduced by 35%. Murugan and Selladurai [2] studied three array-based clustering methods, including ROC, ROC-2, and DCA for manufacturing cell generation in the pump industry. DCA gives better results. Bhuyan [3] applied ROC method to 7 × 8 machine parts matrix. Four alterative layout designs are developed and based on performance measures, alterative no. 4 considered as solutions for problem. Wu et al. [4] developed generalized similarity coefficient method for part family formation. They also proposed new clustering algorithm to assign machines into cell for minimum material movements. Results show that proposed method is effective for solving cell formation problem. Yin and Yasuda [5] reported different performance measures, such as number of exceptional elements, the machine utilization index, the grouping efficiency, the group efficacy, the clustering measure, the grouping index, the bond energy measure, the grouping capability index, and the alternative routing grouping efficiency. Kumar and Sharma [6] developed a cell formation algorithm based on the similarity coefficient. The proposed algorithm generates superior outcomes by eliminating the chaining problem. Ernawati et al. [7] presented a case study of the packaging equipment manufacturing industry. The ROC method is used to generate alternative layouts. Findings show that the total travel distance decreased from 411.51 to 335.14 m. Delgoshaei et al. [8] reviewed different clustering method for cell formation and their impact on performance measures.

3 Methodology

Industry under consideration is engaged in manufacturing of speed reduction and custom-made gear box. Data is collected from industry regarding number of parts and its operation sequence. The gear box is composed of 37 parts in total. Thirteen of the 37 components are manufactured in-house, while the remaining 24 come directly from suppliers. Job shop layout is currently used in industry for manufacturing of 13 components. For this 13 components, totally, 19 different operations are required and these 13 parts are processed through 10 steps before being finished. The route sheets provide the primary input data. This information is presented as a 0–1 matrix, with rows indicating machines and columns representing parts. If the *j*th component is processed at the *j*th machine, an element *aij* of the matrix is one; otherwise, it is zero. Algorithms used to construct families of parts and machine cells aim to rearrange the matrix's rows and columns to obtain a block diagonal form. Ideally,

Table 1 Initial component-machine indices matrix

Parts	1	2	3	4	5	6	7	8	9	10	11	12	13
Machines													
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	0	1	0	0	0	1	1	0	0	0	0	0	1
3	0	0	1	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	0	1	1	0	1	1	1	0	1
5	0	1	0	0	0	1	0	0	0	0	0	0	0
6	1	0	0	1	1	0	1	0	1	1	1	0	0
7	0	1	0	0	0	0	0	1	1	1	0	0	1
8	0	1	0	0	0	1	0	1	1	1	1	1	1
9	0	1	0	0	0	1	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	1	0	0	0	0	0
11	0	0	0	0	0	0	1	0	0	0	0	0	0
12	0	0	0	0	0	0	1	0	0	0	1	0	1
13	0	1	0	0	0	0	0	0	1	0	0	0	0
14	0	0	0	0	0	1	0	0	0	0	0	0	0
15	0	0	0	0	0	1	0	1	0	0	0	0	0
16	1	1	0	1	1	1	0	0	0	0	0	0	0
17	1	1	0	1	1	1	1	0	1	1	1	0	1
18	1	1	0	1	1	1	1	1	0	0	1	0	0
19	1	1	1	1	1	1	1	1	1	1	1	1	1

all diagonals should be in blocks and all zeros should be in diagonal blocks. The methodology begins with the preparation of data into component-machine matrix form as presented in Table 1.

3.1 Rank Order Clustering Algorithm-2

The block diagonal shape is created in this method by continually rearranging the rows and columns of the component-machine matrix based on the values of binary. In comparison to ROC, main advantage of ROC-2 is, it can quickly determine the structure of block diagonal (of a machine component incidence matrix), allowing it to be used interactively even for large matrices.

To find no. of blocks, following Eq. 1 is used [9].

$$\text{Number of block diagonal (cells)} = \frac{\text{Total number of elements in the matrix}}{\text{Total number of positive entries}} \qquad (1)$$

Products/ M/C No.	1	4	5	2	6	7	11	9	10	13	3	8	12
1	1	1	1	1	1	1	1	1	1	1	1	1	1
19	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	0	1	1	1	1	1	1	1	1	0	0
18	1	1	1	1	1	1	1	0	0	0	0	1	0
17	1	1	1	1	1	1	1	1	1	1	0	0	0
16	1	1	1	1	1	0	0	0	0	0	0	0	0
6	1	1	1	0	0	1	1	1	1	0	0	0	0
2	0	0	0	1	1	1	0	0	0	1	0	0	0
8	0	0	0	1	1	0	1	1	1	1	0	1	1
5	0	0	0	1	1	0	0	0	0	0	0	0	0
9	0	0	0	1	1	0	0	0	0	0	0	0	0
7	0	0	0	1	0	0	0	1	1	1	0	1	0
13	0	0	0	1	0	0	0	1	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	1	0	0
15	0	0	0	0	1	0	0	0	0	0	0	1	0
14	0	0	0	0	1	0	0	0	0	0	0	0	0
12	0	0	0	0	0	1	1	0	0	1	0	0	0
11	0	0	0	0	0	1	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	1	0

Fig. 1 Solution of rank order clustering algorithm-2

Here, total number of elements in the matrix is $19 \times 13 = 247$.

The total numbers of positive entries = 98.

Hence, number of block diagonal (cells) = $247/98 = 2.52 \approx 3$.

While creating a block diagonal, the objective is to have the fewest “O”s inside the diagonal blocks i.e. voids and the fewest “1”s outside from diagonal blocks i.e. exceptional elements [10]. Considering the above conditions, a block diagonal is formed as per steps of ROC-2 algorithm as shown in Fig. 1. The final cell arrangements are: Cell 1 consists of machines 1, 19, 4, 18, 17, 16, & 6 and parts 1, 4, 5, 2, 6, 7, 11, 9, 10, Cell 2 contains machines 1, 19, & 4 and parts 13, 3, 8, & 12, whereas cell 3 contains machines 2, 8, 5, 9, 7, & 13 and parts 2 & 6.

3.2 *Voids-Based Approach*

This method was presented by [11], and it is determined by the amount of similar voids between two machines or products. Figure 2 shows the block diagonal form created using the steps of voids-based algorithm. The final cell arrangements are as follows: Cell 1 consists of machines 3 and parts 3; Cell 2 contains machines 8, 9, 11, 13, 7, 6, 1, & 2 and parts 10, 11, 14, 5, 9, 13, 15, 12, & 7, whereas Cell 3 contains machines 16, 6, 8, 18, 4, 17, 2, 1, & 19 and parts 4, 5, 10, 8, 9, 11, 13, 7, 6, 1, & 2.

Parts / Machines	3	12	4	5	10	8	9	11	13	7	6	1	2
3	1	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	1	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	1	0	0	0
14	0	0	0	0	0	0	0	0	0	0	1	0	0
5	0	0	0	0	0	0	0	0	0	0	1	0	1
9	0	0	0	0	0	0	0	0	0	0	1	0	1
13	0	0	0	0	0	0	1	0	0	0	0	0	1
15	0	0	0	0	0	1	0	0	0	0	1	0	0
12	0	0	0	0	0	0	0	1	1	1	0	0	0
7	0	0	0	0	1	1	1	0	1	0	0	0	1
16	0	0	1	1	0	0	0	0	0	0	1	1	1
6	0	0	1	1	1	0	1	1	0	1	0	1	0
8	0	1	0	0	1	1	1	1	1	0	1	0	1
18	0	0	1	1	0	1	0	1	0	1	1	1	1
4	1	0	1	0	1	0	1	1	1	1	1	1	1
17	0	0	1	1	1	0	1	1	1	1	1	1	1
2	0	0	0	0	0	0	0	0	1	1	1	0	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1
19	1	1	1	1	1	1	1	1	1	1	1	1	1

Fig. 2 Solution of voids-based approach

3.3 Hybrid Algorithm

The proposed hybrid approach combines array-based and agglomerative clustering techniques (combination of ROC-2 and similarity coefficient through Single Linkage Clustering). The proposed algorithm is tested with a case study problem and compared to the results of other two methods. The proposed algorithm's steps are as follows:

Algorithm Step 1: Beginning from the last column, relocate the rows containing positive values to the top of the matrix.

Step 2: Step 1 should be repeated for each column.

Step 3: Using McAuley's formula (Eq. 2), compute the similarity coefficient between machines (rows).

$$S_{ij} = \frac{a}{a + b + c} \tag{2}$$

Step 4: In a similarity matrix, display the calculated coefficients. The upper triangular component is required due to the matrix's symmetry.

Step 5: The largest similarity coefficient is determined by using the similarity matrix. It identifies the pair of machines that will comprise the first cluster.

Step 6: Calculate every other coefficients in the similarity matrix in the same manner, then group the associated machines.

Step 7: Repeat steps 5 and 6 until all of the machines are grouped into two groups.

Step 8: Rearrange the matrix's rows in accordance with the identified machine cluster.

Step 9: Beginning with the last row and employing the initial matrix created in step 8, shift each column that has positive values to the left of the matrix.

Step 10: For every row, step three should be repeated.

Step 11: Using McAuley's formula (Eq. 3), compute the similarity coefficient between parts (columns).

$$S_{ij} = \frac{a}{a + b + c} \tag{3}$$

Step 12: To obtain clusters of components, carry out steps 4, 5, 6, and 7.

Step 13: Rearrange the matrix columns based to the clustering of the parts obtained.

Figure 3 shows the solution matrix created using the above procedure. The final cell arrangements are as follows: cell 1 consists of machines 1 & 19 and parts 1, 4, 9, 10, 5, 2, 6, 11, 7, 13, 12, 8, & 3; cell 2 contains machines 4, 17, 6, 18, & 16 and parts 1, 4, 9, 10, & 5; cell 3 contains machines 5, 9, 4, 17, 6, 18, 16, 7, 8, 2, 14, &15 and parts 2 & 6, while cell 4 contains machines 4, 17, 6, & 18 and products 11, 7, & 13.

Parts / **Machines**	**1**	**4**	**9**	**10**	**5**	**2**	**6**	**11**	**7**	**13**	**12**	**8**	**3**
M1	1	1	1	1	1	1	1	1	1	1	1	1	1
M19	1	1	1	1	1	1	1	1	1	1	1	1	1
M5	0	0	0	0	0	1	1	0	0	0	0	0	0
M9	0	0	0	0	0	1	1	0	0	0	0	0	0
M4	1	1	1	1	0	1	1	1	1	1	0	0	1
M17	1	1	1	1	1	1	1	1	1	1	0	0	0
M6	1	1	1	1	1	0	0	1	1	0	0	0	0
M18	1	1	0	0	1	1	1	1	1	0	0	1	0
M16	1	1	0	0	1	1	1	0	0	0	0	0	0
M7	0	0	1	1	0	1	0	0	0	1	0	1	0
M8	0	0	1	1	0	1	1	1	0	1	1	1	0
M2	0	0	0	0	0	1	1	0	1	1	0	0	0
M14	0	0	0	0	0	0	1	0	0	0	0	0	0
M15	0	0	0	0	0	0	1	0	0	0	0	1	0
M10	0	0	0	0	0	0	0	0	0	0	0	1	0
M12	0	0	0	0	0	0	0	1	1	1	0	0	0
M13	0	0	1	0	0	1	0	0	0	0	0	0	0
M11	0	0	0	0	0	0	0	0	1	0	0	0	0
M3	0	0	0	0	0	0	0	0	0	0	0	0	1

Fig. 3 Solution of hybrid algorithm

4 Performance Measures

The current study compares the solutions using metrics, such as number of exceptional elements, number of voids, grouping efficiency, group efficacy, and machine utilization index.

4.1 *Exceptional Elements (E)*

Exceptional elements show that the cell's allocated part must be processed through a machine that is not in the cell. Exceptions are cases, in which one or more operations require parts to be moved from one cell to another.

4.2 *Grouping Efficiency (H)*

The grouping efficiency is a weighted average of two efficiencies, $\eta 1$ and $\eta 2$. The number of exceptional components and machine utilization are taken into account, when grouping efficiency is calculated as shown in Eq. 4.

$$\begin{aligned} \eta &= w\eta_1 + (1-w)\eta_2 \\ \eta_1 &= \frac{o-e}{o-e+v} \\ \eta_2 &= \frac{MP-o-v}{MP-o+e-v} \end{aligned} \tag{4}$$

where, w: Weighting factor, o: Number of 1s in the matrix, e: Number of exceptional elements, v: Number of voids, M: Number of machines, P: Number of parts, and η: 1 implies no voids and no exceptional elements (perfect clustering).

4.3 *Grouping Efficacy (T)*

The grouping efficacy solves the problem of choosing w and the limited range of grouping efficiency. The basic properties of clustering efficiency include non-negativity, range 0–1, and being unaffected by the size of the machine factor occurrence matrix, i.e. the number of parts or machines is not considered, which is calculated using Eq. 5.

Grouping efficacy (τ)

Table 2 Comparative performance results

Sr. No	Algorithm	Exceptional elements (e) %	Grouping efficiency (η)	Grouping efficacy (τ)	Machine utilization Index
1	Rank order clustering-2	24.48	83.15	57.47	85.05
2	Voids-based approach	7.14	71.78	50.83	52.90
3	Proposed hybrid algorithm	23.46	84.34	59.77	86.20

$$\tau = \frac{o - e}{o + v} \quad (5)$$

where, o: Number of 1s in the matrix, e: Number of exceptional elements, and v: Number of voids.

4.4 Machine Utilization (MU) Index

It represents the frequency with which machines in a group are used for production. It is expressed as a percentage and calculated using Eq. 6.

$$MU = \frac{e_d}{\sum_{i=1}^{C} m_k n_k} \quad (6)$$

e_d: Number of positive entries in the diagonal blocks, m_k: Number of machines in the k_{th} cell, n_k: Number of parts in the k_{th} cell, and C: Number of cells. Above-mentioned four performance criteria are computed for three applied methods and the solutions obtained are listed in Table 2.

The solution indicates that the suggested method produces superior outcomes in terms of a greater grouping efficiency (84.34), higher grouping efficacy (59.77), and higher machine utilization index (86.20) compared to Rank Order Clustering-2 and Voids-Based Approach.

5 Conclusion

There are several techniques for creating cells in GT, none of them can provide the best outcome. This study has used CMS methodology to the gear box manufacturing industry. Three clustering methods are analyzed using a performance criteria, viz. exceptional elements, group efficiency, group efficacy, and machine utilization index.

Results show that the suggested hybrid clustering method is more effective than the other methods for forming gear box manufacturing cells.

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Barriers Affecting Formal Recycling of E-Waste in Indian Context

Swatantra Kumar Jaiswal and Suraj Kumar Mukti

1 Introduction

The consumer-oriented market and numerous technological advancements in recent years in the electronic industry have caused many products to become obsolete daily or are experiencing a continuous decline in End of life and End of use of the product. The electronics item industry has experienced exponential growth over the past few decades. The electrical and electronic products so discarded are termed e-waste (electronic waste) [1]. Waste electrical and electronic equipment is the term used in the European Union for electrical and electronic waste products (WEEE). Some of the main causes of the creation of e-waste include the quick advancement of technology, the high rate of obsolescence, short product lifespans, appealing consumer designs, and problems with market compatibility. Yet, the circular economy (CE) extends the product life cycle and encourages reuse, recycling, and recovery, which boosts the economy and reduces resource depletion.

David. W. Pears and Kerry Turner, who are environmental economists, invented the circular economy concept in 1989. Initially, an environmentally destructive take-make-dispose mechanism is employed; the garbage transferred to landfills and incinerators contains precious metals [2]. To end the material loop in the industrial ecosystem, the circular economy idea is introduced. The circular economy aims to design waste by optimizing product and material cycles to retain them at their best value and utility through the use of clean, renewable technology, innovative business models, and the legislation that enable them [3].

Since the informal sector is so prevalent in India, the main problem for the formal recyclers of e-waste is that they have limited access to the e-waste produced there.

S. K. Jaiswal (✉) · S. K. Mukti
National Institute of Technology Raipur, C.G, Raipur 492010, India
e-mail: jaiswalswatantra2011@gmail.com

S. K. Mukti
e-mail: skmukti.mech@nitrr.ac.in

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The informal sector, which includes both the informal value recovery operations and the informal e-waste collection, continues to dominate e-waste management in India. In this sector, the bulk of both domestically produced and imported e-waste is collected and processed [4]. Usually, they do not follow the laws and regulations outlined above by the Indian government. Artisanal recycling techniques are used in informal value recovery processes, but proper safety precautions are not taken.

Some of the literatures are available discussing the recycling of e-waste management, but a few of them have identified the barriers affecting the formal recycling of e-waste, it has a scope of study in Indian context. Limited literatures are available to determine the contextual relationship among barriers. Very few studies have identified the driving and dependence power for barriers for successful implementation of formal recycling for e-waste. The objectives of this study are given below.

- To identify the barriers affecting formal recycling of e-waste in Indian context.
- To develop the contextual relationship between the identified barriers affecting recycling of e-waste.
- To determine the driving and dependence power of barriers.

To achieve the above objectives, intermittent structural modeling (ISM) is used.

2 Literature Review

Electronic waste (e-waste) is one of the world's most rapidly rising waste streams, including a variety of harmful compounds that can harm people's health and pollute the environment, if suitable disposal protocols are not followed for effective waste management. Kiddee et al. (2013) determine the key drivers which will affect the e-waste management. Multi-criteria analysis, life cycle assessment, material flow analysis, producer responsibility (PRO), and extended producer responsibility (EPR) are the tools used by developed countries for e-waste management practices [1]. Proper collection of used products, eco-design devices, disposal of used product with suitable technique and customer awareness toward e-waste are the keys drivers. Anju and Naik (2020) find out the key drivers responsible for the recycling, remanufacturing, and refurbishing of e-waste by using analytical method [5]. Customer awareness toward e-waste is one of the major drivers, without awareness, recycling and remanufacturing cannot be processed with maximum efficiency. Collection center for used product is necessary to reduce the uncertainty in quality, quantity, and timing. Jawad (2019) identifies the factors responsible for the achievement of green computing [6]. Energy minimization is one of the key factors for green computing.

The root causes of e-waste bottlenecks in India include lack of awareness about e-waste recycling and lack of policies that address e-waste issues. [5]. Consumer attitude toward disposal of e-waste and recycling behavior are the key factors which affect circular economy of e-waste [7]. Unclear government policies and regulation, lack of management foresight, and negligence of environment are the main hurdles of e-waste. In Malaysia, the potential challenges of remanufacturing are (a) marketing and competition, (b) raw material collection, (c) skill manpower and expert, (d) product design, (e) environmental and government, (f) technology and method [4].

3 Methodology

In this study, author identified the barriers affecting formal recycling of e-waste in Indian context. Based on literatures and expert opinion, barriers are identified. Furthermore, interrelationship between barriers is developed with the help of experts. After that, driving and dependency of barriers have been determined by using interpretive structural modeling (ISM) as shown in Fig. 1, the complete flowchart of methodology.

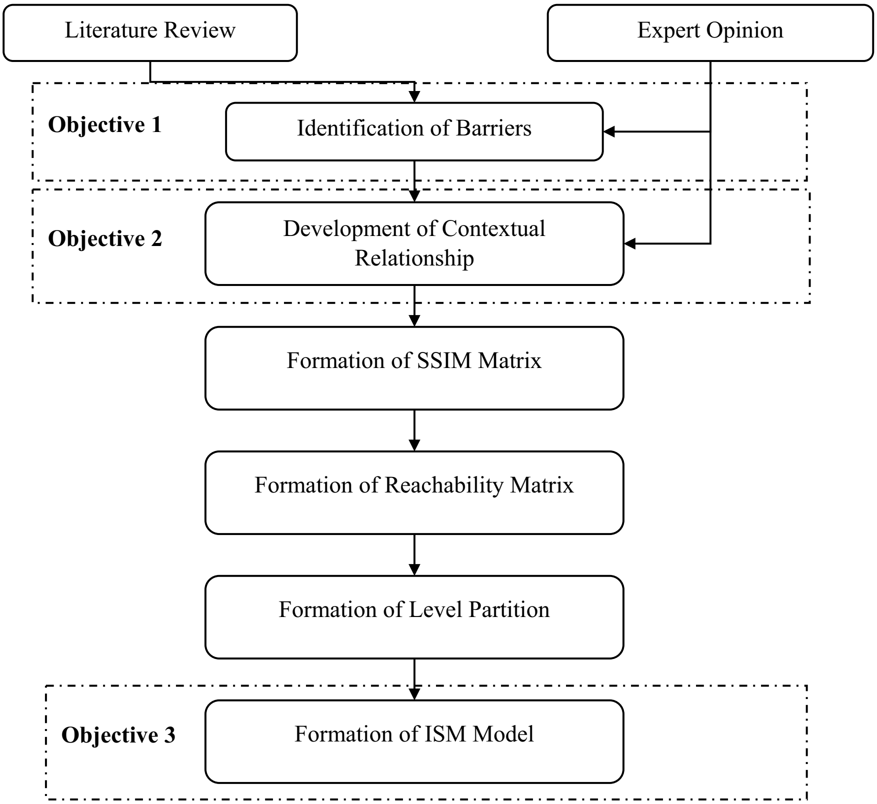

Fig. 1 Flowchart of methodology

3.1 Identification of Barriers

Firstly, author searched different websites like science direct, google scholar, and Scopus with a keywords like e-waste, circular economy, circular economy of e-waste, recycling of e-waste, formal and informal recycling of e-waste. Finally, using previous literature and expert opinion, eleven barriers have been identified viz, Lack of technical skills in circular economy product design (B1), High Investment Cost (B2), Lack of incentives (B3), Lack of government policies (B4), Insufficient infrastructure (B5), Uncertainty in quality of return products (B6), Uncertainty in quantity of return products (B7), Uncertainty in timing of return products (B8), Lack of customer awareness (B9), Lack of producer responsibility organizations (B10), and Lack of collection system (B11), which affect the formal recycling of e-waste. Table 1 shows the brief description of barriers.

3.2 Interpretive Structural Modeling (ISM)

ISM is a statistical tool, used to develop the interrelationship between barriers and to determine the driving and dependency of barriers. ISM is robust tested method used for complex problem by designing the structure of problem and determining the hierarchy. In this study, firstly, author identified the barriers affecting formal recycling of e-waste through literature survey and expert opinion. After barrier identification, self-structured interaction matrix (SSIM) is developed. In SSIM matrix, questionnaire is developed and responses are taken from the experts, four symbols have been used to determine the interrelationship among barriers viz, *V*, *A*, *X*, and *O*. Suppose *i* and *j* are two barriers, (a) '*V*', if barrier *i* impacts *j*, (b) '*A*', if *j* impacts *i*, (c) '*X*', if *i* and *j* both impact each other, (d) '*O*', if both *i* and *j* have no impact on each other. Table 2 shows SSIM matrix.

Furthermore, development of reachability matrix, in present, matrix binary symbols are used to replace the codes of SSIM matrix. If the response in SSIM matrix is '*V*', then the value of *i*, *j* is 1 and *j*, *i* is 0. Similarly, for '*A*', *i*, *j* is 0 and *j*, *i* is 1, if the response is '*X*', then the value for both *i*, *j* and *j*, *i* is 1, and for '*O*', the value is always 0. Table 3 shows the reachability matrix.

After the development of the reachability matrix, the next step is the formation of level partitions. Table 4 shows the level partition, in this, reachability set and antecedent set for each barrier is determined with the help of reachability matrix. Reachability set and antecedent set contains the barrier itself and the barriers affected by it. Different iterations have been performed in level partition to determine the driving and dependency of the barriers. Levels are assigned, if the values of reachability set and intersection set are same.

Last step is the formation of ISM model for determining the driving and dependence barriers in the study. ISM model is developed using level partition. Figure 2 shows the ISM model.

Table 1 Barriers affecting formal recycling of e-waste

Code	Barrier	Description	Source
B1	Lack of technical skills in circular economy product design	Product design is one of the key concepts in circular economy. For sustainable product design, innovation and technical skills are needed	[9–11]
B2	High investment cost	Developing a product that supports circular economy needs high end research and investment. But the return of investment takes long time. There is uncertainty in profit of investment	[12–14]
B3	Lack of incentives	There are no incentives for the organizations who try to achieve circular economy	[15, 16]
B4	Lack of government policies	For effective e-waste management, government plays crucial role. Government policy directly affects the overall process of e-waste management	[17–19]
B5	Insufficient infrastructure	Efficient formal recycling needs huge infrastructure	[17, 20–22]
B6	Uncertainty in quality of return products	Waste products, which are collected, are of different quality, like some products are damaged, parts not working properly	[23–25]
B7	Uncertainty in quantity of return products	Collected waste products are varying in quantity	[23, 26–28]
B8	Uncertainty in timing of return products	Variation in life span of products	[25, 26, 29]
B9	Lack of customer awareness toward recycling	Awareness toward effect of e-waste on human, environment, and economy is needed	[30–32]
B10	Lack of producer responsibility organizations (PRO)	To enable producers to collect and channel the e-waste generated	[33–35]
B11	Lack of collection centers	Very few e-waste collection centers in India	[36, 37]

4 Result and Discussion

Eleven barriers have been identified and analyzed, which affect the formal recycling of e-waste in Indian context. ISM modeling is done to develop inter-relationship among barriers and to determine the driving and dependent power of barriers. Lack of incentives (B3), lack of government policies (B4), lack of customer awareness toward recycling (B9), and lack of technical skills in circular economy product design (B1) are at bottom level of the ISM model, which represents that these barriers are

Table 2 SSIM matrix

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11
B1		V	A	X	X	V	V	V	A	X	O
B2			A	A	X	V	V	V	O	O	O
B3				X	V	V	V	V	V	V	V
B4					V	V	V	V	V	V	V
B5						O	O	O	O	X	X
B6							X	X	A	A	A
B7								X	A	A	A
B8									A	A	A
B9										X	V
B10											V
B11											

Table 3 Reachability matrix

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	DRP
B1	1	1	0	1	1	1	1	1	01	10	0	8
B2	0	1	0	0	1	1	1	1	0	0	0	5
B3	1	1	1	1	1	1	1	1	1	1	1	11
B4	1	1	1	1	1	1	1	1	1	1	1	11
B5	1	1	0	0	1	0	0	0	0	1	1	5
B6	0	0	0	0	0	1	1	1	0	0	0	3
B7	0	0	0	0	0	1	1	1	0	0	0	3
B8	0	0	0	0	0	1	1	1	0	0	0	3
B9	1	0	0	0	0	1	1	1	1	1	1	7
B10	1	0	0	0	1	1	1	1	1	1	1	8
B11	0	0	0	0	1	1	1	1	1	1	1	7
DEP	6	5	2	3	7	10	10	10	5	7	6	

the most influential and directly affect the circular economy. Insufficient infrastructure (B5), uncertainty in quality of return products (B6), uncertainty in quantity of return products (B7), uncertainty in timing of return products (B8), high investment cost (B2), lack of producer responsibility organizations (B10), and lack of collection system (B11) are situated in the top level of ISM model, which shows strong dependence power. Lack of incentives and lack of government policies are at level five in the model, which indicates that a strong government policy is needed to achieve formal recycling. Barrier at level four named as lack of customer awareness toward recycling shows that there is a need for an awareness program toward the hazardous effect of e-waste on human, the environment, and economy. Lack of technical skills in circular economy product design situated in level three, it shows great concern toward

Table 4 Level partition

Barriers	Reachability	Antecedent	Intersection	Level
B1	1,2,4,5,6,7,8,10	1,3,4,5,9,10	1,4,5,10	III
B2	2,5,6,7,8	1,2,3,4,5	2,5	II
B3	1,2,3,4,5,6,7,8,9,10,11	3,4	3,4	V
B4	1,2,3,4,5,6,7,8,9,10,11	1,3,4	1,3,4	V
B5	1,2,5,10,11	1,2,3,4,5,10,11	1,2,5,10,11	I
B6	6,7,8	1,2,3,4,6,7,8,9,10,11	6,7,8	I
B7	6,7,8	1,2,3,4,6,7,8,9,10,11	6,7,8	I
B8	6,7,8	1,2,3,4,6,7,8,9,10,11	6,7,8	I
B9	1,6,7,8,9,10,11	3,4,9,10,11	9,10,11	IV
B10	1,5,6,7,8,9,10,11	1,3,4,5,9,10,11	1,5,9,10,11	II
B11	5,6,7,8,9,10,11	3,4,5,9,10,11	5,9,10,11	II

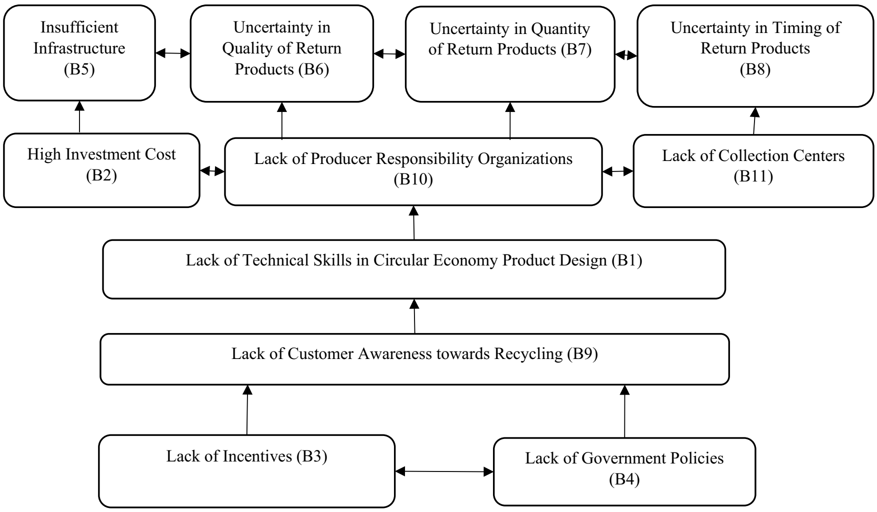

Fig. 2 ISM model

economy and environment. Barriers B5, B6, B7, and B8 are situated in level one of the ISM model, these barriers show strong dependency toward all other barriers, like a good government policy directly or indirectly affects the collection centers which directly impact the quantity, quality, and timing of return product.

5 Conclusion

Formal recycling is one of the most important steps to close the loop of material cycle, extraction of raw materials needs tremendous amount of resources. Formal recycling is needed for effective implementation of e-waste management. The study concludes that a strict government policy is needed to achieve recycling for effective e-waste management. Government policy plays a crucial role in the development of a sustainable environment, countries like USA, UK, and Japan have a strict policy for e-waste management which encourages the company to develop a sustainable product. Customer awareness is necessary, so that we can tell people about the harmful effects of e-waste, some of which fall in the human, environment, and economy. This paper will assist organizations and policymakers in building a sustainable environment strategy.

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Improving the Application Performance by Auto-Scaling of Microservices in a Containerized Environment in High Volumed Real-Time Transaction System

Amarjeet Singh, Vinay Singh, and Alok Aggarwal

1 Introduction

Auto-scaling is a way to scale up and scale down the resources available in a data center or cloud. These resources could be at the machine level or internal resources for a machine-like CPU utilization, memory, or cache [1]. This auto-scaling is decided by depending upon the total transactions and current load on the application in real time. In the AWS, EC2 is the compute platform. EC2 instances offer scalability. Auto-scaling algorithms control threshold values for the parameters. An auto-scaling policy makes some additional changes to the auto-scaling of the speculated desired capacity in response to forthcoming metrics set on thresholds [2–5]. Figure 1 shows the auto-scaling used in any public cloud. The auto-scaling solution is architected using microservices. APIs are triggered and the Application Load Balancer receives by the service and deployed into the cloud. The services perform the scale out/in as per the metrics collected.

2 Versioning of Microservices: Git

The term "versioning" means for microservices have a wide scope which is used to track the developer's changes in Kubernetes or PCF, Dockized container environment but all of the attributes of the service like consuming applications and deployment

A. Singh (✉)
Pittsburg, USA
e-mail: amarteotia@gmail.com

V. Singh
8292 Mount Ouray Road, Littleton, CO 80125, USA

A. Aggarwal
School of Computer Science, University of Petroleum and Energy Studies, Dehradun, India

A. Bhardwaj et al. (eds.), *Optimization of Production and Industrial Systems*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-99-8343-8_27

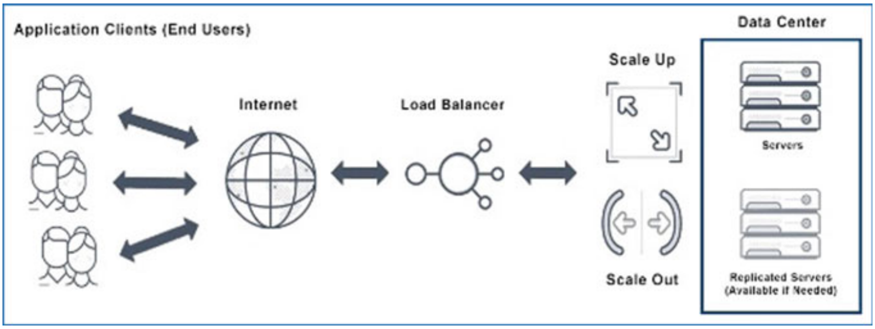

Fig. 1 Auto-scaling Microservices in the cloud

metadata [6–8]. The management of versions of microservices in the containerized environment is crucial and requires a special kind of implementation and capability to track several changes. These values can be stored in Git for future reference along with spring boot applications. To determine whether instances are working efficiently, an auto-scaling group calls a health check API [9, 10]. A health check is always measured based on some launch configuration and decision criteria. These decisions are taken on the scale of its instance type, available machine image, availability zone, CPU size, and memory allocated to that machine [11].

2.1 Types of Scaling

Broadly, there are two types of auto-scaling: vertical auto-scaling and horizontal auto-scaling.

Vertical Scaling: It refers to adding more resources to existing machines like CPU, machines, cache etc. Vertical scaling is not aloof from challenges. There might be a situation that suddenly it cannot cope with the total number of transactions or high load with resources, so there is a need to introduce decoupling application tiers to mitigate and grow at different rates [12].

Horizontal Scaling: It is required when there are one or more machines down and it is needed to scale more instances or existing machines are not able to cope with the peak load. Horizontal auto-scaling gets activated only in those situations where peak load is reached and it is needed to spin up more machines to the resource pool. Horizontal auto-scaling is considered in a different scenario than Vertical auto-scaling [13].

There is a very crucial role for stateless server auto-scaling as they do not maintain the state of any application. It means, when the response to a request is processed, the session is expired, hence, they tend to the security of real-time applications where security of the data is highly sensitive. Horizontal scaling makes a better user experience in this kind of browser-side session storage [14, 15]. There is no business

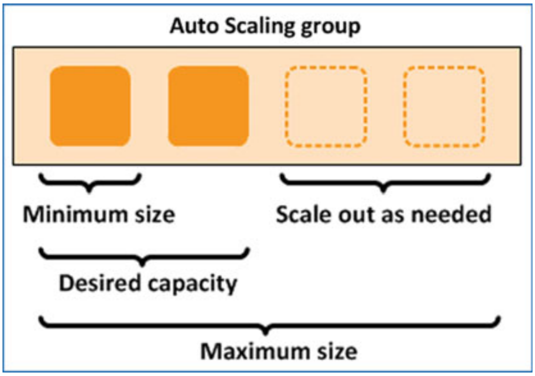

Fig. 2 Auto-scaling group in microservices

discontinuity or downtime in horizontal scaling as they increase the similar kinds of machines with the application already installed with some APIs. This increases high availability and better performance and great user experience. Auto-scaling makes the system resilient for unplanned events, this is the reason it is always preferred for real-time time business critical events.

2.2 Auto-Scaling a Cluster in Kubernetes

In Kubernetes, cluster capacity planning is critical. In very peak hours and high-load circumstances, it is required to scale up the machine power or increase the number of machines automatically to meet resource requirements [16, 17]. Hence, Cloud companies need to provide a cost-effective way to implement auto-scaling keeping costs and high availability at the same time. Auto-scaling group in microservices is shown in Fig. 2.

2.3 Types of Auto-Scaling: Containerization Perspective

Cluster Autoscaler (CA)—They are used to scale up and scale down the total required nodes in the node pool. The algorithm is decided by a scheduler who does pod scheduling [18, 19]. They are of two types: Horizontal Pod Autoscaler and Vertical Pod Autoscaler. Horizontal Pod Autoscaler is used to decide at what point in time, the pods have to be increased or decreased horizontally [20]. Vertical Pod Autoscaler is used to increase the power of a pod within the pod itself like adding CPU capacity or memory or adding more elastic volumes to store more logs or transaction data [21, 22]. Figure 3 explains the several different types of Auto-scaling in Kubernetes.

Kubernetes auto-scaling faces several restrictions and severe challenges especially when there is peak load and the application seeks high flexibility. A new service

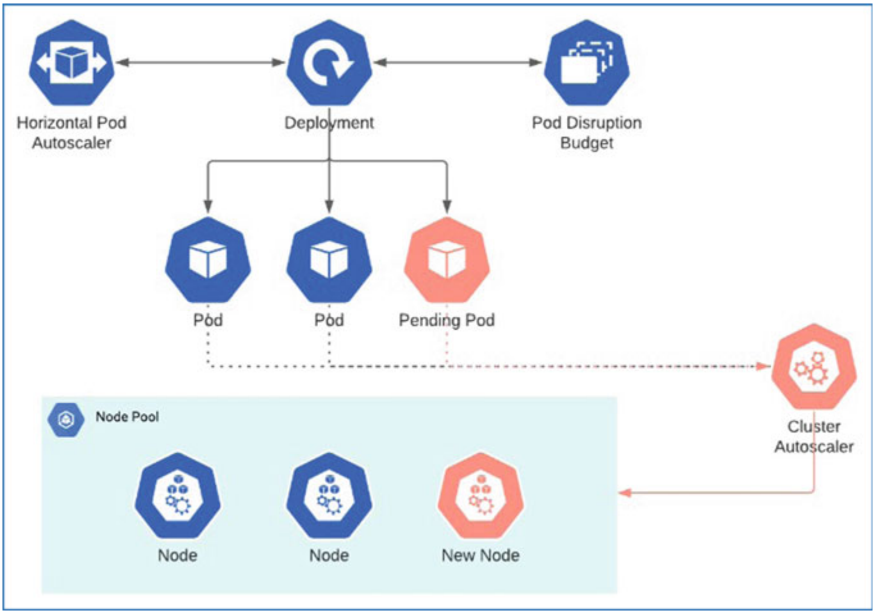

Fig. 3 Types of auto-scaling in Kubernetes

spring boot framework is essentially required to be implemented and create objects like “spring boot-app-svc”.

Figure 4 shows an Overview of Kubernetes Objects. Details of which are:

- The target port needs to be mapped with incoming ports, so that there is no firewall blocking. For example, port 8080 needs to be mapped to container port 80.
- API version needs to be defined in a specified format every time it is built and deployed.
- Service object type is indicated by Node Port.

Fig. 4 Overview of Kubernetes objects

```
apiVersion: v1
kind: Pod
metadata:
  name: nginx
spec:
  containers:
  - name: nginx
    image: nginx:1.14.2
    ports:
    - containerPort: 80
```

- Traffic must come through the Load balancer to Ingress to the Pod cluster.
- Service objects can be created in several formats like YAML or JSON.
- Service object serves the real-time spring boot app with the help of Labeled selectors like Ngnix.

3 Methodology to Improve Kubernetes Performance

In order to increase the performance of any application in Kubernetes deployment, a special type of pattern is required which is called "parents" utilized by a feature in Kubernetes. It is called worker-coordinator. Figure 5 depicts a script written to spin up a small Kubernetes environment and its pre-requisite. There might be several worker-coordinators who support the load transactions and any real-time traffic to each node and monitor their progress.

There might be a situation where the Kubernetes deployment setup and the Pods workloads are quite difficult. Figure 6 is self-explanatory and shows the peak load on Docker system. The performance analysis then becomes very tough as their internal parameters become so complicated and hard to be fetched.

Some important terminologies used are given below:

Nodes—Number of nodes in the cluster. If not provided, test will assign the number of schedulable cluster nodes.
Report-dir—Path to directory for storing summaries files.
Master name—Name of the master node.
Master tip—DNS Name / IP of the master node.
Kubler-port—Port of the kubelet to use the default port.

```
ADD bash /home/kubernetes-performance/bash
ADD jar /home/kubernetes-performance/jar
ADD jmx /home/kubernetes-performance/jmx
ADD python /home/kubernetes-performance/python

WORKDIR /home/kubernetes-performance/bash

RUN chmod +x start_performance_test.sh

RUN apt-get update && apt-get install python3.5 -y
RUN apt-get install python-pip -y
RUN pip install numpy requests schedule
```

Fig. 5 Script to spin up a small Kubernetes environment and its pre-requisite

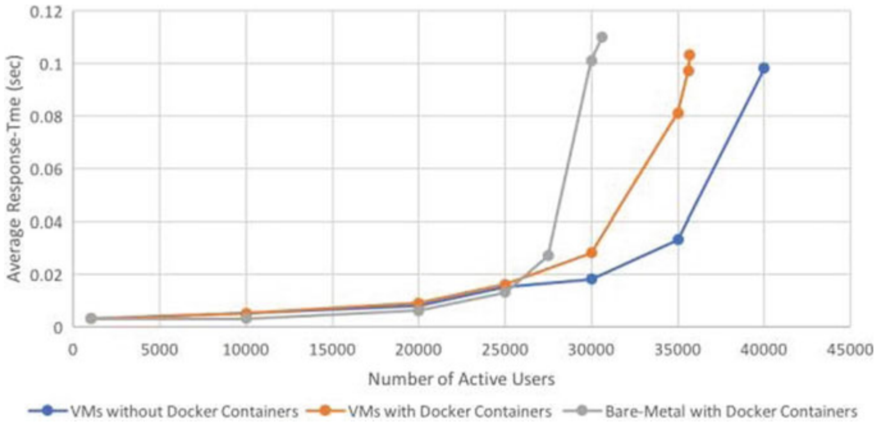

Fig. 6 Load of user requests on the Docker system

A script has been written to improve the application performance and Fig. 7 shows that the python script and its system functions are used to improve the application performance. Run queue plays a crucial role as it can run on demand scaling by increasing resources in each CPU core.

4 Results and Discussion

Initial application deployment comprises of multiple steady load of API calls triggered to the microservice at the speed of about 65–70 messages/second. In the target tracking scaling policy, as per the application, auto-scaling creates the metric alarms shown in the metric checks, one to handle scale out and the other to handle scale in and it makes sure that the average value of the utilization metric is fixed within the range.

As the initial value is about 60–70, the upper threshold alarm of this metric triggers the scale-out. The rate of messages produced is almost doubled messages/rate and another scaling triggered which crosses the set threshold. Scale-out procedures are shown in the Fig. 8 and the API calls during the scale-out are shown in the Fig. 9.

It is observed as the rate is decreased to about 50 messages/second, it brings the consumer tasks to its lower level of two. Prioritizing the availability in response to an increased load on the system is the primary goal of the Auto-scaling. A scale-out is performed relatively faster in case when a metric breach a threshold for three one-minute periods, while the scale in action is executed Fig. 10 in a far more conservative manner, only after the threshold is crossed for 15-min periods.

```
#!/usr/bin/env bash

set -o errexit
set -o nounset
set -o pipefail

print-usage-and-exit() {
  >&2 echo "Usage:"
  >&2 echo "    $0 delete|list <comma-sep-projects> <comma-sep-prefixes> <days-old>"
  >&2 echo "Example:"
  >&2 echo "    $0 list k8s-e2e-gce-1-1,k8s-e2e-gce-1-2  ci-e2e-scalability,ci-e2e-kubemark 30"
  exit "$1"
}
list-old-snapshots() {
  project=$1
  regexp=$2
  days_old=$3
  (
    set -o xtrace
    gcloud compute snapshots list \
      --project "$project" \
      --filter="creationTimestamp < -P${days_old}D AND name~\"${regexp}\"" \
      --format="value(name)"
  )
}
process-old-snapshots() {
  command=$1
  project=$2
  regexp=$3
  days_old=$4
  for snapshot in $(list-old-snapshots "$project" "$regexp" "$days_old"); do
    if [[ "$command" == "delete" ]]; then
      echo "Removing $snapshot ..."
      gcloud compute snapshots delete -q --project "$project" "$snapshot"
    else
      echo "Found: $snapshot"
    fi
  done
}
main() {
  if [ "$#" -ne 4 ]; then
    >&2 echo "Wrong number of parameters, expected 4, got $#"
    print-usage-and-exit 1
  fi
  command=$1
  projects=$2
  prefixes=$3
  days_old=$4

  if ! [[ "$command" =~ ^(list|delete)$ ]]; then
    >&2 echo "Invalid command: $command"
    print-usage-and-exit 2
  fi
  if ! [[ "$projects" =~ ^[a-z0-9,-]+$ ]]; then
    >&2 echo "Illegal characters in projects parameter: $projects"
    print-usage-and-exit 3
  fi
  if ! [[ "$prefixes" =~ ^[a-z0-9,.-]+$ ]]; then
    >&2 echo "Illegal characters in prefixes parameter: $prefixes"
    print-usage-and-exit 4
  fi
  if ! [[ "$days_old" =~ ^[0-9]+$ ]]; then
    >&2 echo "Days-old parameter must be an integer: $days_old"
    print-usage-and-exit 5
  fi
```

Fig. 7 Script to improve the application performance

Figure 11 depicts the average CPU and memory usage during the auto-scaling process. It is also determined that the average CPU and memory usage does not have correlation to the number of partitions for the consuming messages and should not be used as a criteria to perform automatic scaling.

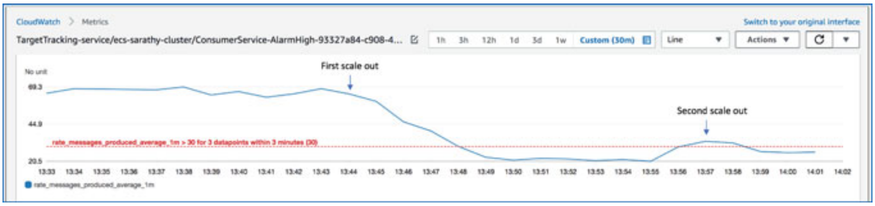

Fig. 8 Scale-out procedures

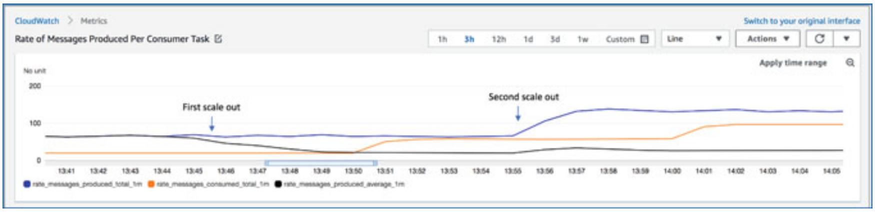

Fig. 9 API calls during the scale-out

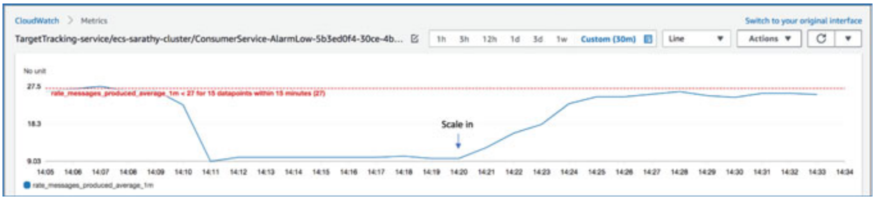

Fig. 10 Scale in procedure

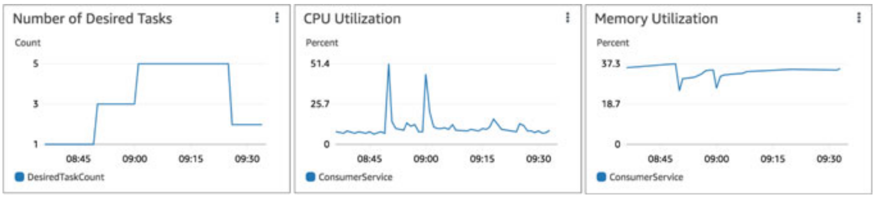

Fig. 11 Average CPU and memory usage

5 Conclusion

Auto-scaling in any cloud provider like Azure, Google, or AWS helps to adjust the Kubernetes capacity at the lowest possible cost. They do it by doing a predictable peak load, so that can preserve the expected performance. In order to set up auto provide better application performance at real-time servers or clusters, auto-scaling requires spinning up the resources across multiple services in no time. The graph shown in Fig. 12 shows that concurrency can also be maintained by the use of auto-scaling which means several workers-nodes can execute parallel transactions at the same time.

CPU usage plays a critical role in auto-scaling as several measurements and decisions are taken based on CPU capability. Figure 13 shows the auto-scaling in CPU performance. All the benefits of a single containerized can be managed easily and scaled just like any other Kubernetes service.

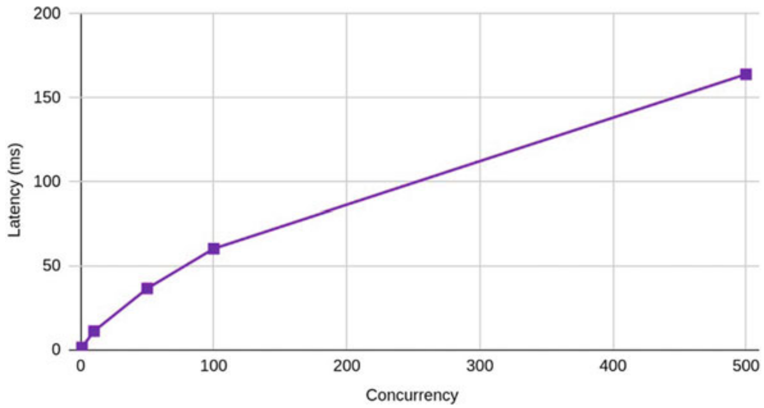

Fig. 12 Graph on Application performance by implementing concurrency

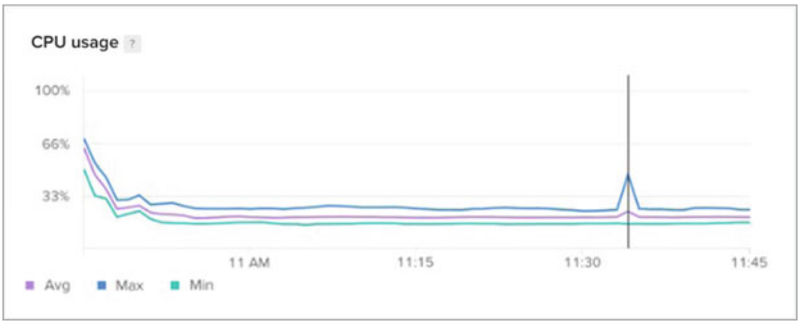

Fig. 13 Increase in CPU performance

It is observed that auto-scaling not only supports scaling up the instances in peak hours but also scales down the instances when there is minimal or no load on the application. Auto-scaling keeps monitoring the instance metadata. It helps in identifying the health status of the instances. With Fig. 6, it can be seen that in peak load situations, if there is a demand for instant user requests or there is a surprise increase in user transactions increase in user requests, auto-scaling automatically adds more resources to handle the situation, which makes the system fault tolerant.

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Development of IoT-Based Drowsiness Detection and Smart Alert System for Accident Prevention in Automobiles

Raghav Sharma, Kapil Kumar Goyal, and Sanjeev Kumar Mahato

1 Introduction

Driver drowsiness has been identified as one of the most prevalent causes of a large number of accidents, due to long drive fatigue, exhaustion, stress, and poor weather and road conditions. A drowsiness detection and warning system for motor vehicles for accident prevention based on Arduino, including eye twitch and alcohol sensor, is developed [1, 2]. Sleep deficiency and other sleep problems can cause drowsiness when driving, which causes 3–30% of all road traffic incidents globally. 20% of drivers need to stop driving due to exhaustion [3]. A real-time driver-drowsiness detection method based on the eye blink pattern and PERCLOS incorporating images, facial features, and physiological signals is created based on the Internet of Things and detects unexpected acceleration and prevents automobile accidents [4–9]. A wearable intelligent system for detecting drowsiness and preventing accidents based on electroencephalogram (EEG) and assessing blink duration utilizing alpha waves is also developed [10, 11]. Some automotive manufacturers use vehicle movement, steering wheel tilt, and other factors to detect driver drowsiness, however, these factors may not be reliable [11]. Drowsy driving is extremely risky, and drivers must be aware of the risks therefore there is Integration and evaluation of an IoT and AI-based accident prevention and detection system to monitor, inform, and improve driver experience [12, 13]. Even applying brakes won't help before the collision since response time increases in drowsiness, and drivers lose control of the automobile due to faster speeds, distractions, and the driver's inability to control this behavior. Deep learning and computer vision are used to create an intelligent driver assistance-based drowsiness detection model [14, 15]. Modern technology needs to be developed to detect drowsiness in drivers and alert them, minimizing road accidents worldwide

R. Sharma (✉) · K. K. Goyal · S. K. Mahato
Department of Industrial and Production Engineering, Dr. B. R. Ambedkar Natrional Institute of Technology, Jalandhar 144027, India
e-mail: raghavsharma1409@gmail.com

A. Bhardwaj et al. (eds.), *Optimization of Production and Industrial Systems*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-99-8343-8_28

[16]. The automated IoT-based system developed in this study analyzes the driver's eye blink rate per minute while driving. If the recorded eye blink rate per minute falls below the average eye blink rate per minute, the system alerts the driver through pulsed vibrations. This approach contributes to the reduction of drowsy driving-related fatalities, injuries, and crashes.

2 Experimentation and Methodology

2.1 Parts Description

The segments that are currently being used are listed below:

1. Power Supply: The current setup utilizes a 12V power supply. This power is obtained from the vehicle's 12V accessory outlet, providing a steady flow of 12 V of Direct Current (DC) power. The power supply is crucial for the proper functioning of the system.
2. Arduino UNO: The Arduino UNO is a widely used open-source microcontroller board. It is based on the ATmega328P microcontroller, offering versatile capabilities for various projects. Equipped with 14 digital pins and 6 analog pins, the Arduino UNO allows for easy interfacing with other components. The board can be powered using an AC to DC converter or a USB cord, providing flexibility in power sources.
3. Eye Blink Sensor: In the current setup, an eye blink sensor is employed to detect eye movements. This sensor utilizes infrared light to detect variations in the reflected ray using a phototransistor and a detector circuit. By measuring and tracking eye blinks, this IR-based module assists in monitoring eye activity. When the eye is closed, the output of the sensor is high, while in other states, the output is low.
4. Vibration Motor Module: The vibration motor module is a compact and integrated component utilized in the system. When an input signal is high, the motor generates vibrations. The module offers control over the ON/OFF status and intensity of the vibrations through digital or PWM signals. This vibration effect is visible, amplified, and serves as a non-audible indicator. Its quick and efficient conversion of electrical signals into mechanical vibrations makes it ideal for various applications.
5. Jumper wires: Jumper wires play a vital role in establishing connections between different points within the circuit. These wires feature male-to-female connector ends, eliminating the need for soldering. By connecting to breadboards and other prototyping tools, jumper wires simplify circuit construction and modification. They provide an easy-to-handle solution for making temporary or permanent connections, facilitating experimentation and prototyping processes. The visualization of components used in present research work has been shown in Fig. 1.

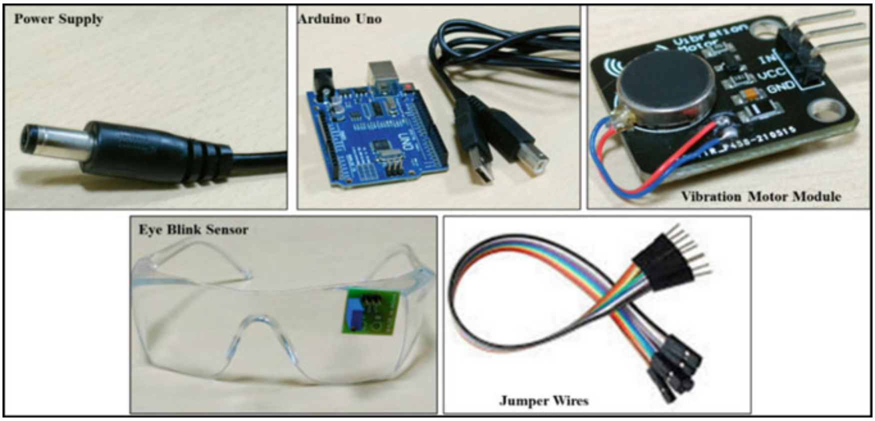

Fig. 1 Components used in the present research

These components work together to create a functional system for various applications, including driver-drowsiness detection, as described in the initial context.

2.2 *Block Diagram and Circuit Arrangement*

The block diagram in Fig. 2 illustrates the workflow of the drowsiness detection and alerting system. The components used in the proposed setup include the Eye Blink Sensor Module, 12 V Power Supply, Arduino microcontroller, and Vibration Motor Module. The Arduino serves as a microcontroller that operates the embedded system circuit.

The eye blink module is utilized to detect changes in the eye blink rate per minute using the transmitter and receiver module. When the system detects that the driver is actively drowsy, the output vibration plate vibrates to alert the driver. The 12 V Power Supply ensures a stable and reliable power source for the system. This system aims to prevent accidents by detecting driver drowsiness and providing timely alerts.

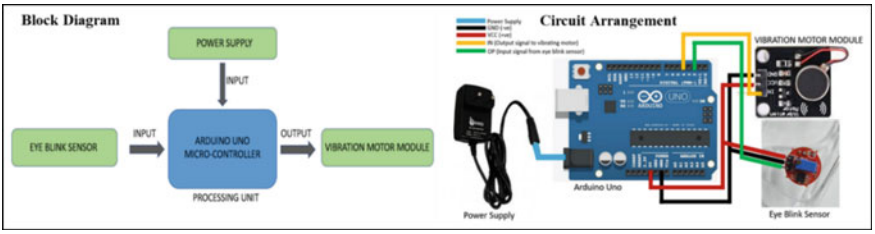

Fig. 2 Block diagram and circuit arrangement

To set up the system, begin by connecting the Arduino to the power supply. Next, establish the connection between the GND (-ve) pin of the Arduino and the GND pin of both the Eye Blink Sensor and Vibration Motor Module. Connect the 5 V (+ve) pin of the Arduino to the VCC pin of both the Eye Blink Sensor and Vibration Motor Module. Additionally, connect a digital pin of the Arduino to the OP (eye blink sensor input signal) and another digital pin to the IN (output signal to the vibrating motor). Figure 2 provides a visual representation of the component circuit arrangement.

After making the physical connections, you can proceed with uploading the code to the Arduino. Use a USB cord to connect the Arduino to your computer and launch the Arduino IDE. Write the necessary code, compile it, and run it. Once the code is ready, select the appropriate Arduino port and click the upload button. This process will update the Arduino with your code. Finally, ensure that the power supply is turned on, and monitor the output of the eye blink sensor to analyze its readings.

2.3 Generation of Code

Initially, the setup code was developed in C++ within the Arduino IDE. Subsequently, the code was compiled using the compiler, which translates the human-readable code into computer-readable commands. This compilation step was crucial for our project. Once the code was successfully compiled, it was uploaded to the Arduino microcontroller, which had been connected to the operational setup.

```
Initialize int Eye Blink Sensor Pin;
Initialize int Vibration Motor Module Pin;     // Defining of sensor pins
void setup ()
{
   Pin mode (Eye Blink Sensor Pin as INPUT);
  Pin mode (Vibration Motor Module Pin as OUTPUT);    //Declaring of pin modes
}
void loop ()
{
    time bucket = 60    // seconds
    now time ()    // present reading time
    previous_now time ()    // reading just before present reading time
    time lapse = now time () - previous_now time ()
if (blink_occurs)
{
     blink_recent[] = {blink, blink, blink… blink};     //recording number of blinks, last 60 s
     average blink rate = blink_recent;
        if (average blink rate < 14.1400)
       {Feed trigger arry[] = {y,y…}; //yes}     //feeding yes if blink rate is less than average
        else
        {Feed trigger arry [] = {n,n…}; //no} //feeding no if blink rate is greater than average
if (60 percent trigger arry “y”)
{Activate digital Output (Vibration Motor Module Pin, HIGH);}
else
{Activate digital Output (Vibration Motor Module Pin, LOW);}
}
```

3 Results and Discussions

3.1 Finding Average Eye Blink Rate Using the Normal Distribution

In the present investigation, the average eye blink rate of 28 randomly selected driving members was calculated using the normal distribution method. These members were categorized into four groups based on age criteria: 18–27, 28–37, 38–47, and 48–57. Each group consisted of 7 members, except for one group that included members aged 18–57 for more comprehensive analysis. The eye blink testing rate was measured for each individual member over a period of 60 min. The collected data from the testing was then analyzed using the normal distribution. This analysis involved calculating the average eye blinks per minute for each group. In the normal distribution equation, $f(x)$ represents the probability, σ represents the standard deviation, $\sigma 2$ represents the variance, μ represents the mean, and x represents the value of the variable.

$$f(x, \mu, \sigma^{2)} = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

Following the data input, graphs were generated for the different age groups, namely 18–27, 28–37, 38–47, 48–57, and 18–57, as depicted in Fig. 3. These graphs were created based on the collected data. Additionally, the average eye blink rate for all age groups was calculated. For the purpose of this study, the average eye blink rate for age group 18–57 was determined to be 14.1400. The values of average eye blink rate are summarized in Table 1.

3.2 Working and Implementation

During the experiment, a vibration motor module was employed to generate vibration impulses on the driver's backside. Simultaneously, the driver's eyeglasses were equipped with an eye blink sensor to analyze the rate of blinking. The microcontroller responsible for processing the sensor data was powered by a 12V DC socket in the car, as illustrated in Fig. 4.

During operation, the system continuously monitors the driver's average eye blink rate per minute. If the driver's eye blink rate per minute falls below the average eye blink rate per minute i.e., 14.1400 blinks per minute, the system identifies that the driver is experiencing drowsiness. In such a scenario, the microcontroller activates the vibration motor module, which generates vibration impulses to assist the driver in waking up. Conversely, if the recorded eye blink rate per minute exceeds or equals the average eye blink rate per minute, the microcontroller sends a signal to switch off the vibration module, as depicted in Fig. 4.

4 Conclusions

Throughout the study, an automated approach was developed to determine the drowsiness level of vehicle drivers. The developed module was tested on a group of 28 drivers, who were further divided into four age groups for comprehensive analysis. The system was constructed using components such as an Arduino Uno, an eye blink sensor, and a vibration motor module. The results of the study demonstrated that by performing computations on the eye blink rate data collected from drivers of different age groups, the average eye blink rate was determined to be 14.14 blinks per minute when considering all age groups combined (18–57 years of age). This approach proved effective in distinguishing between drowsy and alert drivers. Following the classification of drowsy drivers, a seat vibration system was designed to promptly notify the driver. This system has the potential to save numerous lives by preventing traffic accidents caused by drowsy drivers.

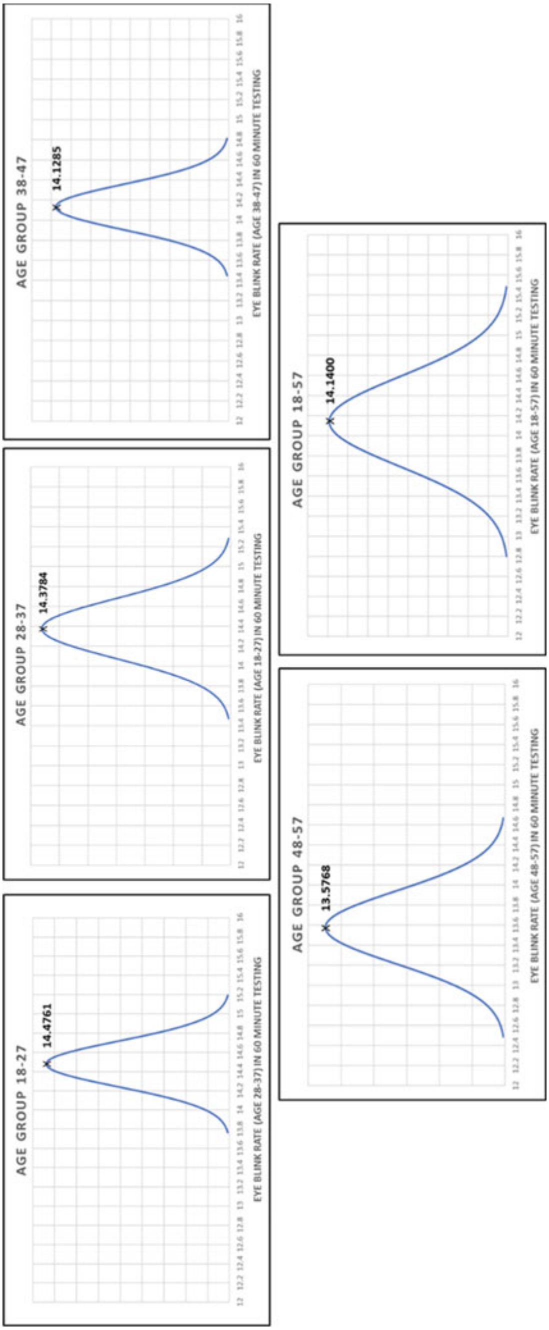

Fig. 3 Graphs for different age groups

Table 1 Average eye blink rate per minute of different age groups

Age group	Average eye blink rate per minute
18–27	14.4761
28–37	14.3784
38–47	14.1285
48–57	13.5768
18–57	14.14.00

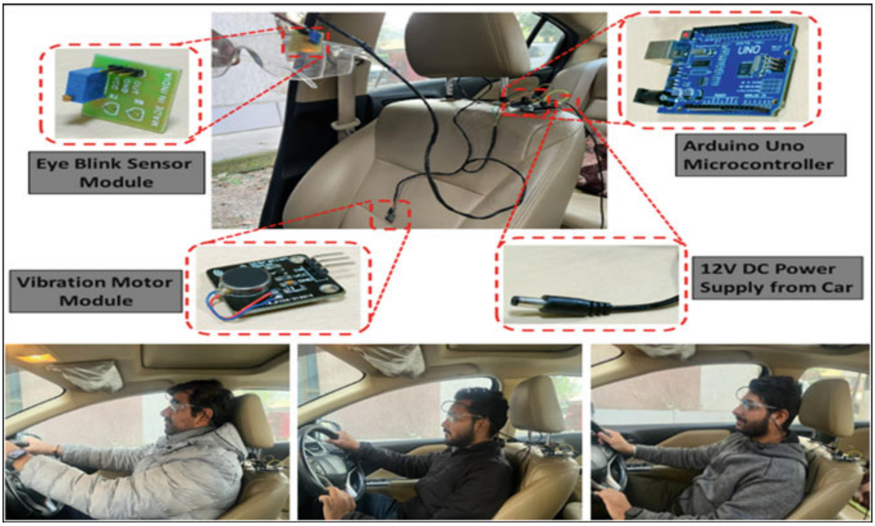

Fig. 4 Experimental setup and pictures during the experiment

In the future, driver-drowsiness detection technology could potentially be employed in self-driving cars to detect not only drowsiness but also stress, distractions, and road accidents. To mitigate potential issues, the system can be further optimized to send an SOS signal along with the driver's location to the nearest police station and hospital in case of persistent drowsiness. Future research can focus on enhancing the detection method by incorporating a combination of physiological factors, deep learning algorithms, and electroencephalogram (EEG) sensor technologies.

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Conceptual Design of Automatic Solar Panel Cleaning Technique for Efficiency Improvements of Solar System

Ramkrishna Bharsakade, Rajesh Chaudhari, Darshan Deore, Jyoti Mohite, Aman Hadap, Vaibhav Tompe, and Shreya Bhosale

1 Introduction

Solar cells are used in photovoltaic (PV) systems to convert solar radiation into electricity. Panels, batteries, charge controllers, and loads make up the system. Direct current (DC) energy through solar PV panels, energy from solar panels, is transformed into electrical energy, which are frequently mounted on roofs and connected to buildings by inverters. The four most common types of PV solar cells are single-crystal silicon cells, silica solar cells, thick film silicon, and silicon solar cells [1]. When light hits the surface of a material, most of the photon energy is converted to heat, which can be refracted, transmitted, or absorbed. However, some elements have transformed capabilities [2]. The energy of electrons coming into electricity. Photons use the principle of conservation of speed and energy to transfer energy to

R. Bharsakade · R. Chaudhari
Vishwakarma Institute of Technology, Pune 411037, India
e-mail: ramkrishna.bharsakade@vit.edu

R. Chaudhari
e-mail: rajesh.chaudhari@vit.edu

D. Deore (✉) · J. Mohite · A. Hadap · V. Tompe · S. Bhosale
Production Engineering, Vishwakarma Institute of Technology, Pune 411037, India
e-mail: darshan.deore21@vit.edu

J. Mohite
e-mail: jyoti.mohite21@vit.edu

A. Hadap
e-mail: Sandip.aman21@vit.edu

V. Tompe
e-mail: Vaibhav.tompe21@vit.edu

S. Bhosale
e-mail: Shreya.bhosale21@vit.edu

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electrons. The emitted electrons can move around the crystal known as the photoelectric effect. It is undesirable for the efficiency reduction of the solar module during its lifespan due to the expensive initial investment of the system and the restricted lifetime of around 25 years [3]. Additionally, it takes a solar panel around six years to deliver the same amount of power as was used during production. When dust builds up on a solar panel, its efficiency suffers significantly. The nature of the problem may differ depending on where the facility is located. In Malaysia, for example, a humid atmosphere promotes moss and fungi to develop on PV modules [4]. Solar panel dust is mostly made up of industrial and urban pollutants. Dust particles such as Silicon dioxide, Iron oxide, CaMg, Ca $(OH)_2$, CaO, and Hydrocarbons can be detected by solar panels. The effectiveness of the system is significantly impacted by the accumulation of particles on the panel's surface. Cleaning that is automated and self-sufficient is a fair solution [5]. Because dust density affects the electrical properties of solar panels, an automated cleaning device to clear the module's surface of dust particles must be supplied to assure excellent performance, improved efficiency, and increased power output [6]. Additionally to natural shading and overheating, certain geographic areas are more prone to unpleasant dust accumulation on PV panel surfaces [7]. Therefore, a precise mechanism to remove accumulated dust is required to restore panel efficiency. Natural cleaning, manual cleaning, automated cleaning, and electrostatic cleaning are the most often used PV panel cleaning techniques. All cleaning techniques recommended in the literature have both distinct advantages and disadvantages. In this study, propose a semi-automated and inexpensive dust removal method for solar panels. The main objectives of our study are as follows,

- Development of a cleaning system which can be controlled with a motor.
- Avoidance of physical manual labor work.
- To overcome the inefficiencies caused by dust accumulation on the solar panel.
- To increase the overall efficiency of solar panels.

2 Literature Review

Solar panels are often cleaned with water and cleaning becomes tough, expensive, and difficult in some areas due to water constraints The fundamental goal of all research is to lessen human effort by creating automatic PV module systems and involving humans in the solar panel cleaning process because doing so puts them in a dangerous situation under the hot sun [8]. Bari et al. conducted a study on the topic of expanding solar energy applications and how solar power has emerged as a source of sustainable energy. By using Arduino programming to operate the cleaning system, the module is cleaned. In order to improve energy efficiency, it is necessary to remove dust from PV panels. If the panels are not cleaned for a month, the power production can drop by up to 50% automatic cleaning system for solar modules [9].

Climate change and the depletion of most oil supplies, along with the rise of photovoltaic (PV) cells viable and ecologically acceptable alternatives for sustainable development. In the PV panels dust is the key element significantly influencing its performance [10]. This study investigated the impact of dirt on the operation of the solar system and uncovered impediments to other important factors. As potential countermeasures, this study offers a framework for comprehending the numerous mechanisms influencing dust settling, to meet the constantly rising need for energy around the globe for a variety of uses [11]. Mondal et al. reported the prospects for solar automatic cleaning systems. This paper discusses the dust problem and recent advancements in automated cleaning systems [12].

Milan Vaghani et al. researched a project that was created to benefit solar panel consumers by utilizing the most recent technological advancements; it provides transparency into the cleaning process and offers a higher performance, completeness, and scalable solution for removing stains. Compared to dusty solar panels, this cleaning device produces about 32% more power[13]. Govinda Rajulu, et al. created a cleaning system design using a microcontroller. This system proved to be an efficient and affordable method for cleaning solar panels and is the one used as a specially-built automatic cleaning system. It will eliminate dust-related inconsistencies in a solar panel's power output. According to experimental research, routine cleaning can boost the average solar panel's power by up to 20.5% [14].

Paradkar et al. discussed that the maintenance issue is still not being addressed precisely and the effectiveness of solar PV panels is significantly reduced due to poor cleaning of the panels [15]. To meet the needs of the household sector, an automation and control device is designed in this study. The primary benefit of this equipment is that it makes sure to clean PV panels three times during each pass. The solar PV panels' electricity is used by the device to run it [16]. Maindad et al. have created a GSM-based cleaning solution for solar panels for 2020. For real-time operation, a module and linear actuators are employed to move the brush. For rotating the brush, the gear motors are linked with the brush. A pump is then utilized to lift the water from the ground to the solar panel's top surface [17].

However, each of the cleaning techniques discussed above has a specific set of restrictions that prevent it from being used in the domestic sector. In this study, an inexpensive automated cleaning system is designed to use in the domestic sector as well as industrial sector.

3 Methodology

The proposed solar panel cleaning system uses two directional cleaning techniques. The conceptual design of the cleaning system was initially idealized, followed by the commencement of the Computer-Aided Design (CAD) modeling process using software such as Creo and SolidWorks. The standard dimensions of the components were carefully correlated to ensure accurate representation. The design process involved creating individual components and subsequently assembling them into the final system.

The body of the aspect is mostly composed of mild steel, which guarantees a good strength-to-weight ratio and offers resilience to all types of weather. Wheel pairs are attached to the outside frame using nutbolts, which causes them to roll along the edges of the panels. Similar to the outer frame, the inner frame consists of two cleaning rollers on either side.

3.1 Material Selection and 3D Models of Major Components

The design of the system involved the selection of the following materials:

- Frame-Mild Steel
- Pulleys-Aluminum alloys
- Wheels-Plastic
- Cleaner roller-fiber.

The detailed component configuration of the solar panel cleaning system constructed using 3D model is shown in Fig. 1a–j which highlights its inherent modularity and seamless interaction with existing solar arrays. A solar panel is to be cleaned is shown in Fig. 1a. The other details parts of cleaning mechanism system are shown in subsequent figures. The assembly of cleaning system is supported on the frame as shown in Fig. 1b. A stepper motor and DC motor are used for driving motion for the cleaning mechanism are shown in Fig. 1c, d respectively. Step pulleys of different types such as two step, three step, and one step are shown in Fig. 1e, f, and g respectively. The rest of the elements are wheel, rubber belt, and cleaning roller are shown in Fig. 1h–j respectively which are useful for innovative functioning of the system. The prominent elements of cleaning system play a crucial part in carrying out a thorough and precise cleaning process facilitated by the integration of DC and stepper motors ensured as there is no waste and maximum coverage. The addition of rubber belts and 1–2–3 step pulleys boosts the delivery system's dependability and effectiveness by enabling regulated movement and synchronized operation.

3.2 Working Principle of Solar Panel

The solar cleaning assembly was mounted on the solar panel for cleaning process with appropriate number of fasteners. Then cleaning system can be initiated by setting parameters such as cleaning time, frequency, roller speed as per the requirements and size of solar panels. These parameters can be varied depending on the cleaning frequency of panels and amount of layer of dust accumulated on solar panel surface. A belt and pulley mechanism with a DC motor activates and cleaning rollers reciprocate up and down on the solar panel when switching on the power. The dirt and dust layers are effectively cleaned by wiping action of reciprocation rollers on solar panel surface. The synchronized horizontal and vertical motion of rollers ensures a very clean and

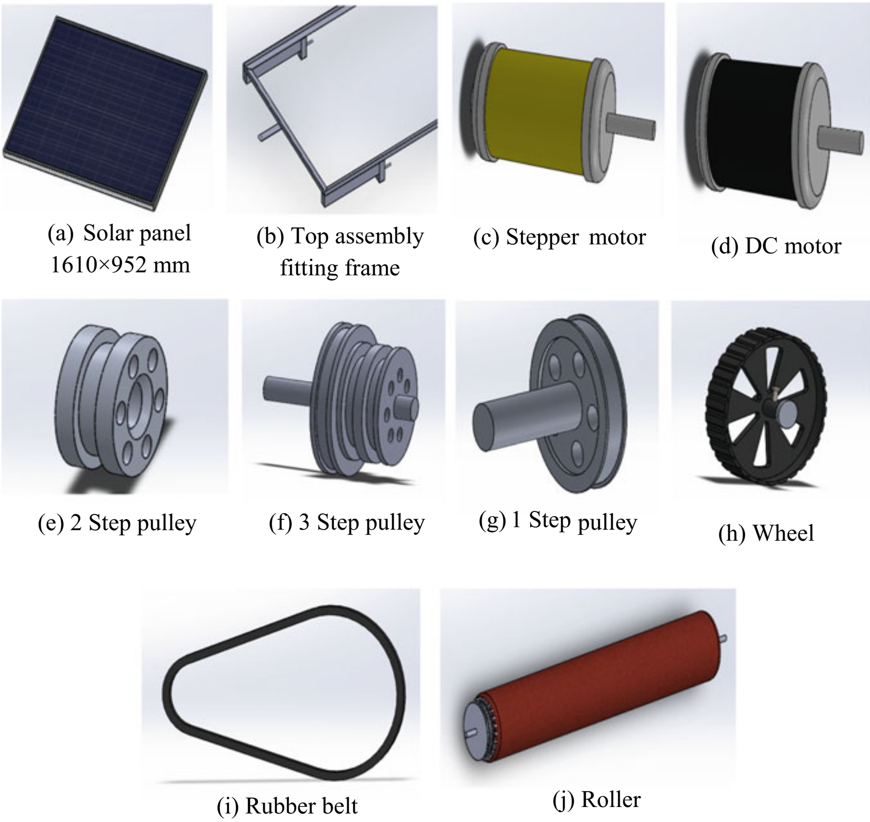

Fig. 1 Three dimensional models of major components of solar panel

dust free surface of solar panels. The horizontal movement of cleaning roller head is due to stepper motor which ensures a thoroughly clean surface of panels along the length.

In the proposed system, a pair of pulleys are positioned on shafts, parallel and linked by a spinning flexible belt to transmit and adjust rotational movement from one shaft to the other. The belt drives transfer motion from one rotating pulley to the next, which are both supported by a shaft. Shafts and pulleys are manufactured by steel bars and cast aluminum respectively. Pulleys are most often made of lightweight material such as cast aluminum alloy. Figure 2a, b shows the arrangement of pulleys, belts, and rollers used in the system.

The main objective of mechanism design and selection of components fulfilled two parameters such as inexpensive and user friendly to operate during cleaning process. The functioning of cleaning mechanism is very smooth and portable for handling due to its being easily disassembled after use.

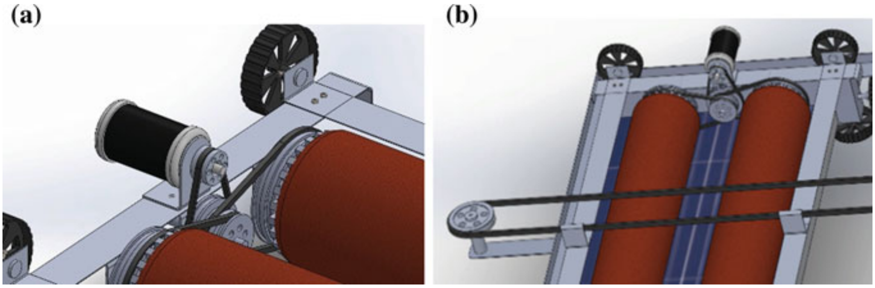

Fig. 2 **a** Pulley and belts used for rollers. **b** Pulley and belts used for top assembly displacement

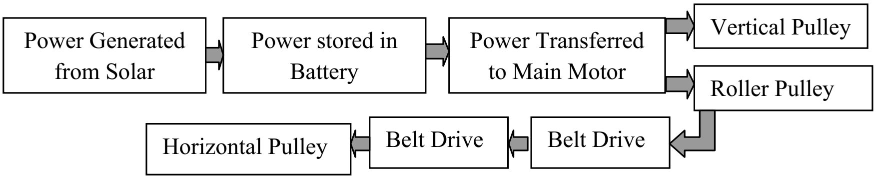

Fig. 3 Flow chart of power and motion transfer

3.3 Power and Motion Transfer

The power and motion transfer sequence begins with the generation of power from solar energy as shown in Fig. 3, which is harnessed and stored in a battery. When the need arises, the stored power is transferred to the main motor, initiating the movement. To transfer the motion vertically, a pulley system is employed, with the vertical pulley receiving power from the main motor and transferring it to the main pulley. The motion is then further conveyed horizontally using another set of pulleys. The vertical pulley drives a belt, which in turn drives the rollers, facilitating the desired horizontal motion. This intricate system of power and motion transfer ensures the efficient utilization of solar energy and enables smooth and controlled movement in the desired direction.

4 Results and Discussion

4.1 Dust Effect on Solar PV Panel Performance

The performance of a photovoltaic (PV) cell is often effective; this is the ratio of the cell's electrical output to the incident solar radiation falling on the cell. The performance of a photovoltaic cell depends on many variables such as reflection, protective layer, absorption, and type of ARC material. Photovoltaic panels perform better in places with strong electricity and low temperatures. Due to dust, photovoltaic semiconductors cannot receive light from the sun for two reasons: first, dust reflects and absorbs solar radiation, causing turbidity; second, the dust pollutes the solar panel.

4.2 Productivity Improvement

Economics plays a crucial role in designing and installing PV systems. Factors like cost, maintenance, lifespan, and cleaning are carefully considered. Manual cleaning is affordable but impractical for remote areas due to transportation costs and time constraints. Automated systems are more preferable as they require less human intervention. These systems operate on solar power, are cost-effective, easy to use, and use rollers to clean panels thoroughly. Users can set specific cleaning times, reducing dependence on labor. The roller brush moves up, down, and rotates for effective cleaning.

Consider a 150m^2 commercial solar plant consisting of 96 solar cells. The conventional manual cleaning method requires maintenance six times a year, totaling a cost of Rs. 16,000. Each cleaning session involves 6 laborers and takes around 8 h to complete, ensuring thorough cleaning. On the other hand, a semi-automatic cleaning system can be implemented for the same plant. This system reduces the cleaning time to 2 h per session. The initial investment for installing this system is Rs. 12,000, and it requires maintenance once a year, which costs Rs. 2000.

By adopting the semi-automatic cleaning system, the plant can save time and labor costs associated with manual cleaning. The initial investment for the system pays off in terms of increased efficiency and reduced labor requirements. Additionally, the system's annual maintenance cost is relatively lower compared to the total expense of manual cleaning.

4.3 Human Ignorance on Solar Panel Cleaning

Many people underestimate the significance of regular maintenance and cleaning when it comes to solar panel systems, which can have serious consequences on their efficiency and lifespan. Neglecting the cleaning needs of solar panels can lead to the accumulation of dirt, dust, debris, and even bird droppings, causing a barrier that obstructs sunlight absorption and reduces energy production. Lack of awareness about proper cleaning techniques and schedules often results in negligence, negatively impacting the return on investment for solar installations. Unintentionally hindering the potential of this sustainable energy source, individuals limit its capacity to contribute to a greener future. Therefore, it is crucial for people to educate themselves and take proactive measures to ensure the cleanliness and efficiency of their solar panel systems.

4.4 Improvements in This System

In the proposed system, a rechargeable battery is used, and the battery is immediately recharged by the solar panel, thus no additional power source is needed. The cost and power consumption of this system are lower than those of other systems since it is composed of lightweight, durable materials. Also, the cleaning system is semi-automated and cost-efficient. The frame used in the assembly is extensible so that it can mount the frame on various sizes of solar panels up to a certain limit. With the help of our cleaning system, can achieve up to 50% improvement in efficiency, which results in the enhancement of the overall performance of the plant.

4.5 Key Features

The complex structure of the solar panel cleaning system is illustrated in Fig. 4, which emphasizes the interaction of parts such as stepper motors, DC motors, 1–2–3 step pulleys, rubber belts, and cleaning rollers. This comprehensive representation highlights the system's capacity to handle the difficulties of effective and precise solar panel cleaning, which is necessary for maintaining optimal energy generation. The illustration clearly illustrates how mechanical and electronic components work together, demonstrating a paradigm leap in solar panel maintenance technology.

Salient Features of Solar Panel Cleaning System are Listed as Following:

- Rechargeable battery—uses panels own solar energy
- The extensible frame—it can accommodate on any size of solar panels
- Waterless functioning
- Cleaning—flexible for cleaning frequency
- Bi-directional
- Remote controlled functions
- It is cost-effective and reliable

5 Conclusion

- In this work, solar panel cleaning system design is inexpensive and environmentally friendly as there is no need for water requirement for cleaning purposes.
- It is well suitable for remote places where water source is not available for panel cleaning.
- It is a two-dimensional cleaning mechanism and can be extended to any size of solar panels.

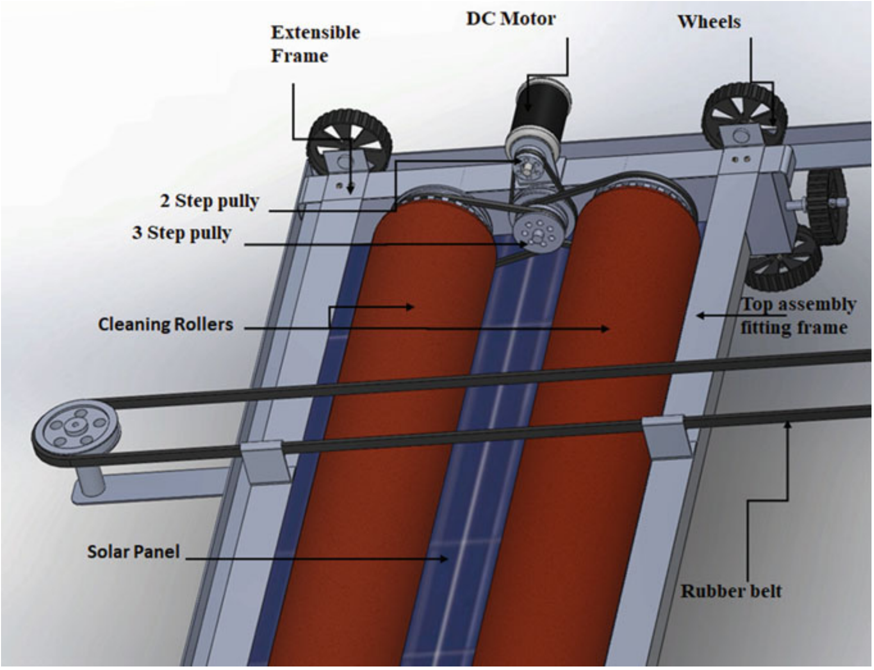

Fig. 4 Solar panel cleaning system

- The presence of dust on solar modules significantly reduces their efficiency, resulting in a decrease from a maximum of approximately 18.5% to a minimum of 5.5% without dust. However, with the accumulation of dust, the efficiency further decreases to a maximum of approximately 5.5% and a minimum of 1.5%.
- In specific instances, the presence of dust can cause a significant 70% reduction in electricity production. The maximum power output of a single solar panel is typically 1KW, but due to dust buildup, it can be diminished to 300W. However, after cleaning, the power production can increase from 600 to 800W.
- It is essential to have an auto-cleaning system to remove dust particles from the panel's surface since the electrical parameter of a solar panel is sensitive to dust density.
- The estimated cost for the system is approximately ₹12,000.00. Each solar panel can potentially realize annual expense reductions ranging from ₹10,000 to ₹15,000. The research highlights the impact of different contaminants on solar panel efficiency and the effectiveness of cleaning devices in addressing these issues. Furthermore, the cleaning method can help identify potential future problems.

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Performance of Solar Photovoltaic System Under Partial Shading Conditions Using an Improved Cuckoo Search Algorithm

Arati Kane and Manish Talwar

1 Introduction

Renewable energy sources have gained importance due to environmental issues such as global warming, degradation of Mother Nature, depletion of energy sources and shortage of energy. Technological improvement in electronics area caused the rapid increase in use of renewable energy sources as an alternative to traditional source of energy. Solar energy is the abundantly available resource of renewable energy which has a large scope of research. Solar cells convert incident radiant energy of sun into electrical energy based on the principle of photovoltaic effect [1]. The PV technology gives no emission of greenhouse gases while producing electric energy. Also, PV technology involves no moving parts which reduces the service and operating charges of system. Although it is an environmentally safe and clean source of energy, it has some challenges in its widespread use for renewable energy generation technology such as low conversion efficiency, large space requirement and installation constraint in order to avoid shadowing effect. The non-uniform irradiation of PV panel is caused by various reasons such as cloud movement, leaves or shadowing of panel by surrounding trees or shadow of any other object which cause reduction in power generation and high loss of energy. Due to non-uniform irradiation of PV panel, the power-voltage graph gives many local MPPs and one global MPP. This global MPP indicates the maximum power of PV panel that is to be achieved by tracking. In real time tracking of PV power, this global MPP tracking is difficult. The conventional algorithms like perturb and observe (P&O), hill climbing and incremental conduction (INC) are efficient for uniformly shaded PV panel. In case of partially shaded panel, these algorithms may get stuck at local MPPs and fail to achieve global MPP which defeats the purpose of their application [2–5].

A. Kane (✉) · M. Talwar
Bharati Vidyapeeth's College of Engineering, New Delhi, India
e-mail: arati.kane@bharatividyapeeth.edu

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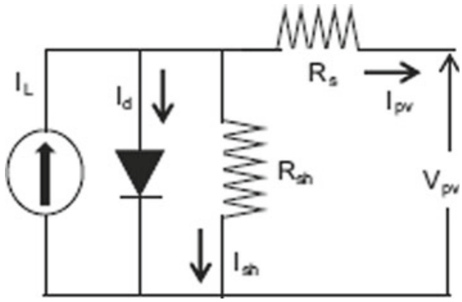


Fig. 1 Electrical representation of single solar cell

To address this problem, computational intelligence approach is used for designing MPPT algorithms. These algorithms are based on concepts like particle swarm optimization (PSO), genetic algorithm (GA), artificial neural network (ANN), artificial bee colony and cuckoo search (CS) [6–10]. Though these approaches work more efficiently than traditional algorithms and track the global MPP, these algorithms are time-consuming as they involve more computation [11, 12]. Therefore, enhanced Cuckoo Search algorithm is suggested in this paper where the varying step size is implemented for quick search of MPP.

1.1 PV Cell Modelling and PV Array Configuration

PV panel consists of PV arrays that are made up of solar cells connected in serial-parallel combination to get the required voltage and current. Thus solar cells are the basic unit of PV panel. Ideally, solar cell doesn't involve resistances but when applied for power generation, the series and parallel resistance come into picture as depicted in Fig. 1. R_s is series resistance which is formed by the bulk resistance of semiconductor material and connection wires whereas the leakage current is represented as parallel resistance. Power generated by solar cell depends on the series resistance hence series resistance is always included in solar cell output power calculations whereas shunt resistance has very less effect on output power and can be neglected for power calculations.

1.2 Mathematical Modelling of PV Cell

Electrical behaviour of solar cell is shown by applying the energy conversation concept. Solar cell excited by energy source can be represented as a diode and diode current is given as [14, 15]

$$I_d = I_0\left\{\exp\left(\frac{qv_d}{nkT}\right) - 1\right\} \tag{1}$$

where

I_d—Diode current

I_0—Diode reverse saturation current

V_d—Diode voltage

K—Boltzmann's constant (1.38×10^{-23} J/K)

n—Ideality factor of diode (lies in the range of 1–2).

Under solar radiation, output current in the circuit is given by the following equation

$$I_{pv} = I_L - I_d \quad (2)$$

where I_L is photocurrent generated by incident solar irradiation which is given by

$$I_L = G[I_{sc}\{1 + a * (T - T_{ref})\}] \quad (3)$$

where

G—Solar irradiance (KW/m^2)

I_s—Short circuit current of the Solar cell which depends on solar irradiance

A—Short circuit current temperature coefficient (%/C).

The standard expression of solar cell is as follows

$$I_{pv} = I_L - I_0\left\{\exp\left(\frac{q(v + IR_s}{nkT}\right) - 1\right\} - \frac{v + IR_s}{R_{sh}} \quad (4)$$

R_s—Series resistance

R_{sh}—Shunt resistance

T—Absolute temperature

q—Electric charge (1.69×10^{-19} °C).

Parallel resistance R_{sh} has no effect on the efficiency of PV cell. It is taken as infinity which gives almost zero current flowing through it. Hence R_{sh} is neglected in modelling of PV cell.

A commercially available MAX60 solar cell is employed to build a PV array of 4 × 4 serially connected solar cells with 60W output power is considered in this work. The series configuration is depicted in Fig. 2. The specification sheet is given in Table 1.

In this paper, the system is proposed for extracting maximum power of PV panel. This system comprises of MPPT charge controller, battery and load coupled through the battery. MPPT controller along with boost converter is designed for operating PV

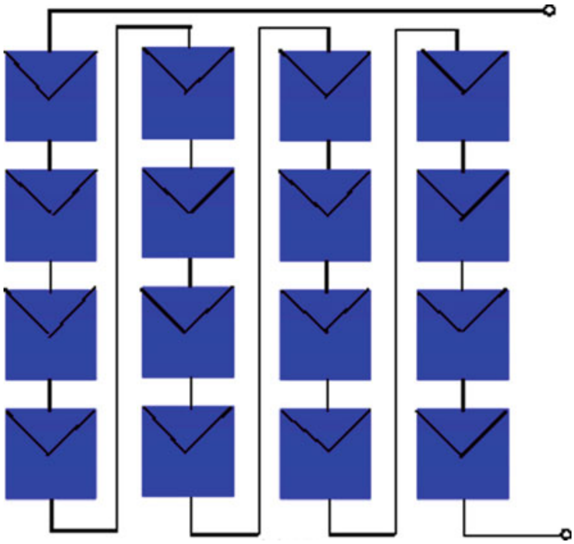


Fig. 2 4 × 4 PV cells series configuration

Table 1 MAX60 based Solar cell arrangement specification sheet

Electrical data	Nominal values
Open circuit voltage (V_{oc})	21.1 V
Short circuit current (I_{sc})	3.8 A
Peak power	59.5 ≅ 60 W
Rated voltage	17.1 V
Rated current	3.5 A
Solar cells	36

such that its maximum power is extracted at every point. Figure 3 shows proposed system for extracting maximum solar power.

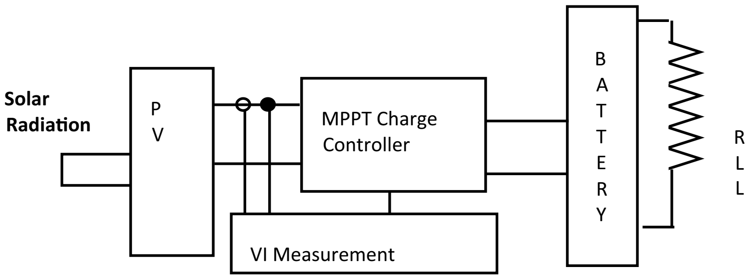


Fig. 3 Proposed system for extracting maximum power of partially shaded solar panel

2 Mathematical Modelling of Proposed System

PV array will operate at its open circuit voltage as long as no load is connected to PV array. As the circuit is closed by connecting the load to PV array, its output voltage changes to some other value depending upon the impedance of load. This voltage is also subject to change as per temperature and incident radiation conditions. The building blocks of MPPT controller, boost converter and load are shown in Fig. 3. MPPT controller operates on Cuckoo Search algorithm to compute the MPP.

Cuckoo Search (CS) algorithm is a bio-inspired computation algorithm extensively used in optimization techniques. Cuckoo search algorithm was presented by Xin-She Yang and Suash Deb in 2009. It has been noticed that in some Cuckoo bird species, nest stealing behaviour is observed in which the obligate brood parasites steal the nest of host by placing their eggs in the host bird's nest. If the host bird finds the parasite bird's eggs, it discards them or builds new nets. The eggs of these cuckoo birds are evolved in such a way that they look similar in colour and pattern to the host bird eggs which reduces the chances of identification of these parasite eggs from host eggs. Cuckoo bird behaviour is implemented in optimization techniques for finding best solution to given problem.

A large no of algorithms are implemented for tracking PV MPPT. In this work, a Cuckoo Search algorithm plus additional factor of varying step size is applied to track the MPP quickly [14, 15].

Generally, cuckoo's search for host bird's appropriate nest is comparable to the search for food, which generally happens in an arbitrary or semi-arbitrary way. A Cuckoo Search algorithm is based on three standardized conventions [16–18]:

1. A cuckoo bird lays one egg at a time and puts its egg in an arbitrarily selected nest;
2. The subsequent generations will have the best nests with high-quality eggs;
3. The host nests offered are predefined as well and the probability that cuckoo's egg is revealed lies between 0 and 1.

In some cases, the host bird may discard the cuckoo's egg, quit the nest and build a fresh nest. Furthermore, Yang and Deb observed the improvement by adopting arbitrary step size search by Lévy flights over simple random walk search. Lévy flight random walk style is based on Lévy distribution in which step length is determined by heavy tailed probability distribution.

The following approaches can be designed on the basis of the above three rules.

$$x_i^{(t+1)} = x_i^t + \propto \oplus \text{Levy}(\lambda) \quad (5)$$

where x_i^t is related to sample and its index, and t is the iteration count. The product $\oplus$ shows admission based multiplication,

$$\alpha = \alpha_0\left(x_{cgb} - x_i^{t-1}\right) \quad (6)$$

A basic structure of levy distribution is presented as

$$\text{Levy}(\lambda) \approx \frac{\mu}{(|\gamma|)^{\frac{1}{\beta}}} \tag{7}$$

Here $\beta = 1.5$, $\propto_0$ represents levy multiplication coefficient (selected as per requirement), while u and v are calculated from the normal distribution curves, as

$$u \approx N\left(0, \sigma_u^2\right) \tag{8}$$

$$v \approx N\left(0, \sigma_v^2\right) \tag{9}$$

Now Γ denotes integral gamma function thereafter the Eqs. 10–11 are used to define the variables $\sigma\ u$ and σv

$$\sigma_u = \left[\frac{\mathcal{T}(1+\beta) \times \sin(\pi \times \beta/2)}{\mathcal{T}\left(\frac{(1+\beta)}{2}\right) \times \beta \times (2)^{\left(\frac{(\beta-1)}{2}\right)}}\right]^{1/\beta} \tag{10}$$

$$\sigma_v = 1 \tag{11}$$

Lévy distribution contains combination of steps including many small, rarely large steps and long jumps to search for the best solution. It searches MPP point on PV curve with the help of variation in searching steps to converge rapidly.

3 Simulation Results

A stand-alone PV system with 800W rating composed of solar cells connected in series is employed for simulation purpose. This system is developed for achieving maximum power of PV panel using MPPT controller, boost converter and resistive load as depicted in Fig. 4. The developed system is exposed to various shading patterns for testing its performance under various shading conditions.

The developed simulation model for PV system using MATLAB/Simulink software is given in Fig. 4. The developed model is tested for various shading conditions.

The shading conditions are shown in Fig. 5. In case:1, third and fourth row of PV panel is exposed to solar radiation of 800 W/m^2 and 600 W/m^2 respectively whereas in case:2 s, third and fourth row of PV panel are exposed to partial shading conditions as 800 W/m^2, 600 W/m^2 and 400 W/m^2 respectively.

Figure 6 presents current versus voltage characteristics when PV panel is partially shaded. Here two partial shading conditions are considered for simulation purpose. It is clear that when PV panel is shaded then I-V curves show multiple knee shape points.

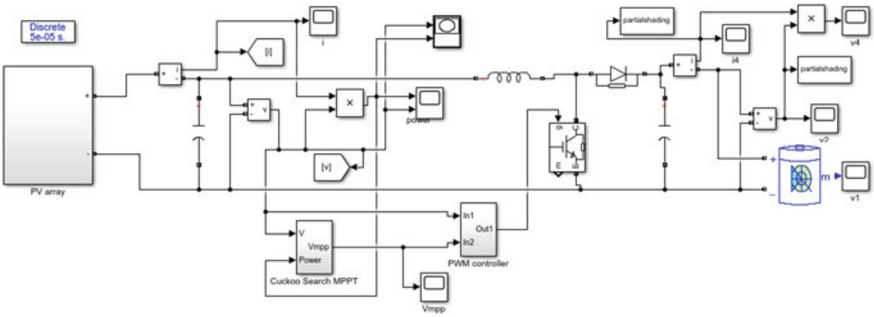
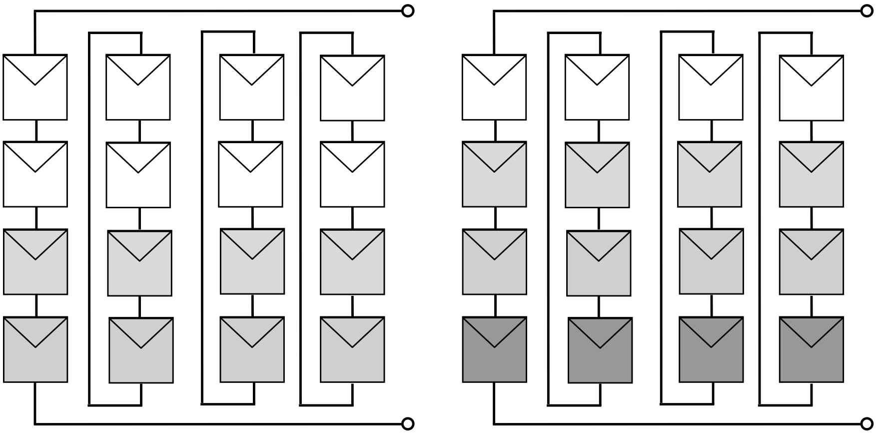


Fig. 4 The developed MPPT controller and PV system to simulate the PV system



(a) Case:1 (1000W/m^2, 1000W/m^2, 800W/m^2 and 600W/m^2)

(b) Case:2 (1000W/m^2, 800W/m^2 and 600W/$m^{2,}$ 400W/m^2)

Fig. 5 Shading patterns of PV panel

Figure 7 shows power and voltage characteristics for these two shading conditions. The P–V characteristic is non-linear in nature with multiple peaks containing many local MPPs and one global MPP. It is clear from Fig. 7 that 660W and 480W are extracted from partially shaded PV panel for given solar irradiation.

Figure 8 shows the power curve plotted to study the performance of designed MPP technique for considered shading conditions. It is clear from these plots that the global maximum peak power of 660 and 480 W for two partial shading conditions is tracked by proposed system.

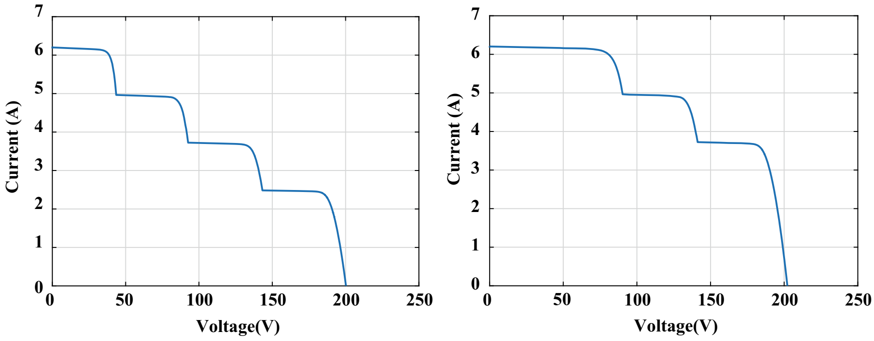


Fig. 6 V-I curve of partially shaded PV panel with considered solar irradiation

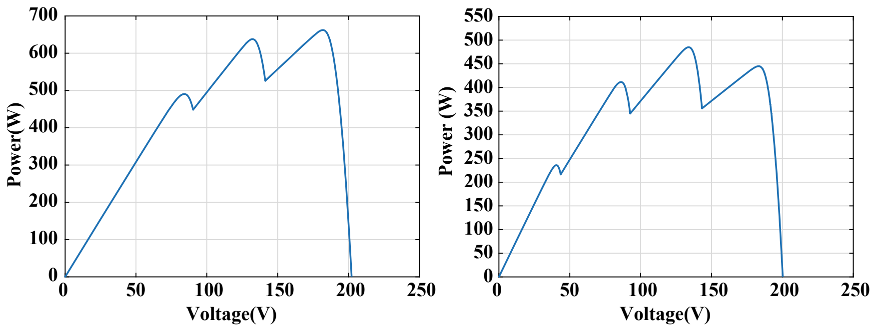


Fig. 7 P–V curve of partially shaded PV panel with considered solar

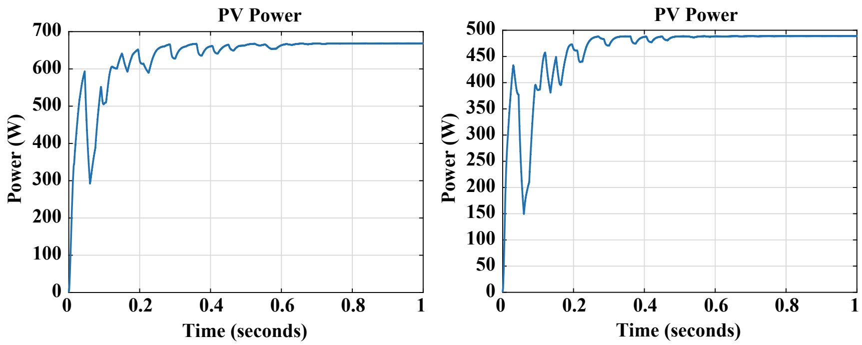


Fig. 8 Tracking of MPP by developed Improved Cuckoo Search Algorithm for two shading scenario

4 Conclusion

In this study, an improved cuckoo search algorithm is applied to operate PV system at its MPP in order to extract its maximum power. Here two scenarios of partially shaded solar panel are considered for verifying the performance of PV model. For tracking MPP, the operating voltage of PV panel is scanned in between two loading conditions. The achieved maximum power and maximum voltage points are matched with recorded maximum power and voltage points. The developed simulated system gives result which confirms the efficient tracking of maximum power point using developed improved cuckoo search algorithm for all considered shading patterns.

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Design and Development of Manual Strip Twister Machine

Girish Lonare, Sandhya Jadhav, Rishikesh Tungar, Mukul Rathod, Deelip Radkar, and Govind Jagatap

1 Introduction

Twisting is a technique for plastically deforming material and reshaping it to distort metal. The material is under stress below the ultimate tensile strength but above the yield strength. Twisting is usually referring to deformation about one axis [1].

According to the study, we have found one problem which all the small-scale industrialists face in their sliding grill-making workshops that is the twisting of strips and bars used in sliding grills. Either the manufacturer has to buy the twisted component from outside or fabricate it in the workshop, but to do such, there is no such machine available on the market at an affordable price. So basically, this invention seeks to carry out the design of the twisting machine for sliding grills which works on simple machine principles and should be cost-effective. The twisting of the metal bar and the strip has great importance in the manufacture of sliding grills. To fulfill the need, arising from the industry, we have designed the Twister machine, which can work without electricity and with less human effort. Twisting of strip and bar with a Twister machine will help to generate the number of strips and bar being twisted and ultimately increases the efficiency and production. In our design, both ends of the bar or strip are fixed, and with the help of the handle, we can twist the bar with low torque and get output as shown in Fig. 1. It reduces human effort, and also it requires the less skilled worker to operate this machine [2].

G. Lonare · S. Jadhav · R. Tungar · M. Rathod · D. Radkar · G. Jagatap (✉)
Department of Mechanical Engineering, Bharati Vidyapeeth College of Engineering, Sector 7, CBD Belapur, Navi Mumbai, Maharashtra 400614, India
e-mail: govind.jagtap@gmail.com

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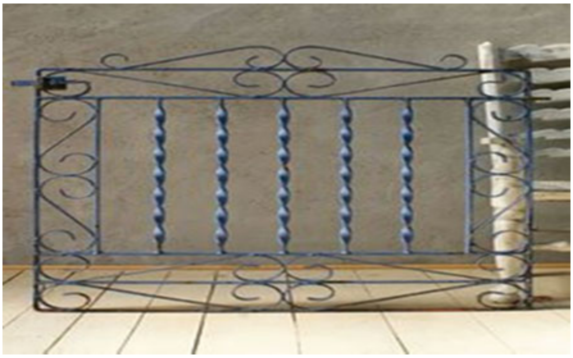


Fig. 1 Twisted bars

2 Review of Existing Systems

2.1 Literature Review

Research was conducted to ensure that the project accomplishes its goals before moving forward with it. This literature evaluation included observation, research into potential processes and their compatibility, as well as formulas and calculations that we carried out with the aid of the survey of the literature.

Some of the machines are available in market but they are not that much cost-effective as well as they need electricity to do the work one of them is shown in Fig. 2. Nargesa Stainless Steel Iron Bar Twisting Machine MT150A, 0.5 HP, Capacity: 20 mm ₹8.68 Lakh (*Product Brochure*).

But to design and develop cost-effective and hand operated machine, we got help from some of the research papers and some of them are listed below.

Fig. 2 Electric bar twister machine

Ghinmine [3] explains the design and fabrication of bending with twisting and cutting machines. The mechanism fabricated by them is also used in workshop for twisting metal strips with electric motor and some die sets.

Sutar et al. [4] explains the design and development of automatic pipe bending machine. It is used for automobile and industrial purposes. It reduces human efforts and also requires less skilled workers. This article helps us to get basic mechanism for twister machine with less complicated parts and assembly.

Bhandari [5] from his book "Design of machine elements," we get an idea about how to design shaft and bearings for particular loads and torques.

2.2 Background of Invention

The components made of metal strips and bars are used for fabrication of sliding grills. In sliding grill industries and workshops, it is necessary to form components (Twisted, bended, and rolled) which are aesthetically pleasant as well as rigid enough to provide safety for window and where it is used. But the components are firstly manufactured in various industries and then supplied it to sliding grill makers which lowers the productivity by increasing its cost and time. Also, traditional method to form these components was hot forming which is not cost-effective, forming uneven components, and requires high effort.

However, existing machines are also available in market which can fulfill this requirement or can overcome this problem by using cold-forming method but thinking according to cost perspective, it is not feasible. Also, these machines require electricity to do their work and cannot be applicable in rural areas where shortage of electricity [6].

By taking this problem into account, we decided to design and manufacture Twister machine which will produce even outputs with less cost, efforts, and time with secured operation.

3 Methodology

3.1 Establishment of Design Concept

The Indian market lacks a cost-effective and efficient manual twister machine that can reach small-scale industrialists. Most Indian workshops use non-technical machines to turn the bars and strips. They also use hot forming methods that are more expensive and take longer to complete. The cold-forming process used in the proposed system can twist the bar and strip metal without affecting its properties [7].

With the help of this project, it will be possible to include a significant continuous force into the machine that will run the full length of the metallic strip being twisted.

All the spiral portions end up being the same length and strength. The specifications and requirements were met when the machine was developed. Existing machines can also be found on the market that can meet this need or can solve this problem using cold forming, but this is not feasible due to cost. Also, these machines require electricity and are not applicable in rural areas where there is a shortage.

3.2 Calculations

Design of twisting machine—From the literature study [8], it was found that the maximum dimensions of strip used by the Sliding grill makers are 30 mm (width) × 5 mm (thick).

Now, the torque required to twist the plate,

For M. S

$\tau = 126$ n/mm^2

$\tau/r = T/J = G$ theta/L ....(formula)

Assume $L = 300$ mm, $b = 30$ mm, $t = 5$ mm

$J = bt\ (b^2 + t^2)/12$ .... (Design data book)

$J = 11{,}562.5$ mm^4

Now, $\tau/r = T/J$ 126/15 = T/11562.5 $T = 97.12$ Nm near about 100 N m

Design According to torque

Calculated shaft diameter = 35 mm

Calculated bearing size = 6007 Ball bearing.

3.3 Development of Device Prototype

The elements comprising our mechanism are depicted in this section.

Shaft This is the main component of whole assembly which holds the strip/bar in its jaws with the help of bolts and manually applied torque gets transmitted through this to the workpiece. It is the stepped shaft made up of mild steel as shown in Fig. 3.

Handle Handle is used to apply torque on shaft which will get transmitted to workpiece as shown in Fig. 4. Handle is attached at the end of the shaft and it is designed ergonomically to help workers to produce desired strip with less effort.

Frame Frame is a rigid member of whole assembly which supports all elements attached to it, we designed T-shaped frame as shown in Fig. 5.

Fig. 3 Shaft

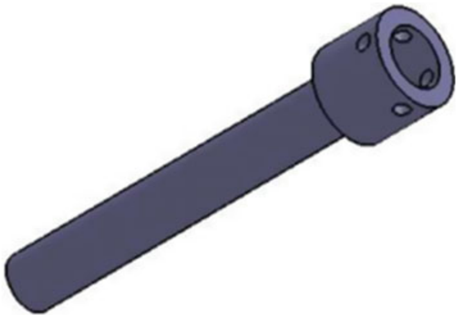


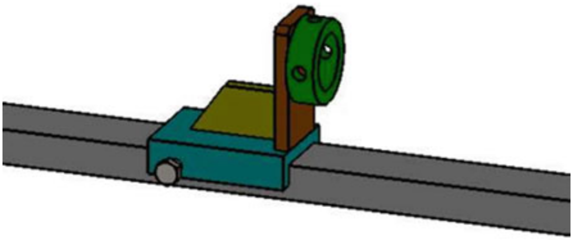
Fig. 4 Handle

Fig. 5 Frame

Bearings According to our calculations, 6007 bearing is best suited for this application. It supports the shaft at two ends which are fixed. 6007 bearing is shown in Fig. 6.

Fig. 6 6007 Bearing

Fig. 7 Holder assembly



Holder Assembly It is a fixed end of the assembly which holds the other end of workpiece in its jaws with bolts, as shown in Fig. 7. This assembly is free to slide over frame to achieve the required length of workpiece.

3.4 Assembly and Working of the Model

3.4.1 Assembly

The CAD model assembly of twister machine is shown in Fig. 8, and actual Assembly is shown in Fig. 9.

Fig. 8 Assembly

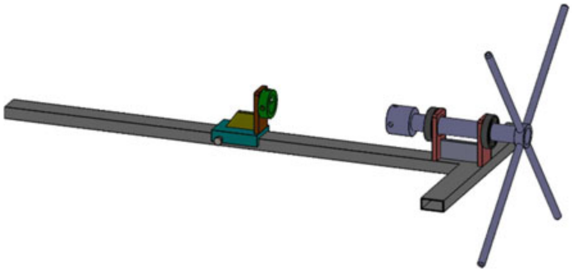


Fig. 9 Actual Assembly

3.4.2 Working

Twister machine for sliding grills with generally used in fabrication as an alternative method for the operation. This machine is manually operated which gives the constant result after the twisting operations. Twister machine is known for forming equipment by twisting motion of the working scroll to make the metal strip or bar produce the continuous metal deformation to obtain the desired shape of the strip or bar. It is widely used in metal structure designing, decorating, safety purposes, etc.

In this, the metal strip and bars were twisted either square or rectangular which one end of the strip is fixed and another end is free to rotate. This rotating end is mounted on the rotating shaft so the metal gets stressed over elastic limit and gets cold formed permanently. Motion which is required for the twisting operation is provided manually. This metal twisting gives the accurate twist to the strip which is mostly used in gallery's windows and for other purposes.

4 Result

4.1 Experimental Environments

The mechanism testing was carried out in real time rural area where lack of electricity was there even so that to twist the strip with less effort and time. The strip gets per meant set with accurate spiral. The testing was successfully carried out on actual assembly as shown in Fig. 9.

The machine was tested on various geometry of bars and strips as shown in Table 1 and got some outputs of twisted bar as shown in Fig. 10.

Table 1 Geometry with forces

Force	Strip thickness (mm)	Bar dimensions $h \times b$ (mm)
Light	5	8
Medium	10	9
High	12	10

Fig. 10 Final product

5 Conclusion

This project is a machine that by nature always creates a smooth, even spiral, with each section's length being the same as every other section. It also includes a way to prevent twists from forming next to the ends of the metallic rod so that the length of the twisted rod can be chosen beforehand. This project can offer mechanisms built into the machine to apply a force that is essentially continuous along the longitudinal length of the metallic strip being twisted during the whole twisting operation, resulting in the production of spiral sections that are all the same length. The device was created in accordance with specifications and needs. So, the objective of creating a "Metal Twisting Machine" is achieved successfully.

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Advancement of Cooling Methods in Laptops

Bhaskar Reddy Challapureddy, Mahesh Paleti, and Ravindra Jilte

1 Introduction

One of the most crucial considerations for consumers when buying an electronic device nowadays, such as a laptop, is a cooling system with great performance and minimal noise. In tasks that call for high performance, such as video processing and gaming laptops are employed. A CPU is only allowed to operate at temperatures under 70 °C. After that, for every 2 °C above the permitted operating temperature, chip reliability drops by 10%. A laptop that is overheated may have problems including sudden shutdowns, blue screens, hardware failures, and most importantly a shorter lifespan. Additionally, using consumer electronics on hands or laps for an extended period can cause skin damage if the skin temperature is higher than 45 °C. There is a wide range of experimentation going on thermal management devices, such as enhancing heat rejection with cooling pads, liquid cooling, and using Peltier cooling by providing external setup to laptops. It is true that adding external setup reduces portability, but these external cooling experiments have proven to be much effective especially based on liquid cooling and thermoelectric cooling.

2 Classification

The cooling systems for laptops are majorly classified into two types: Active cooling system and passive cooling system.

B. R. Challapureddy (✉) · M. Paleti · R. Jilte
Department of Mechanical Engineering, School of Mechanical Engineering, Lovely Professional University, Phagwara, Punjab 144402, India
e-mail: bhaskarcr02@gmail.com

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2.1 Air Cooled

Air cooling systems have emerged as a prevalent and efficacious thermal management solution for contemporary laptops, mitigating the risks of overheating and ensuring optimal performance under demanding workloads. These systems incorporate a sophisticated integration of heat sinks, fans, and strategically positioned ventilation pathways within the laptop's architecture.

The heat sinks act as proficient heat-absorbing elements, efficiently extracting excess thermal energy from the CPU and GPU. Synergistically, internal fans facilitate the dissipation of this heat, creating a well-regulated airflow that expels the heated air through precisely engineered ventilation ports. This continuous and well-coordinated process ensures that laptops maintain a controlled operating temperature, preserving the integrity of critical components and optimizing sustained performance during prolonged usage. The ingenuity of air-cooling systems lies in their capacity to safeguard laptops from overheating-induced damage while promoting sustained efficiency and reliability during extensive computing tasks.

Shamsul Kamal Ahmad Khalid [1] proposed a notable amount of temperature drop by multi-voltage fan controller using real-time processor for temperature readings. Xianguri Meng et al. [2] found that maximum cooling effect with natural air convention can be achieved by mounting the heat sink at 90°. Results show that even with the 6.88% lower than 90, it is 15 at which the lowest cooling effect is achieved. Heat-transfer stagnation zone is one of the key factors in natural air convention cooling.

2.2 Liquid Cooled

The integration of liquid cooling systems in laptops represents a groundbreaking advancement in thermal management, offering substantial benefits in terms of sustained performance and superior heat dissipation during resource-intensive computing tasks. Distinguished from conventional air-cooling methodologies, these systems deploy a sophisticated closed-loop architecture, comprising essential components such as a coolant, pump, heat exchanger, and a sleek vapor chamber seamlessly integrated into the laptop's design. The coolant, thoughtfully composed of a precise blend of water and specialized additives to optimize thermal conductivity and corrosion resistance, exhibits exemplary efficiency in absorbing heat emanating from the CPU and GPU.

Subsequently, the pump propels the heated coolant through the heat exchanger, where it undergoes a rapid and efficient release of accumulated thermal energy, leading to prompt cooling. Following this process, the now-cooled liquid returns to the vapor chamber, initiating an uninterrupted cycle of efficient heat transfer. This advanced approach ensures consistent and expedited heat dissipation, effectively safeguarding laptops from overheating while preserving the optimal operational temperature of crucial components. The remarkable advantages of laptops equipped with liquid cooling systems encompass not only markedly improved performance and extended operational longevity but also a notably quieter and refined user experience. As such, these systems have solidified their position as the preferred choice for discerning users seeking unparalleled thermal efficiency and optimal performance in their computing devices.

Liquid cooling system for reducing heat flux of laptop applied successfully for its high heat dissipation rate. Nicholas Pinenn [3] proposed liquid cooled air blower system provides better cooling than stock cooling system. The liquid cooling system works on the principle for constant flow of liquid and pool boiling majorly. Hsiao-Kang Ma [4] proposed piezoelectric micropump (OAPCP-micropump) with fins, the OAPCP-micropump with its 4.4 m/s flowrate increases quite an amount of heat dissipation.

2.3 Thermoelectric Coolers

Thermoelectric coolers (TECs) have emerged as a compelling and innovative thermal management solution for laptops, presenting distinctive advantages over traditional cooling methodologies. Operating on the principle of the Peltier effect, TECs leverage the phenomenon of heat absorption and transfer through junctions of dissimilar materials upon the application of an electric current. Seamlessly integrated into the laptop's heat sink assembly, these compact and energy-efficient devices augment the cooling capacity of laptops. By actively removing heat from hot components and redirecting it to cooler regions, TECs effectively maintain lower operating temperatures, crucial for optimizing system performance and reliability.

One of the key merits of TECs lies in their ability to provide precise and localized cooling, empowering focused targeting of specific hotspots on the laptop's motherboard. This feature is particularly advantageous in mitigating thermal bottlenecks and reducing the risk of critical component failures. Moreover, the dynamic control mechanism inherent to TECs allows for adaptive cooling, enabling their operational parameters to be adjusted based on real-time thermal demands. This dynamic regulation results in improved energy efficiency compared to conventional cooling systems, contributing to the laptop's overall power efficiency and extending battery life during prolonged usage.

However, successful implementation of TECs in laptop thermal management requires careful consideration of potential challenges. Proper insulation and thermal management strategies must be employed to prevent condensation formation and mitigate the risk of electrical issues. Furthermore, the integration of TECs should be undertaken with meticulous engineering to ensure optimal heat dissipation and system compatibility.

As a novel approach to laptop thermal management, TECs hold significant promise for addressing heat dissipation challenges, enhancing system performance, and ensuring a reliable computing experience. The ongoing advancements in TEC technology are expected to further refine these devices, consolidating their position as a viable and effective solution for achieving efficient cooling in laptops. Continued research and development efforts in this domain are likely to yield increasingly sophisticated TEC implementations, contributing to the advancement of laptop thermal management techniques and broader applications in electronic devices.

Benefits of Thermoelectric Coolers for Laptop Cooling:

1. Smaller Size: TECs are well-suited for incorporation inside laptops without adding a lot of bulk because of their solid-state construction and tiny size.
2. No Moving Components: Since TECs are solid-state devices without moving components, they operate quietly and without vibration.
3. Accurate Temperature management: TECs provide accurate temperature management, enabling laptops to keep vital components at constant temperatures, improving performance and dependability.
4. Effective Cooling: TECs can swiftly cool down and adapt to variations in the ambient temperature.

Difficulties with Thermoelectric Coolers for Laptops:

1. Power Consumption: TECs need electricity to run, and the electrical current delivered has a significant impact on how well they cool. This may reduce the overall battery life of a laptop.
2. Heat Dissipation: Although TECs may cool the parts that come into direct touch with the cold side, they require efficient heat dissipation on the hot side to keep the hot side operating at its best. Ineffective management may result in localized heating.
3. Limited Cooling Capacity: TECs may be unable to handle heat loads that are exceedingly high, which can be problematic in high-performance laptops with really potent components.
4. Cost: When compared to more conventional cooling methods like heat pipes and fans, TECs can be more expensive. The added cost of TECs may affect the laptop's total price and reduce its affordability.

The major disadvantage of TECs is their lower efficiency. TECs have very poor cooling efficiency. According to research findings, the TEC1-127 series has a cooling efficiency of 0.5% [5]. A lightweight and compact design is made possible with the aid of TECs. However, heatsinks and fans need to be added since we must dissipate heat produced by other side of TECs. The device's weight is increased as an effect. TECs consume a lot of electricity as a result of their lower efficiency [5–8]. Using a USB supply will not be enough for this power needs.

The normal active coolers used in laptops circulate the air to take down temperatures. This will work but not in an effective way. The solution for this problem is circulating cooled air using thermoelectric cooler modules or we can say Peltier cooling [5, 6]. There are two ceramic plates within the Peltier module. When a positive DC voltage is applied to an n-type semiconductor, electrons will transfer from p-type to n-type elements, reducing temperature on cold surfaces and increasing heat on hot surfaces [5]. The quantity of thermoelectric couplings and applied current affect how quickly heat is absorbed. We can use thermoelectric module in combination of fans or blowers with a cooling pad setup thereby passes cooled air into the laptop to optimize its temperatures. Also, we can add specifications like controlling mechanism using sensors and Artificial intelligence [5]. An investigation is conducted using the Thermoelectric cooler module of TEC1-12,706, which is used in a manner passing cold air that is cooled by a Peltier module and blown by a fan. The operated TECs are mapped on a GUI and the variation of the laptop's internal temperature is plotted on a graph [5].

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2.4 Loop Heat Pipes (LHP)

LHPs, a development of conventional heat pipes, are particularly excellent at managing larger heat loads and extended distances while maintaining the laptop's small size. Loop heat pipes (LHPs) are incredibly effective heat-transfer mechanisms. A LHP is made up of a condenser unit and an evaporator with fine-pored wick structures that are joined by separate liquid and vapor flow lines. In loop heat pipe heat is transferred through the latent heat of evaporation and condensation and circulates the working fluid around the loop using capillary pressure produced by the wick structure. Because of their high heat transmission capacity and adaptable design structures, mini versions of LHPs might be considered of as suitable convectional heat pipe substitutes for laptop cooling [9–11].

Benefits of Loop Heat Pipe Technology for Laptop Cooling:

1. Effective Heat Dissipation: Loop Heat Pipes are very effective in transferring heat away from the heat-generating components. They can manage heavy heat loads and disperse the thermal energy uniformly, reducing localized overheating.
2. Uniform Temperature Distribution: LHPs assist in preserving a more uniform temperature throughout the laptop's internal components, lowering the possibility of hotspots and thermal throttling, which can affect performance.
3. Miniature form: LHPs are appropriate for incorporation into laptops and other electronic devices with limited space because of their comparatively tiny form.
4. Noise Free Operation: Unlike conventional cooling methods that may rely on fans or pumps, LHPs function passively without any moving parts, delivering in quiet and upkeep-free cooling.

When CFD is designed with two evaporators, each measuring 47 × 37 mm, rectangular evaporator, which has 20 microchannels each measuring 0.7 mm deep and 0.5 mm broad, was fabricated on the interior of the active zone, which measures 22 × 22 mm. Both evaporators are positioned between the CPU, graphics card, and RAM, three components where most of the heat is produced. A 10 × 10 mm^2 copper foundation with 49 rectangular channels that have distinct depths, widths, spacings, and lengths of 1.3, 0.1, 0.1, and 7 mm was created for the Microchannels heat sink design.

2.5 Thermal Energy Storage (TES)

The thermal energy storage system involves usage of phase change materials (PCMs) to optimize temperature especially hydrated salts. Hydrated salts, paraffin waxes, and their eutectics are the most widely utilized PCMs. A PCM's phase shift (melting or freezing) causes energy to be absorbed or released at a constant temperature. This is how PCMs work, according to the latent heat theory. PCMs are used in electronics and laptops to regulate the heat produced by parts like the graphics processing unit (GPU) and central processor unit (CPU).

The CPU and GPU create a lot of heat while under stress. These heat-generating components are carefully put in contact with PCM pads or films. The PCM absorbs extra heat as the temperature rises, which causes it to transition from a solid to a liquid form. On the other hand, the temperature of the components drops as the burden on the laptop lowers or while it is idle. When the PCM solidifies, the heat energy is released back into the laptop. This procedure aids in preserving a constant and ideal temperature range, reducing overheating, improving performance, and extending the lifespan of the laptop.

Advantages of PCMs:

1. High Latent Heat Capacity: PCMs are ideal for laptops and other small electronic devices because of their high latent heat capacity, which allows them to store a lot of thermal energy in a small space.
2. Numerous PCMs used in electronics are non-toxic and ecologically benign, assuring user safety and lessening the influence on the environment.
3. No Energy Lost throughout Storage: PCMs absorb heat isothermally, which means that there is little or no energy lost as a result of temperature changes throughout the energy storage process.
4. Reliability and Durability: PCMs are robust and dependable as thermal energy storage solutions since they have a long life cycle and experience little to no deterioration over time.

The most common PCMs that have been found are hydrated salts. Due to their widespread application in latent heat storage systems, they have received substantial research. The benefits of hydrated salts include high latent heat of fusion per unit volume, minimal volume change during melting and freezing, and good thermal conductivity in comparison to paraffin waxes. Salts that have been hydrated are not very toxic or corrosive [12, 13].

In 2015, Mohammed A. Bou-Rabee et al.. Proposed a cooling technique using PCMs for laptop which is proven to decrease GPU's temperature by 6 °C. In 2011, Russell et al. produced a cooling pad for laptop computers utilizing PCM, a paraffin wax made by Shell and reported a more than four times improvement in the laptop's comfortable operation duration, which was increased to 5.5 h with 0.2 h to spare [13].

For an investigation, a laptop with a DELL Vostro dual core CPU was used. A 32 by 22 by 1 cm TES system for laptop cooling was built using 1 mm thick stainless-steel sheet. A combination of hydrated salts called PCM HS207, made in India by Green High-Tech Energy Limited, was put into the system [13].

3 Conclusion

Heat dissipation of laptops with various cooling mechanisms has been reviewed. Based on the reviewed papers, it reveals that research on the cooling mechanisms needs to be more focused. Reviewed cooling methods are much effective but there are limitations to use in laptops. Air cooling and liquid cooling are still preferred options for consumer laptops when affordability and reliability are important factors. More sophisticated alternatives, such as LHPs or PCMs, may be used for laptops with stringent performance requirements or specialized thermal difficulties. A few specialized applications where precise temperature control is crucial are where thermoelectric cooling finds its place. Most of cooling techniques discussed require external setup which makes portability a difficult task. With increase in compactness, intense applications and advancement in technology take place, and progress in development of cooling systems is required.

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Sustainable Growth of Automobile Industry in India

Surender Singh, Krishan Kumar, and Om Prakash Mishra

1 Introduction and Literature Support

The automotive industry is a major industrial and economic force all over the world. India is the 4th largest manufacturer of automotive vehicles in the world. In the fiscal year 2022, India's total vehicle production volume was about 22.9 million units, with growth from the previous year [1]. Globally, the growing usage of automobiles has led to serious environmental problems such as worsening air quality, ozone layer depletion and unfavorable climatic change [2]. Global increase in demand of automobile creates the pressure on the automotive manufacturing industry. To regulate these environmental problems, government issues and guidelines time to time, this guideline is not sufficient to control the issue, some initiatives are suggested by different researchers from time to time like green building, Eco design and green supply chain [3].

The need of environment regulation has already discussed, but the main question is how to implement it. The main issue in its implementation is the budget requirement, to meet requirements of machines, infrastructure, training, updating technology, etc. Though industries are aware of these environmental issues, due to the high cost associated with them are making the management back out. Original Equipment Manufacturer (OEM) at global levels implements these guidelines but associated industries face difficulties. Different authors have identified different enablers such as Use of Green Packaging Material, Latest Technology and Market Competition [4]. Zala et al.. identified 12 critical factors for improvement of industries and some industries were not interested as they were owned by family owners [5]. Different authors have done ranking of these enablers and barriers in order to their importance by different MADM techniques like TPOSIS, AHP, ANP, etc. The purpose of these

S. Singh (✉) · K. Kumar · O. P. Mishra
Department of Mechanical Engineering, J C Bose University of Science and Technology, YMCA, Faridabad 121006, India
e-mail: surendersngh056@gmail.com

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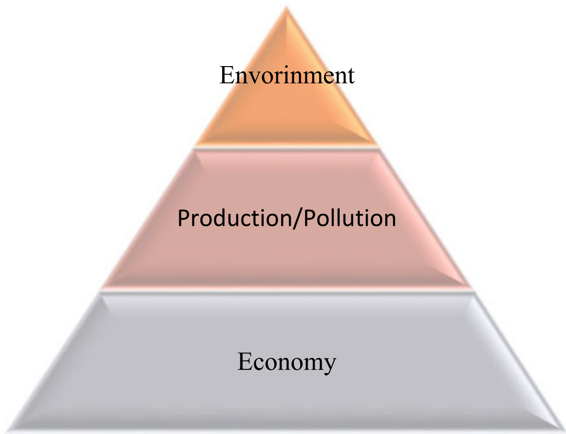
Fig. 1 System approach to sustainability



ranking is to focus on the most important factor which affects the environment most. This will reduce the financial burden as no need to focus on least important factors.

Fundamentally economy of any country depends on the production. These industries affect the environment where they are located. Therefore, economy, production, pollution and environment are interrelated. To make the automotive industries sustainable, balance of each of the factors mentioned is to be focused on. Figure 1 represents the system approach to sustainability.

The purpose of this paper is to recognize the latest initiatives in the field of GM in automobile industries. Green concept was coined in 1995 but the major works started after 2010. Green Initiatives are continuous processes in the green manufacturing to reduce pollutions and deteriorations. High volume of automobiles is due to the advancement of mass production system. This has harmed the environment at an alarming rate. Therefore, different green initiatives in the automotive manufacturing industries to safeguard the further deteriorations have made academicians to work together.

After several studies also, the green initiatives on actual ground are not clear. Therefore, there is a need to review the automobile producer's strategy in this regard.

2 Methodology

This study has reviewed the green initiatives in automobile industries. For this, several reputed Journals and secondary data have been investigated. Automobile giants of India have been reviewed for their green steps to make their manufacturing environmentally free.

3 Sustainable Approach for Growth of Automotive Industry (AM)

The AM industry is very vast and produces a big volume across the world. The high rate of growth of this industry is also posing a threat to the environment. Such threat is having multi-faceted. Figure 1 shows the impact on economic growth, production process and then the environment, for example, increasing carbon emission, shortage of raw materials, waste piling up, etc. The sustainable approach to these industries is urgently required. The automobile industry is classified on the basis of vehicle type. Two-wheelers, three-wheelers, passenger vehicles and commercial vehicles comprise the four main segments of the Indian automobile market. Table 1 represents the classification of industry. Due to favorable cost–benefit conditions compared to other countries, the Indian auto industry is expanding at a very rapid rate.

As per the Report of IBEF November 2022 in Fig. 2 represents the production of automobiles in India, the production in 2019 is 30 million which is increasing up to 2019 and then decreasing due to COVID-19 up to 2021. Now it is again increasing production.

In 2015, 197 countries signed an agreement in Paris to reduce global warming by absorbing CO_2 and reducing emission [7]. CO_2 emissions cannot be reduced without technological development and an increase in consumers demands for fuel-efficient automobiles. Both consumer preferences and technological advancement are crucial [8]. Babel et al. presented a case study on top 5 OEM to reduce water and energy usage to minimum and found out BMW is more water efficient and generates more revenue [9]. Thakkar and Rane developed a model on Green supply development and successfully implemented it in seven companies out of selected ten companies [10]. Mutumi and Simatele investigated the applicability of sustainability in the automobile industry in Africa [11].

Table 1 Classification of automotive industries

Vehicle type		Segment
Four-wheelers	Passenger vehicles	Passenger car
		Utility vehicles
	Commercial vehicles	Light commercial vehicles
		Medium commercial vehicles
		Heavy commercial vehicles
Three-wheelers		Passenger carrier
		Goods carrier
Two-wheelers		Scooter, motorcycle, electric two vehicle

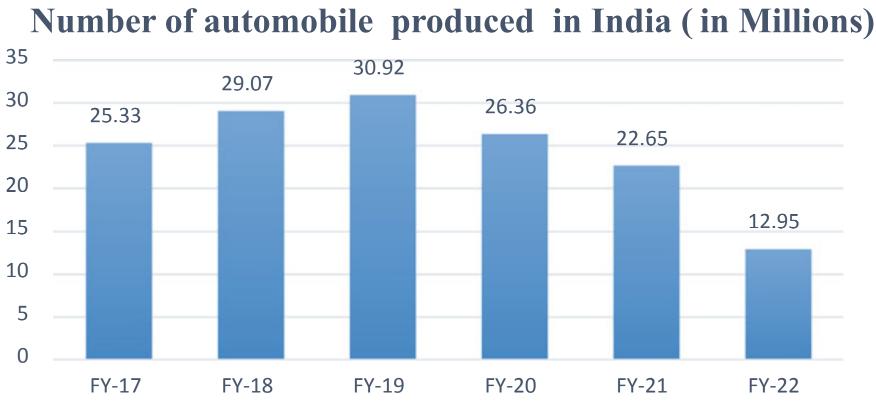


Fig. 2 No of vehicles produced in India in the last 5 years [6]

Table 2 Aspects of different activities in automotive industries

Major activities	Environment aspect	Environment impact
Manufacturing	Land use, air quality, water quality, energy use, emission in processes	Consumption of natural resources, increase the waste material
Painting	Heath of workers, land use, air and water quality	Generates water and air pollution impacting the health of workers
Logistic	Air quality, road congestion and damage	Generates air pollution
Testing of finished product	Air quality	Generates air pollution
Waste management	Land quality, occupy unused land	Creates health hazards

3.1 Activities Impacting the Environment

This section of the paper discusses the major activities involved in the automotive industries in which pollution is generated. Different aspects of activities are shown in Table 2, which needs to be looked into.

4 Green Initiatives and Their Benefits

With the development of technologies, pollution levels have increased that created the problem. But the same to reduce this problem, new solutions are to developed. In this section, Table 3 provides different initiatives provided by different researchers to maintain the environment.

Table 3 New green initiatives by industries

Green initiatives	Objectives	Benefits	Related paper
CO_2 pricing	To reduce emissions as close to zero Limit the global warming below 1.5 degree centigrade Reduce the highest emitters reaching net zero	Awareness of pollution produced by vehicles. Greener area will increase as the funds collected through CO_2 pricing will invested in tree plantation	[7] 12
Zero emission vehicles	To find out the conducive factors for EV adoption	Pollution free environment. Improved air quality. Development of infrastructure of EV charging	[2]
Environment regulations	To explore the impact of environment on Chinese automobile industries	Although implementation has a negative effect on production, but forces the technical innovations	[13]
Circular economy	To investigate the obstacles and future of circular economy	Decrease the raw material use to save the environment degradation. Proper policy will be developed for scarp material	[14]
Greener materials (Fiber composites)	To select the light weight material suitable for which replaces the conventional materials	Fuel efficiency of vehicle improves, this leads to lesser amount of emission to environment	[15]

5 Green Initiatives by Indian Automotive Sector

In this section, we have studied the major green initiatives to make the environment pollution free. The projected sale of cars in India is to increase about 10.5 million from the present sale of 3.5 million by 2030, which is approximately 3.5 times which will increase the exhaust emissions from the vehicles [16]. The several Indian automotive giants are taking the lead role to make this industry more sustainable represented in Table 4.

Table 4 Green initiative by Indian automobile producers

Company name	Initiative name	Description
Tata motors	Go green	1. Plantation drive with each unit sold and tracking 2. BS6 product for a low-carbon strategy 3. As a RE100 initiative, Tata Motors goals to source 100% renewable electricity by 2030
Mahindra motors	Project hariyali, Mahindra Susten	1. Clean mobility, 2. Green Supply Chain 3. Electric vehicles and alternative fuels
Suzuki motors	Go green suzuki	1. Launched a new engine to use more gasoline with ethanol 2. To reduce emission, components like an upgraded fuel pump and fuel injector, an engine management system and other mechanical upgrades have been developed to guarantee engine and vehicle durability 3. Comply with the stringent BS6 Phase-II emission norms
Ashok leyland	Mission gemba	1. Conduct massive plantation drives 2. BS6 Phase-II emission norms 3. Electric vehicles through National Electric Mobility Mission Plan [NEMMP] 4. By 2026 introduction of electric buses
Bajaj auto	Green bajaj	1. Focus on green fuel usage Like CNG, LPG 2. Wind power usage 3. Tree plantation 4. Water recycling
Honda	Green path	1. Significantly reducing the CO_2 emitted by each vehicle built in plants, 2. Reducing the water use of our manufacturing operations

6 Conclusion

This study has explored the requirement of Green manufacturing in order to reduce several problems due to high volume production of automobiles in India. The main issue is CO_2 emission, which has reached alarming level. Several initiatives such as; CO_2 pricing, zero emission vehicles, environment regulations, circular economy and green materials are some new trends that can control pollution. The major giants of automobile producers are explored for their steps taken to make green manufacturing realistic. Each industry is emphasizing to go for EV, BS6 emission, tree plantation, use of renewable sources of energy, etc. The sustainable growth is needed to make this industry profitable. India is now hub of manufacturing of AMs in all ranges, on the same time, it has highly polluted environment. In such situation, Go green is the only way of sustainable growth.

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Application of Monte Carlo Approach to Determine Stock Out in Public Distribution System (PDS)

S. Shyama Prasad, S. Swapnesh, and Ponnu Jafar

1 Introduction

The public distribution system in Kerala is the major safety net program that guarantees the distribution of food grains to people at affordable prices. Stock outs in public distribution system are a common issue causing negative impacts on availability and affordability of essential goods for vulnerable population. Stock outs can have severe consequences on the lives of the poor, who rely on PDS for their basic food needs. These are a persistent problem in the PDS, leading to disruptions in the distribution of essential commodities and causing hardship to the intended beneficiaries. This occur due to higher than expected demand, unexpected supply chain disruptions, ineffective inventory management, and poor forecasting practices. Stock outs can also lead to operational and financial costs for the distributors, as they may have to deal with increased demand, lost sales, and possible damage to their reputation. The risk can be minimized by computing accurate forecasting and inventory management system in place. The Monte Carlo approach is used to analyze and model stock outs in PDS with respect to the demand patterns delivery schedules and inventory levels. Monte Carlo simulation on both monthly and seasonal approach with the actual demand data to find the stock out is computed. T-test values of these approach are determined to know if they are useful for managerial decisions. This helps PDS to access their inventory and demand risk by calculating stock out probability.

S. Shyama Prasad (✉) · S. Swapnesh · P. Jafar
Rajiv Gandhi Institute of Technology, Kottayam, Kerala, India
e-mail: shyama996@gmail.com

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2 Problem Statement

The Alappuzha Supplyco Depot is considered for this project. The depot also faces the problem of limited storage capacity. There are 26 outlets for Alappuzha depot, consisting of Maveli Store, super markets, and people's bazar. The depot have a capacity of 17,937 bags, and outlet demand is about 20,940 bags. The depot capacity is not sufficient to meet demands of the outlets in the area.

3 Objectives

To determine the stock-out days with respect to forecasted demand using Monte Carlo simulation method.

4 Methodology

The aim of this study is to find the future demand and stock out periods of items in the public distribution system using Monte Carlo simulation. The data consisting of monthly data are collected for analysis that were demanded by the outlets. The frequency of data is monthly. The data composed of demand of the outlets for 24 months that begins at January 2021 to December 2022. A two-stage analysis is done. Figure 1 shows the methodology opted for finding the stock outs, and Table 1 provides the monthly data.

First stage: In this stage the Monte Carlo simulation was performed using the actual data between January 2021 and December 2022. Stock out period is determined.

Second stage: The actual data is seasonally divided into three before performing the Monte Carlo simulation. The stock out period of this stage is also determined.

Both data values are then given for risk analysis, and then the best method is determined.

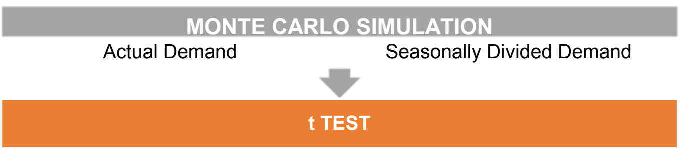

Fig. 1 Methodology

Table 1 Monthly data of depot

Sl No.	1	2	3	4	5	6	7	8	9	10	11	12
2021												
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Demand	2490.50	2569.67	3820.55	4308.35	4059.71	5109.51	4570.48	3511.46	2165.28	3202.86	3235.29	3955.28
2022												
Sl. No.	1	2	3	4	5	6	7	8	9	10	11	12
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Demand	2861.59	3184.50	3293.84	4487.75	4674.22	5110.74	3028.29	2651.87	2841.88	3130.51	2576.20	3175.58

5 Literature Survey

It is a probabilistic model used for the predicting or decision making by modeling and analyzing various types of uncertainties, such as demand lead time and inventory levels. The Monte Carlo simulation method is used for determine the stock out duration in this study. The simulation involves creating different scenarios based on different probability distribution and running simulations to determine the likelihood of certain events occurring. Monte Carlo simulation helps to predict the likelihood of stock outs occurring due to different factors like demand variability, transportation delays, and supplier lead times. Bradley et al. [1] discussed the concept of demand forecasting with Bayesian simulation approach. This probability method can be useful in the uncertain demand–supply. The suggested Bayesian technique beats the alternative approaches, allowing the inventory optimization model to set stock levels that achieve greater fill rates, leading to better inventory investment decisions. The paper contributes that the evaluation of forecasting technique for service parts utilizing an integrated inventory optimization and simulation environment.

Zizka [2] discussed how the simulation approach in this study involves using Monte Carlo simulation to evaluate the performance of different safety stock levels under various demand and lead time scenarios. The unpredictability and uncertainty of demand and lead time are taken into consideration in this method, allowing for a more sophisticated and realistic analysis of supply chain dynamics. Mooney [3] pointed out the use of Monte Carlo simulation in the inventory management which includes stock outs of the commodities. This includes simulating various inventory management strategies which determines optimal stock levels, reorder points, and safety stock. This shows how Monte Carlo simulation can be useful in evaluating the impact of uncertain demand, lead time, and supplier reliability on inventory performance which enables to identify cost-effective inventory policy.

6 Results and Discussions

We did Monte Carlo simulation to determine the stock outs in the public distribution system. A probability distribution of the products demand is established and used as the input for numerous simulations, while using Monte Carlo simulation for stock out analysis. The inventory is updated in accordance with the demand scenario generated by each simulations. The method is repeated numerous times, producing a fresh set of results for inventory levels, stock outs dates, and stock out duration with each iteration.

6.1 Stage I

The first or initial stage of Monte Carlo simulation is arranging the given data in ascending order. Then, determine the difference between the higher and lower value, and the no. of intervals to be taken. The interval values are also determined with a difference of 736.50 obtained. Frequency distribution is computed from the above interval values. The probability values and cumulative probability are determined from these values which are given in Table 2. The probability plotting of the given data is taken and shown in Fig. 2.

A test was carried out for finding the normality of the monthly data provided.

The probability plot shows that every point falls between upper and lower bounds, indicating that the data has normal probability distribution. Furthermore, the results of Anderson darling test, which is a formal test, indicate that the null hypothesis cannot be rejected, indicating that the data have normal probability distribution (p-value

Table 2 Probability distribution of monthly data

Interval no.	Interval values	Frequency	Probability	Cumulative probability	Probability intervals
1	2164–2900	6	0.2500	0.2500	0.0000–0.2500
2	2901–3637	6	0.2500	0.5000	0.2501–0.5000
3	3638–4374	7	0.2917	0.7917	0.5001–0.7917
4	4375–5111	5	0.2083	1.000	0.7918–1.0000

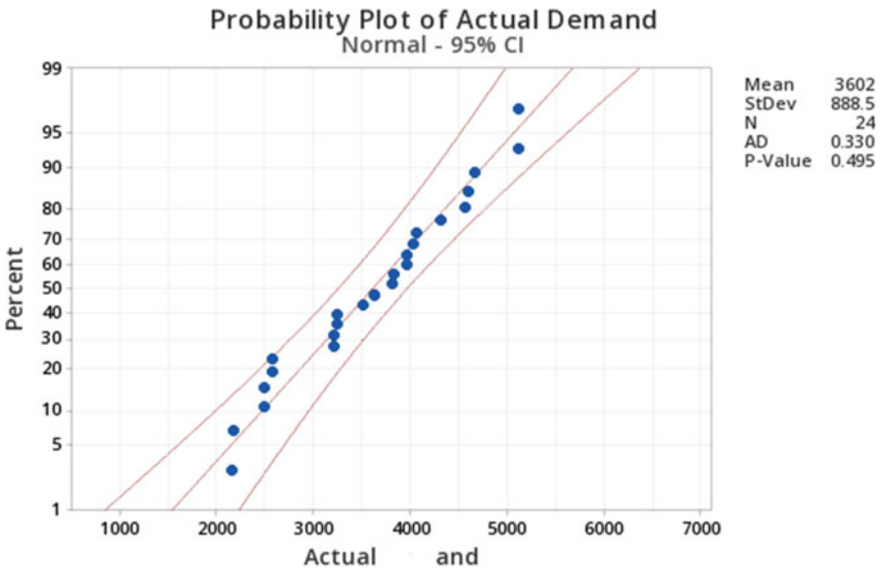

Fig. 2 Probability plotting

= 0.495, α = 0.05). For this reason, 1000 random number were generated using Minitab which follow normal probability distribution for twelve months (January 2021–December 2021). The generated random number is given in Table 3.

For each interval that the random number falls into, the average is calculated by taking the mean of upper and lower bound values. The average values are then determined and used for further analysis or interpretation as given in Table 4.

Table 3 Random number generation

Month	Random number			Average row
	RN1	RN2	RN1000	
January	3247.734	833.0438	5307.207	3606.591
February	5241.551	3450.828	4720.879	3566.934
March	3052.252	4754.811	2118.507	3616.843
April	4199.636	5199.335	2916.615	3602.752
May	4715.768	2944.298	3353.718	3552.224
June	4282.226	4045.823	3908.198	3665.377
July	3312.999	1494.103	2382.609	3583.294
August	4078.828	4416.397	3835.589	3633.871
September	2947.689	2689.329	4240.709	3606.884
October	3079.276	4257.772	3380.913	3612.505
November	3916.572	4849.062	5738.23	3606.196
December	3152.394	3612.6	2996.246	3614.579

Table 4 Comparison on actual demand and simulated demand

Month	Actual value	Monte Carlo estimates	Stock
January	2861.59	3606.591	745.00
February	3184.51	3566.934	382.43
March	3293.84	3616.843	323.00
April	4487.75	3602.752	−885.00
May	4674.22	3552.224	−1122.00
June	5110.74	3665.377	−1445.36
July	3028.29	3583.294	555.00
August	2651.87	3633.871	982.00
September	2841.88	3606.884	765.00
October	3130.51	3612.505	482.00
November	2576.20	3606.196	1030.00
December	3175.58	3614.579	439.00

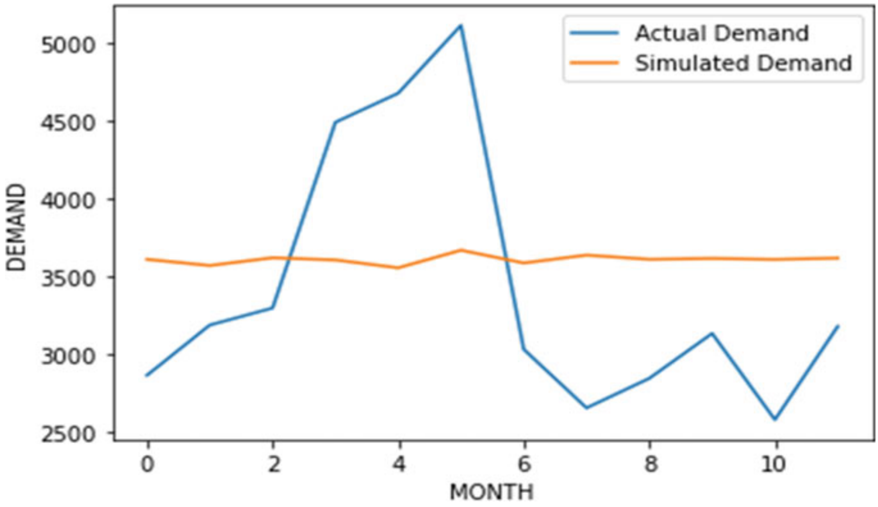

Fig. 3 Monthly demand variation between actual demand and simulated demand

In Fig. 3, the actual demand and estimated demand values are tightly clustered around the value 3600, indicating a close similarity between the two. Specially, there is a remarkable proximity between the actual and estimated demand.

6.2 Stage II

The data from January 2022 to December 2022 was divided into three seasons: the first season include January, February, and March; the second season included April, May, June, and July; and the third season included August, September, October, November, and December. The mentioned procedure was reaped for each seasonal dataset. Tables 5, 6, and 7 presented below display the computed frequency, probability values, and cumulative probabilities of three seasons.

Then cumulative probability distribution used for the computation of the probability intervals (the upper and lower intervals) is given in Table 8.

Table 5 Probability distribution for season 1

Interval no.	Interval values	Frequency	Probability	Cumulative probability
1	2164–3146	2	0.6667	0.6667
2	3147–4128	1	0.3333	1.0000
3	4129–5110	0	0.0000	1.0000

Table 6 Probability distribution for season 2

Interval no.	Interval values	Frequency	Probability	Cumulative probability
1	2164–3146	0	0.0000	0.0000
2	3147–4128	2	0.4000	0.4000
3	4129–5110	3	0.6000	1.0000

Table 7 Probability distribution for season 3

Interval no.	Interval values	Frequency	Probability	Cumulative probability
1	2164–3146	1	0.2500	0.2500
2	3147–4128	3	0.7500	1.0000
3	4129–5110	0	0.0000	1.0000

Table 8 Probability intervals of season 1, season 2, and season 3

Month	Probability intervals		
	Season 1	Season 2	Season 3
1	0–0.667	–	0–0.250
2	0.668–1.000	0–0.4000	0.251–1.000
3	–	0.401–1.000	–

Average of upper and lower bound values are determined for each of the interval that the random number is classified and average values are computed. Table 9 represents the values from random number generation and computed average values.

The average values are computed from each row corresponding to each season. The computed values are mentioned as estimates of Monte Carlo simulation for season 1, season 2, and season 3. These values are compared and computed; the stock difference with the actual demand is given in Table 10. Fig. 4 represents the variation shown by actual demand value and estimated demand value of seasonal distribution.

Table 9 Random number generation for season 1, season 2, and season 3

Month	Random number			Average row
	RN1	RN2	RN1000	
Season 1	3270.941	3094.993	2376.399	2915.324
Season 2	3969.504	4092.153	4892.862	4304.381
Season 3	3696.237	2547.904	2797.603	3153.61

Table 10 Comparisons of actual demand, simulated demand, and stock variance

Actual demand	Monte Carlo estimates	Stock
2779.324	2915.324	136
3983.381	4304.381	321
2552.61	3153.61	601

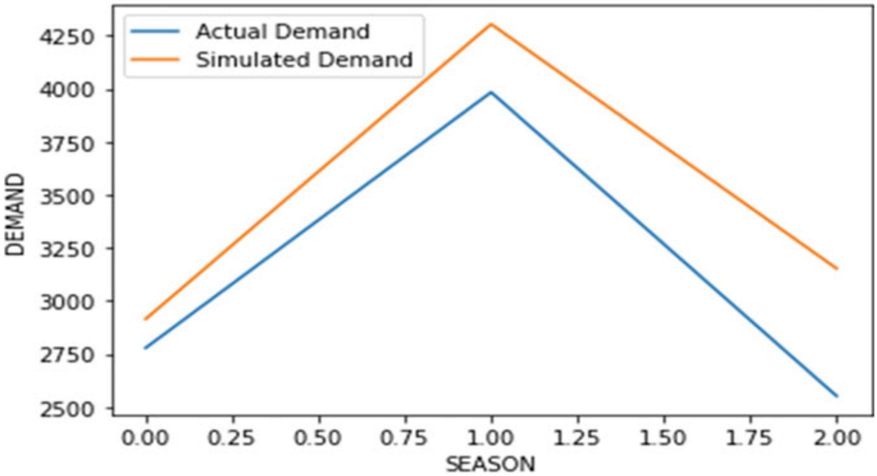

Fig. 4 Seasonal demand variation between actual demand and simulated demand

7 T-Test

The two series of the simulation is tested with independent samples t-test which is conducted whether the population means are equal or not. The p-value is considered which should be greater than $\alpha = 0.05$, and in both cases, the values are greater (*p*-value—0.451). Therefore, the null hypothesis cannot be rejected. The observations from the t-test in Minitab is shown below.

Method
$\mu 1$: population mean of actual demand,
$\mu 2$: population mean of simulated demand,
Difference: $\mu 1 – \mu 2$
Equal variances are assumed for this analysis.

Tables 11, 12, and 13 present the t-test values of the actual demand and estimated demand.

Test
Null hypothesis H0: $\mu 1 – \mu 2 = 0$
Alternative hypothesis H1: $\mu 1 – \mu 2 \neq 0$

Table 11 Descriptive statistics

Descriptive statistics				
Sample	N	Mean	St. dev	SE mean
Actual demand	12	3418	847	244
Monte Carlo estimate	12	3605.7	29.4	8.5

Table 12 Difference

Difference	Pooled st. dev	95% Ci for difference
188	599	(−695, 320)

Table 13 Test values

T-value	Df	P-value
−0.77	22	0.451

Table 14 Stock out duration of stage 1

Month	April	May	June
Stock out	855	1122	1445

The results from multiple simulations are analyzed, and the average is computed to determine the stock level with respect to the actual demand. In the monthly Monte Carlo simulation, multiple possible scenarios of demand for each month of the year is obtained. The difference between the future demand and Monte Carlo estimates is computed for obtaining the stock-level probability. The results show that at the months of April, May, and June, stock outs are identified, and remaining months they are closer to the average demand value followed by the Monte Carlo estimate 3600. Monte Carlo simulation method helps in providing the details on expected stock and inventory on a monthly basis. Table 14 presents the stock out duration computed from the monthly Monte Carlo simulation.

Similarly, in the seasonal Monte Carlo simulation, multiple possible scenarios of demand for each season of the year is considered. The difference between the average seasonal demands and Monte Carlo estimates are computed. The results shows similar demand pattern but slightly close on three seasons. The overall demand pattern of the product is analyzed. As the previous method, seasonal method also provides the information on expected stock and inventory on the given period of time. Table 15 presents the stock out duration of stage 2 or from seasonal Monte Carlo simulation.

Table 15 Stock out duration of stage 2

Seasons	1	2	3
Stock out	136	321	601

The t-test measures the standard error of the difference between the simulation results and actual or expected value, which provides a measurement of the significance of the difference. If the difference is significant, it suggest that the simulation results are not a good representation of real system. The p-value is the probability of observing a t-statistic as extreme as or more extreme than the calculated from the data. The p-value for the simulation is 0.451. P-value of 0.451 implies that the simulation results are good representation of the real system and the difference between the Monte Carlo estimate and actual demand is likely due to random variation. The study proves that the simulation results are reasonably accurate, and the system being modeled is well described by assumptions and inputs used in the simulation.

8 Conclusions

Monte Carlo simulation is a valuable approach to determine the stock outs in public distribution system. The approach offers a way to represent complex and uncertain systems by taking into account multiple inputs and dependencies to produce a variety of potential results. The result of simulations can provide valuable information for inventory management and decision making. The t-test is also important since they compute if the data simulation are statically significant or not, i.e., if they show a significant difference, the simulated data need to be re-evaluated or redefined; and if a not significant difference is shown, then they are taken as a good representation of actual data. While in the case of PDS stock outs, the approach was useful in determining the probability of stock outs, the expected duration of stock out, and the expected inventory level at any given time. The accuracy of the simulation results depend on the quality of the input data and the assumptions used. This can be reduced by comparing with the historical data available. Monte Carlo simulation being a powerful tool can be used for understanding and managing the risk of stock out in a PDS.

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An ISM-DEMATEL Integrated Perspective for Investigating the Drivers of Sustainable Manufacturing for an Indian SME

Amber Batwara, Vikram Sharma, and Mohit Makkar

1 Introduction

Sustainable manufacturing significantly impacts the economies of the world's created countries. The automotive industry has an impressive manufacturing stake in India and is responsible for carrying new green, and smart manufacturing advances. History and practice have demonstrated the rapid growth of industrialization in the global economy. However, such accelerated industrialization has followed an increasing number of adverse consequences, such as resource scarcity, environmental degradation, and climate change, which are significant global issues (Yan Yeow Kar and Yazdanifard [1]. Recent trends in ecological awareness indicate the necessity of changing the production philosophy and strengthening the fundamental changes in the existing production system. The Indian government has developed various manufacturing policies, leveraged the existing incentives/schemes, and implemented new strategies to support green technology. Manufacturing businesses face a significant challenge due to the rising worldwide demand for natural resources and their associated difficulties. In addition, sustainable technologies improve comprehension of the intricate interdependencies between the components of the industry [2]. However, adopting environmentally sustainable concepts is difficult for enterprises to complete, therefore, [3] discussed some difficult factors based on their literature review.

Makers quickly meet their obligations and focus on them in their serious business sectors in accomplishing feasible creation rehearses in new business conditions [4]. Organizations using green manufacturing processes have credibility and a superior consumer experience. Green manufacturing is urgently needed in today's environmental scenario [5]. SM is a blueprint that works as a directorial torch for the organizational worker and implements a new philosophy. The framework may provide

A. Batwara (✉) · V. Sharma · M. Makkar
Department of Mechanical-Mechatronics Engineering, The LNM Institute of Information Technology, Jaipur 302031, India
e-mail: 20pmm001@lnmiit.ac.in

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a deep understanding of the subject and the means to achieve it. Since SM requires many important decisions, including routine production disruption, huge start-up investment, and apprehension of success [6], the change must be made smoothly and gradually. It was found that the study of drivers that make such a change possible should be explored for the government to function as a powerful catalyst for change without having a significant adverse effect.

In summary, drivers need to be evaluated to encourage improving SM practices with the help of a planned approach. It will be expected to understand better the value of SM in the Indian context, which is still in its early implementation phases. Prioritization of these drivers from many viewpoints would assist policymakers in government and industry, focusing on critical factors to help SMEs with limited resources implement integrated SM. By using this study as a standard, companies from other developing countries can examine their country-specific drivers using the methodology presented by this research. As a result, the following research topics are addressed in this paper:

RQ1. What are the key drivers for implementing integrated SM in Indian manufacturing SMEs?
RQ2. How do the rankings of these factors differ from an environmental, social, and economic standpoint?

The following is how the rest of the paper is organized: The literature review is defined in Sect. 2 to identify research gaps and drivers of SM adoption. The proposed framework is described in Sect. 3. Section 4 also highlights the use of proposed DEMATEL and ISM methodologies to prioritize the drivers, followed by Sect. 5's results and discussion. Section 6 discusses management ramifications, while Sect. 7 is the study's conclusion.

2 Literature Review

Green manufacturing is characterized as complete waste disposal and redefining existing processes to reduce CO2 during each cycle without raising costs and disturbing production targets [7]. Organizations cannot think of a program that does not lead to environmental consequences. Therefore, companies should also accept the SM program as a mechanism for environmental protection and reduce product costs. SM reflects a new paradigm of production [8], which incorporates different green procedures, drivers, and methods for making them more eco-proficient. SM contains assembling or creating frameworks that utilize less energy, less material, and subbing input materials to decrease undesirable yields, waste, contamination, and reuse. SM has measures that utilization low natural effect [9]. The creation of the item kindly and innocuously is the obligation of GM, which will limit the unfavorable consequences for the climate through the best utilization of assets.

SM implementation ensures various crucial parameters that should be understood as existing or developing conditions or practices [3]. Several studies suggested different factors identifying potential directions for an SM system. Proposed four criteria (reduction, recycling, remanufacturing, and reuse) to explain the green features of the production method [10]. Companies designing their SM programs [11] suggested four phases: evaluation, base, waste minimization, and eco-efficiency. Variables are significant in implementing environmental technologies such as SM procedures, operational capital, technological creativity, and program control [12].

Studies extended with advancement research in SM. Analyzed the requests of Chinese organizations depending on green development rehearses hypothetically [13]. They found that capital, suppliers, regulations, competitors, and consumers are central pressures for green innovations. Jabbour provided future opportunities to conduct environmental training for organizations. Some studies have suggested that corporations successfully implement green management practices to achieve greater profitability and organizational performance [14]. Research also studied green development factors in various countries and sectors, including India [15, 16] and Sweden [17].

A few investigations have created and carried out numerous MCDM in green administration methodologies like AHP, ANP, DEMATEL, TOPSIS, and PROMETHEE, for choosing a green provider, utilized fluffy DEMATEL, fluffy ANP, and fluffy TOPSIS techniques that offered new points of view in assessing green assembling factors. The DEMATEL approach was used by [15] to determine the green assembling drivers and approve the discoveries using affectability investigation of two-stage [18] utilized the fluffy TOPSIS strategy to evaluate the green and lean assembling driving factors in small and medium Indian undertakings. Table 1 represents various MCDM technique implementations with sustainable manufacturing.

Table 1 Implementation of MCDM in SM

MCDM technique	Objective	Source
DEMETAL	Application of Industry 4.0 technology for moral and sustainable business practices	[19]
AHP- DEMETAL	Adoption of Industry 4.0 for sustainable multi-tier manufacturing supply chains in developing countries	[20]
“Fuzzy AHP-COPRAS”	Lean implementation framework	[21]
“Fuzzy AHP”	Choosing sustainable suppliers	[22]
“Fuzzy AHP”	Evaluation of frequent roadblocks to the combined lean-green-agile manufacturing system	[23]
“DEMATEL” and “Delphi”	Assessment of green manufacturing drivers	[17]
“AHP and VIKOR”	Choice of the best tire reusing measure	[24]
“DANP” and “ PROMETHEE”	Assessment of green development rehearses	[15]

While the literature review reveals that SM has been a basic idea for the industrial sectors to tackle environmental and social sustainability, several problems require more study. This study aims to close that gap by identifying and prioritizing SM drivers for Indian manufacturing SMEs. The following findings and gaps are noted.

The manufacturing industry is concerned about moving to SM.

While various research has defined drivers, these appear to be restricted to conceptual drivers such as fiscal opportunities, legislation, and shareholders.

3 Drivers for Implementation

Data sets like “Scopus,” “Web of Science,” “Emerald Insights,” and so forth were looked for to distinguish drivers with keywords such as “sustainable manufacturing drivers,” “sustainable manufacturing factors,” “green manufacturing enablers,” and “green manufacturing criteria”. Based on a literature review, a list of drivers was compiled. An expert committee of eight individuals has been constituted to identify critical drivers. Ten experts from India’s automobile sector were contacted. Four out of ten research participants followed a conversation with these industry experts. Essentially, four out of ten establishments’ scholastics consented to submit a criticism. Nonetheless, to avoid inconsistencies, no joint gatherings or answers were held with the respondents during the information assortment segment. A list of identified drivers for sustainable manufacturing is given in Table 2.

4 Proposed Framework and Method

Indian companies have started instilling environmentally friendly activities in the system as a reaction to intensified pressure from policymakers, consumers, profitability, and many more.

This paper aims to get approved driver alleviation systems by joining ISM-DEMATEL. Figure 1 represents the methodology of the proposed framework. The logical procedure utilized for the ISM approach can be used to finish the lattice of double numbers, for example, (0, 1) between drivers, while the DEMATEL approach can take different decisions, for example, (0–1, 2, 3, and 4) between drivers for the investigation of circumstances and logical results. It is a sort of primary demonstrating approach. It is instrumental in dissecting the connections of circumstances and logical results between framework segments. DEMATEL may set up the reliance among factors and guide to address their relative references, which can be utilized to break down, addressing muddled and interconnected issues.

Table 2 Identified drivers for the development of sustainable manufacturing

Drivers	Explanation	Reference
Government rules and legislation (D-1)	The requirement for SM is founded as the most comprehensive most existing factor in various firms	[15, 25]
Social and environmental responsibility (D-2)	Awareness caused by various NGOs has led to a sense of responsibility in firms toward environmental issues	[13, 26]
Economic benefits or cost reduction benefits (D-3)	Green practices contribute to achieving economic benefits leading firms to adopt SM	[23, 27]
Customers awareness, pressure, and support (D-4)	Customers' awareness and preferences to choose firms with SM	[16, 28]
Suppliers pressure and willingness (D-5)	Suppliers pressure on firms to work with SM	[27–29]
Investors and shareholder Pressure (D-6)	Investors' and shareholders' demands for eco-friendly products have led to SM	[30, 31]
Employees motivation, health, and safety (D-7)	Firms are found to be keen on self-responsibility for SM and sustainable development	[7, 31]
Scarcity of resources and higher waste generation (D-8)	Limited availability of natural resources forces firms for contributing to GM	[6, 25]
The interest of the firm in overall efficiency (D-9)	Firms' strategies to improve their general effectiveness contribute a lot to GM	[18, 30]
Organizational capabilities and awareness, co-operative organizational structure (D-10)	Individual ability and supporting infrastructure of firms also contribute a lot toward the firm's sustainable development	[9]
Limited space available for disposal (D-11)	Limited availability of space for disposal forces firms for adopting to GM	[32]
Availability and use of recycled materials in manufacturing (D-12)	The allowability of consumption of recycled materials in the manufacturing system gives direction to GM	[14, 33]

5 Application of the Proposed Framework

5.1 ISM Analysis

The ISM approach was created to determine the test of confounding elements. It is a vivid strategy for intuition. This strategy groups parts into a point-by-point underlying model, straightforwardly and by implication. The model shows the construction of a mind-boggling issue in a modern example, including designs and words. It is a strategy in demonstrating since a graph model shows the vital relationship and the overall design. The intricacy of the connection between the framework's various components assists with setting up requests and heading.

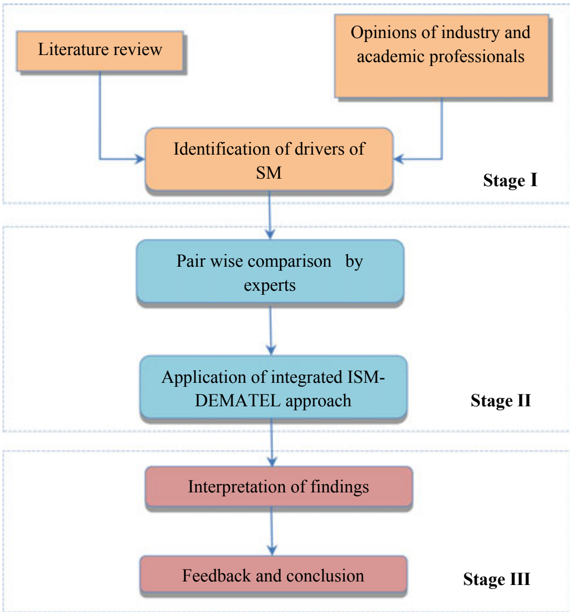

Fig. 1 Methodology of the proposed framework

The ISM strategy has a few stages, which are as per the following:

- Step 1: Identification of variable,
- Step 2: The setup context-oriented connection between factors,
- Step 3: Develop a "structural self-interaction matrix (SSIM),"
- Step 4: Develop the reachability matrix,
- Step 5: Partition the reachability grid into various levels,
- Step 6: Develop a digraph,
- Step 7: Represent the relationship among factors in the structure.

The structural "self-interaction matrix (SSIM)" is discussed with experts. Based on their responses, this matrix is prepared as given in Table 3.

where.

V: "Factor i influences factor j."
V: "Factor i influences factor j."
A: "Factor j influences factor i."
X: "Two-way relationship (i and j affect each other)."
O: "No factor relationship."

Reachability and predecessor variables are calculated from the finalized matrix, as given in Table 4. The "reachability set" contains different variables that may help accomplish it for a given factor. The "precursor set" is simply the factor and the leftover factors that may help achieve it. The component gave similar reachability and convergence sets as a first level. At that point, the accompanying level-cycle

Table 3 Structural "self-interaction matrix (SSIM)"

	D-1	D-2	D-3	D-4	D-5	D-6	D-7	D-8	D-9	D-10	D-11	D-12
D-1	–	A	X	V	X	V	A	A	O	O	A	A
D-2	V	–	O	V	O	O	V	X	O	V	V	X
D-3	X	O	–	O	A	A	O	A	A	O	O	O
D-4	X	A	O	–	O	X	O	A	O	O	O	O
D-5	A	O	V	O	–	X	O	A	V	V	A	A
D-6	A	O	V	X	X	–	O	A	V	A	O	A
D-7	V	X	O	O	O	O	–	O	V	V	O	O
D-8	V	X	V	V	V	V	O	–	V	V	O	V
D-9	O	O	V	O	A	A	A	A	–	A	O	A
D-10	O	A	O	O	A	V	A	A	V	–	O	A
D-11	V	A	O	O	V	O	O	O	O	O	–	V
D-12	V	X	O	O	V	V	O	A	V	V	A	–

measure isolates this factor from different variables. Rehash an equal level-cycle measure until all factor level is set up. Only the first level iteration is represented in Table 5 and remains in the appendix (Tables 10, 11, 12, 13, 14, and 15).

The standard of "MICMAC (cross-impact matrix multiplication applied to classification analysis)" relies upon the duplication properties of grids. Figure 2 shows the MICMAC analysis of the drivers.

The hierarchical structure model is created from the iteration level of each driver shown in Fig. 3.

Table 4 Final reachability matrix

	D-1	D-2	D-3	D-4	D-5	D-6	D-7	D-8	D-9	D-10	D-11	D-12
D-1	–	0	1	1	1	1	0	0	1'	1'	0	0
D-2	1	–	1'	1	1'	1'	1	1	1'	1	1	1
D-3	1	0	–	1'	1'	1'	0	0	0	0	0	0
D-4	1	0	1'	–	1'	1	0	0	1'	0	0	0
D-5	1'	0	1	1'	–	1	0	0	1	1	0	0
D-6	1'	0	1	1	1	–	0	0	1	1'	0	0
D-7	1	1	1'	1'	1'	1'	–	1'	1'	1	1'	1'
D-8	1	1	1	1	1	1	1'	–	1	1	1'	1
D-9	1'	0	1	0	0	0	0	0	–	0	0	0
D-10	0	0	1'	1'	1'	1	0	0	1	–	0	0
D-11	1	1'	1'	1'	1	1'	0	0	1'	1'	–	1
D-12	1	1	1'	1'	1'	1'	1'	1'	1	1	1'	–

Table 5 Driver's iteration level-I

Drivers	Reachability set	Antecedent set	Intersection set	Level
D-1	1,3,4,5,6,9,10	1,2,3,4,5,6,7,8,9,11,12	1,3,4,5,6,9	
D-2	1,2,3,4,5,6,7,8,9,10,11,12	2,7,8,11,12	2,7,8,11,12	
D-3	1,3,4,5,6	1,2,3,4,5,6,7,8,9,10,11,12	1,3,4,5,6	I
D-4	1,3,4,5,6,9	1,2,3,4,5,6,7,8,10,11,12	1,3,4,5,6	
D-5	1,3,4,5,6,9,10	1,2,3,4,5,6,7,8,10,11,12	1,3,4,5,6,10	
D-6	1,3,4,5,6,9,10	1,2,3,4,5,6,7,8,10,11,12	1,3,4,5,6,10	
D-7	1,2,3,4,5,6,7,8,9,10,11,12	2,7,8,12	2,7,8,12	
D-8	1,2,3,4,5,6,7,8,9,10,11,12	2,7,8,12	2,7,8,12	
D-9	1,3,9	1,2,4,5,6,7,8,9,10,11,12	1,9	
D-10	3,4,5,6,9,10	1,2,5,6,7,8,10,11,12	5,6,10	
D-11	1,2,3,4,5,6,9,10,11,12	2,7,8,11,12	2,11,12	
D-12	1,2,3,4,5,6,7,8,9,10,11,12	2,7,8,11,12	2,7,8,11,12	

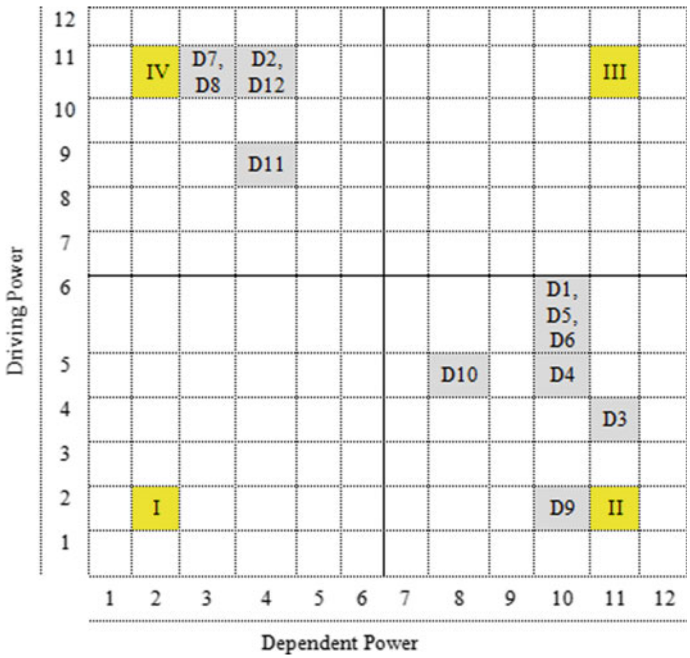

Fig. 2 MICMAC analysis of the drivers

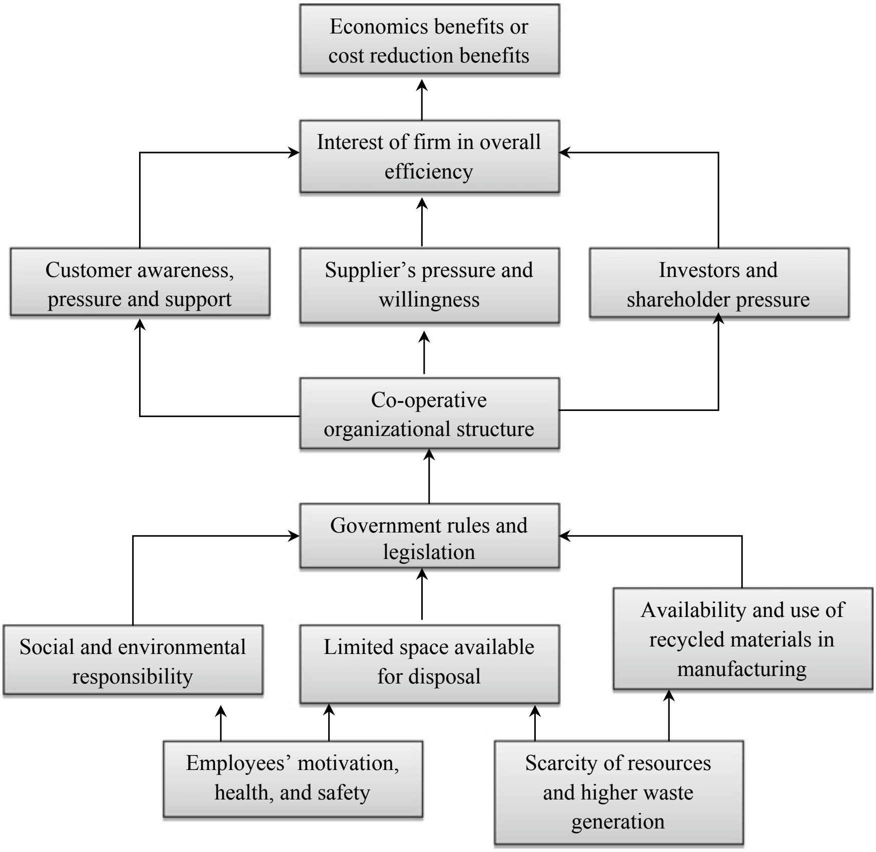

Fig. 3 Hierarchical structure model

5.2 DEMATEL Analysis

The DEMATEL strategy was presented somewhere between 1972 and 1976 by the Geneva Research Center. It is an underlying displaying approach and is precious in examining the connections of circumstances and logical results between framework parts. DEMATEL may set up the reliance among factors and guide them to address their relative references, which be utilized to break down and address confounded and related issues. Hsu et al. (2013).

The DEMATEL approach has a few stages, which are as per the following:

- Stage 1: Identification of variable,
- Stage 2: Generate a direct-connection framework,
- Stage 3: Normalizing direct connection lattice,
- Stage 4: Calculate the all-out connection framework,
- Stage 5: Developing a causal chart.

The DEMATEL approach explains the drivers' relationship between cause and effect in this section. In this approach, the drivers are scored 0–4 by experts, based on the impact of one driver on the other drivers. Then, based on the expert answer, a pair-wise comparison matrix is built. The final average pair-wise comparison matrix and normalized relation matrix are given in Tables 6 and 7, respectively.

The total relationship matrix (T) for calculating the all-out connection framework is given in Table 8. In the following stage, "conspicuousness" values, for example, (Ri + Cj), and "connection" values, (Ri − Cj), are determined, and in general, DEMATEL conspicuousness easygoing connection chart as examined in Fig. 4.

Table 6 Average matrix (A)

	D-1	D-2	D-3	D-4	D-5	D-6	D-7	D-8	D-9	D-10	D-11	D-12
D-1	–	3	1.33	1.33	1	1	2.33	3	2.33	1	2	2.33
D-2	2	–	1	2.33	1.33	1.33	2	2.33	1	1	2	2
D-3	1.33	1	–	2	1.33	2.33	2	1	2.33	1.33	1	1
D-4	2.33	2	1.33	–	2	1.33	1.33	2	1.33	1.33	1.33	2.33
D-5	2.33	1.33	2	1	–	2.33	1	1.33	2	2.33	1.33	1.33
D-6	1	1.33	1.33	1.33	1.33	–	1.33	1.33	2.33	2	1.33	1.33
D-7	2	2	1	1.33	1	1.33	–	1.33	1.33	1.33	1.33	2
D-8	3	2	1.33	1.33	1.33	2	1	–	1.33	1	1.33	2
D-9	1	2	2	1	1.33	2.33	1.33	2	–	2	2	2
D-10	1	1.33	2	1	2	3	1.33	1.33	3	–	1.33	1.33
D-11	2	1.67	1	2.33	1.33	1.33	2.33	3	1.33	1	–	3
D-12	3	2	1	2	1	1.33	1.33	3	2	1	3	–

Table 7 Normalized initial direct relation matrix (D)

	D-1	D-2	D-3	D-4	D-5	D-6	D-7	D-8	D-9	D-10	D-11	D-12
D-1	–	0.145	0.064	0.064	0.048	0.048	0.112	0.145	0.112	0.048	0.096	0.112
D-2	0.096	–	0.048	0.112	0.064	0.064	0.096	0.112	0.048	0.048	0.096	0.096
D-3	0.064	0.064	–	0.096	0.064	0.112	0.096	0.048	0.112	0.064	0.048	0.048
D-4	0.112	0.096	0.064	–	0.096	0.064	0.064	0.096	0.064	0.064	0.064	0.112
D-5	0.112	0.064	0.096	0.048	–	0.112	0.048	0.064	0.096	0.112	0.064	0.064
D-6	0.048	0.064	0.064	0.064	0.064	–	0.064	0.064	0.112	0.145	0.064	0.064
D-7	0.096	0.096	0.048	0.064	0.048	0.064	–	0.064	0.064	0.064	0.064	0.096
D-8	0.145	0.096	0.064	0.064	0.064	0.096	0.048	–	0.064	0.048	0.064	0.096
D-9	0.048	0.096	0.096	0.048	0.064	0.112	0.064	0.096	–	0.096	0.096	0.096
D-10	0.048	0.064	0.096	0.048	0.096	0.145	0.064	0.064	0.145	–	0.064	0.064
D-11	0.096	0.08	0.048	0.112	0.064	0.064	0.112	0.145	0.064	0.048	–	0.048
D-12	0.145	0.096	0.048	0.096	0.048	0.064	0.064	0.145	0.096	0.048	0.145	–

Table 8 Total relationship matrix (T)

	D-1	D-2	D-3	D-4	D-5	D-6	D-7	D-8	D-9	D-10	D-11	D-12	Ri
D-1	0.73	0.83	0.59	0.65	0.56	0.71	0.7	0.89	0.78	0.6	0.72	0.76	8.52
D-2	0.74	0.63	0.52	0.63	0.52	0.65	0.63	0.78	0.66	0.54	0.65	0.67	7.35
D-3	0.65	0.63	0.44	0.57	0.49	0.65	0.58	0.66	0.67	0.53	0.56	0.58	7.01
D-4	0.77	0.73	0.54	0.54	0.56	0.67	0.61	0.78	0.69	0.57	0.64	0.7	7.8
D-5	0.74	0.68	0.56	0.57	0.46	0.7	0.58	0.73	0.71	0.61	0.62	0.64	7.6
D-6	0.64	0.64	0.5	0.55	0.49	0.56	0.56	0.68	0.68	0.6	0.58	0.6	7.08
D-7	0.66	0.64	0.45	0.53	0.46	0.58	0.48	0.66	0.6	0.5	0.56	0.61	6.74
D-8	0.76	0.7	0.52	0.58	0.51	0.66	0.57	0.66	0.66	0.53	0.61	0.66	7.42
D-9	0.71	0.72	0.57	0.59	0.54	0.71	0.61	0.78	0.63	0.6	0.67	0.68	7.81
D-10	0.69	0.68	0.57	0.58	0.56	0.73	0.6	0.73	0.75	0.51	0.63	0.64	8.42
D-11	0.74	0.7	0.51	0.63	0.52	0.65	0.64	0.8	0.67	0.54	0.56	0.63	7.59
D-12	0.86	0.8	0.58	0.69	0.57	0.72	0.67	0.9	0.78	0.61	0.77	0.66	8.61
Ci	8.69	8.38	6.36	7.11	5.78	7.99	7.23	8.27	8.95	6.74	7.57	7.83	

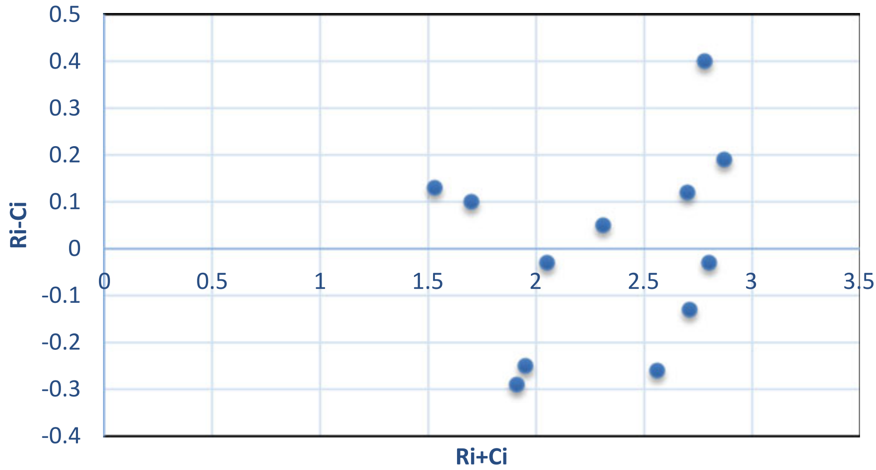

Fig. 4 Overall DEMATEL prominence-casual relation diagram

The next steps (Ri + Cj) and (Ri − Cj) are calculated as given in Table 9.

Table 9 Degree of influence

Drivers	|Ri + Cj|	Ri-Cj	Rank
D-1	2.87	0.19	1
D-2	2.7	0.12	5
D-3	1.53	0.13	12
D-4	2.56	−0.26	6
D-5	1.7	0.1	11
D-6	1.95	−0.25	9
D-7	2.31	0.05	7
D-8	2.78	0.4	3
D-9	2.05	−0.03	8
D-10	1.91	−0.29	10
D-11	2.71	−0.13	4
D-12	2.8	−0.03	2

6 Discussions

This study focuses on a few key drivers included in the structured hierarchical model. It is clear from Fig. 3 that "employees motivation, health, and safety" (D-7) and "scarcity of resources, and higher waste generation" (D-8) are very significant drivers of green or sustainable manufacturing with a weak dependence on power and high driving power. So, these drivers are vital for implementing SM in the Indian scenario. In addition, these drivers focus on "social and environmental responsibility" (D-2), "limited space available for disposal" (D-11), and "availability and use of recycled materials in manufacturing" (D-12).

MICMAC analysis provides valuable insights. Figure 2 shows that there are no autonomous drivers in this study. The autonomous driver group's empty sector suggests that all identified drivers significantly impact SM implementation. Dependent drivers with fragile driving power are affected by driving drivers. In this work, seven drivers are "government rules and legislation" (D-1), "economic benefits or cost reduction benefits" (D-3), "customers awareness, pressure, and support" (D-4), "suppliers pressure and willingness" (D-5), "investors and shareholder pressure" (D-6), the interest of the firm in overall efficiency (D-9), and organizational capabilities and awareness, co-operative organizational structure (D-10) are detected to have weak driving but strong dependence power. These drivers are critical and require special attention to be paid to them. There is no driver in the linkage region. It indicates that no drivers have any more dependence on driving power. No driver is unstable because it does not affect any other driver. In the MICMAC analysis, drivers have strong driving power and weak dependence power. In this study, "social and environmental responsibility" (D-2), "employees motivation, health, and safety" (D-7), "scarcity of resources, and higher waste generation" (D-8), "limited space available for disposal" (D-11), and "availability and use of recycled materials in manufacturing" (D-12) are under this category and are classified as the main driver. Therefore, policymakers and professionals will assign a high priority to drivers under this group.

From the DEMATEL analysis, a reputation rank is calculated by the value of Ri + Cj. The driver having the utmost relationships with other drivers is "government rules and legislation" (D-1) with Ri + Cj score of 2.87, whereas "economic benefits or cost reduction benefits" (D-3) is the driver having the least interrelationship with the lowest Ri + Cj value of 1.53. Based on the descending values of Ri + Cj, the ranking pre-order of the selected drivers is derived as (D-1) > (D-12) > (D-8) > (D-11) > (D-2) > (D-4) > (D-7) > (D-9) > (D-6) > (D-10) > (D-5) > (D-3). "Social and environmental responsibility" (D-2), "employees motivation, health and safety" (D-7), and "scarcity of resources, and higher waste generation" (D-8) are the most prominent drivers of ISM and DEMATEL methods. Therefore, for the successful implementation of SM, priority consideration should be given to substantial influence or cause group drivers. Thus, the findings from ISM and DEMATEL processes are somewhat reliable. The integrated results of ISM-DEMATEL set the foundation for GM drivers and analyze their interrelation.

Though most findings from ISM and DEMATEL align, the actual differences were evaluated in this section. For example, drivers (D-11 and D-12) are classified as driving potential in ISM, but in DEMATEL, they belong to the affected driver. Similarly, the drivers (D-1, D-3, and D-5) are classified as cause group drivers in DEMATEL, whereas these are in the dependent driver quadrant in the ISM methodology. As mentioned earlier, high priority must be given to tackling the driver's cause/influential group. Additionally, the ISM approach does not consider any autonomous and linkage driver.

This study outcome can also be supported by past literature. The staff is generally unwilling to change in factories and adhere to their usual schedules. Top management must plan motivational and educational programs for sustainability ideas, systems, and emerging technology. Schoenherr's ISO-4000 certification, material recycling, and waste reduction are key drivers of GM. According to Chhabra et al., there are social and business necessities for the Indian automotive sector to practice and adopt green measures. Government regulations, international standards, and scarcity of resources are essential contributors to SM, which can help achieve economic and environmental objectives. Cheng and Liu argue that the ecological sustainability impact of increased levels of public attention pressured producers to enhance their environmental efficiency. Therefore, a growing understanding of environmental sustainability will foster greener manufacturing sectors.

7 Research Implications

Due to global environmental pressures and regulations, SM guidance has progressed in India, especially over the last decade. According to the findings of the research, there are 12 SM-related drivers. After assessing how drivers interrelate, it is noted that the framework applied valued the essence of the connections between drivers. Choosing the right SM driver is challenging for several industrial managers since poor driver selection leads to a financial and environmental burden. This research allows factory managers to pick drivers from the SM implementation context. From the results of this study, managers can focus more on critical drivers to maximize the performance of their SM approaches, which will contribute to the reputation of their company, customer satisfaction, worker satisfaction, etc. Finally, policymakers will build successful SM implementation mechanisms and policies depending on the novel ISM-DEMATEL findings.

We addressed the findings found with the managers, and our analysis revealed that D-2, D-7, and D-8 are critical drivers from their perspective. They have not focused on drivers, resulting in poor SM implementation due to a lack of attention toward potential solutions. The overall effectiveness of our research will be verified if these activities are incorporated into their organization. Managers should decide to help this research in supporting practical SM approaches. From the perspective of administrators and analysts, the conclusions of this analysis are firmly established, and no significant improvements have been made.

8 Conclusion

Today's dynamic market pushes businesses to boost their enterprise and environmental efficiency. Higher performance contributes to competitiveness. To remain competitive, manufacturing companies must diligently assess their output in light of green challenges, aiming to protect the environment by reducing resources, reducing pollution, and managing waste. In addition, SM has a solid requirement to comply with the global climate [34]. Therefore, we have identified 12 essential drivers that need to be addressed. The combined ISM-DEMATEL methodology helps turn ambiguous and poorly formulated systems models into structural ones. It helps create an internal dependency between drivers by classifying them as cause-and-effect group drivers.

The findings of the research show that "social and environmental responsibility" (D-2), "employees motivation, health, and safety" (D-7), and "scarcity of resources and higher waste generation" (D-8) are considered to be the most prominent driver together by ISM and DEMATEL methods. Thus, the effective implementation of SM in the Indian context must be focused more. In addition, these research implications are essential for SM in the Indian SME with specific contexts and drivers. This research offers valuable strategic guidance to key policy and industrial decision-makers in prioritizing measures to solve SM practices. This research allows scientists and practitioners to efficiently activate the collection of green drivers required to turn development from conventional to green.

Each study has its strengths and limits. However, the authors have taken sufficient precautions to ensure that SM's research findings are accurate, credible, and informative. The present model relies heavily on the panel's judgment. Furthermore, the research will explore further drivers, test this model using structural equation modeling, and conduct a detailed case study at an Indian manufacturing firm to further understand the sustainable manufacturing execution model.

Table 10 Drivers iteration level-II

Drivers	Reachability set	Antecedent set	Intersection set	Level
D-1	1,4,5,6,9,10	1,2,4,5,6,7,8,9,11,12	1,4,5,6,9	
D-2	1,2,4,5,6,7,8,9,10,11,12	2,7,8,11,12	2,7,8,11,12	
D-4	1,4,5,6,9	1,2,4,5,6,7,8,10,11,12	1,4,5,6	
D-5	1,4,5,6,9,10	1,2,4,5,6,7,8,10,11,12	1,4,5,6,10	
D-6	1,4,5,6,9,10	1,2,4,5,6,7,8,10,11,12	1,4,5,6,10	
D-7	1,2,4,5,6,7,8,9,10,11,12	2,7,8,12	2,7,8,12	
D-8	1,2,4,5,6,7,8,9,10,11,12	2,7,8,12	2,7,8,12	
D-9	1,9	1,2,4,5,6,7,8,9,10,11,12	1,9	II
D-10	4,5,6,9,10	1,2,5,6,7,8,10,11,12	5,6,10	
D-11	1,2,4,5,6,9,10,11,12	2,7,8,11,12	2,11,12	
D-12	1,2,4,5,6,7,8,9,10,11,12	2,7,8,11,12	2,7,8,11,12	

Table 11 Drivers iteration level-III

Drivers	Reachability set	Antecedent set	Intersection set	Level
D-1	1,4,5,6,10	1,2,4,5,6,7,8,11,12	1,4,5,6	
D-2	1,2,4,5,6,7,8,10,11,12	2,7,8,11,12	2,7,8,11,12	
D-4	1,4,5,6	1,2,4,5,6,7,8,10,11,12	1,4,5,6	III
D-5	1,4,5,6,10	1,2,4,5,6,7,8,10,11,12	1,4,5,6,10	III
D-6	1,4,5,6,10	1,2,4,5,6,7,8,10,11,12	1,4,5,6,10	III
D-7	1,2,4,5,6,7,8,10,11,12	2,7,8,12	2,7,8,12	
D-8	1,2,4,5,6,7,8,10,11,12	2,7,8,12	2,7,8,12	
D-10	4,5,6,10	1,2,5,6,7,8,10,11,12	5,6,10	
D-11	1,2,4,5,6,10,11,12	2,7,8,11,12	2,11,12	
D-12	1,2,4,5,6,7,8,10,11,12	2,7,8,11,12	2,7,8,11,12	

Table 12 Drivers iteration level-IV

Drivers	Reachability set	Antecedent set	Intersection set	Level
D-1	1,10	1,2,7,8,11,12	1	
D-2	1,2,7,8,10,11,12	2,7,8,11,12	2,7,8,11,12	
D-7	1,2,7,8,10,11,12	2,7,8,12	2,7,8,12	
D-8	1,2,7,8,10,11,12	2,7,8,12	2,7,8,12	
D-10	10	1,2,7,8,10,11,12	10	IV
D-11	1,2,10,11,12	2,7,8,11,12	2,11,12	
D-12	1,2,7,8,10,11,12	2,7,8,11,12	2,7,8,11,12	

Table 13 Drivers iteration level-V

Drivers	Reachability set	Antecedent set	Intersection set	Level
D-1	1	1,2,7,8,11,12	1	V
D-2	1,2,7,8,11,12	2,7,8,11,12	2,7,8,11,12	
D-7	1,2,7,8,11,12	2,7,8,12	2,7,8,12	
D-8	1,2,7,8,11,12	2,7,8,12	2,7,8,12	
D-11	1,2,11,12	2,7,8,11,12	2,11,12	
D-12	1,2,7,8,11,12	2,7,8,11,12	2,7,8,11,12	

Table 14 Drivers iteration level-VI

Drivers	Reachability set	Antecedent set	Intersection set	Level
D-2	2,7,8,11,12	2,7,8,11,12	2,7,8,11,12	VI
D-7	2,7,8,11,12	2,7,8,12	2,7,8,12	
D-8	2,7,8,11,12	2,7,8,12	2,7,8,12	
D-11	2,11,12	2,7,8,11,12	2,11,12	VI
D-12	2,7,8,11,12	2,7,8,11,12	2,7,8,11,12	VI

Table 15 Drivers iteration level-VII

Drivers	Reachability set	Antecedent set	Intersection set	Level
D-7	7,8	7,8	7,8	VII
D-8	7,8	7,8	7,8	VII

Appendixes-ISM Iteration Level

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System Cost Analysis for the Designed Permanent Magnet Synchronous Motor for Solar Pumping System

Harjyot Kalyan and Poonam Syal

1 Introduction

Agriculture has always been important to the economy of India and also continues to do so. Nearly more than half of the population is directly or indirectly engaged in agricultural activities. When it comes to remote areas, irrigation also becomes a cumbersome task. Solar pumping system has overcome the problems of orthodox pumping in remote areas for irrigation. Earlier diesel pumpsets were used which were not efficient and required regular investment for fuel. After diesel pumpsets, electric pumpsets came into prominence and are being used till now. Their major drawback is they cannot be used in a remote area as they require an electrical supply for their operation. Moreover, they put a large burden on the existing power system thus creating other problems. A solar pumping system is the best option and does not require the prerequisites of the former pumping systems. The comparison of various water pumping systems is given in Table 1.

It can be seen that the overall cost, including operating cost, of solar water pumping system is lower than other pumping systems [1]

The scope of this paper is to design a highly efficient IPMSM [2]. For this, different arrangements of rotors were simulated. V-shaped, U-shaped, and bar-shaped arrangements of magnets are simulated. Then, the results are compared with the existing induction motor and BLDC motor. Cost analysis is done so as to find the efficacy of the designed IPMSM-based pumping system.

H. Kalyan (✉) · P. Syal
Department of Electrical Engineering, National Institute of Technical Teachers' Training and Research, Chandigarh 160019, India
e-mail: harjyotkalyan1@gmail.com

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Table 1 Comparison of conventional water pumping system with solar pumping system

5 HP water pump (for operating 7 h)			
Energy source	Diesel	Electric	Solar
Efficiency (%)	30	85	97
Energy/fuel required	8.5 Ltr	22 Units	20 Units
Cost per unit (₹)	100	7	0
Fuel cost/day (₹)	850	154	0
Fuel cost/month (₹)	25,500	4620	0
Fuel cost/year (₹)	306,000	55,440	0
Five years' fuel cost (₹)	1,530,000	277,200	0
Servicing/davies and malengret replacement parts cost in 5 years (₹)	80,000	100,000	0
Initial cost (₹)	20,000	25,000	236,000
Total cost (₹)	1,630,000	402,200	236,000

2 Literature Review

There are mainly three types of motors being used for the solar submersible application. Some research has been specified below.

2.1 Induction Motor

Davies and Malengret [3] describe the design and evaluation of the water pumping system driven with an induction motor. A comparison of it was done with the DC water pumping system, and it was found to be more effective, robust, and cheaper. The system efficiencies are controlled with an optimized self-adaptive control method which uses the speed as an input. A PV panel of 350Wp is used and has an efficiency of 67%. An AC system has resulted in 15% of the total input powers with far better performances. Kopyrin et al. [4] studied the design of a 70 kW induction motor design for a submersible application and developed a Simulink model for the same. The relative error between the experimental and simulation results does not exceed more than 10%. Starikov et al. [5] developed an analytical model with an error not exceeding 0.03% for the determination of the speed of the submersible motor.

2.2 Brushless Direct Current Motor (BLDC)

Pongiannan et. Al. [6] have developed a 370W, 24 V brushless direct current motor (BLDCM)-driven self-priming pump with a two-pole configuration and compared it with induction motor. The efficiencies of the whole pumpset are compared, and it was observed that the total efficiency of the system was increased by 5%. The magnets used were ferrite magnets. Sridhar and Fernandes [7, 8] have developed a cheaper three-phase brushless direct current motor (BLDCM) with a "semi-modular dual stack" style rotor which can be used for solar-powered bore-well ESP.

Shukla and Payami [9] designed surface-mounted brushless direct current motor (BLDCM) for submersible pump application. Two-dimensional finite element analysis was done by ANSYS Maxwell, and thermal analysis was done with the help of Motor-CAD. The designed motor has good flux concentrations and low cogging torque. A motor with 2HP power is designed for a bore-well size of 4 inches. A slot pole combination of 15/10 is used, and the motor is run at 2900 RPM. The magnet material used is ferrite. The efficiency was approximately 88%.

2.3 Permanent Magnet Synchronous Motor (PMSM)

Hennebergeret. Al [10] developed a 3.7 kW permanent magnet synchronous motor (PMSM) and compared it with the existing IM for open-loop operation. Putrie [11] developed spoke type for replacing V-shape type permanent magnet synchronous motor (PMSM) with NdFeB magnets for household applications. Magnets used for the development of motors are ferrite magnets. The same output graphs were matched with the V-shape one, but some parasitic effects were found like increased torque ripples and uneven forces. Cui et al. [12] developed an optimization model to achieve maximum efficiency and minimum cogging torques. For proper design, Taguchi's robust design method is used. All results were verified with FEM analysis. The optimized model shows an efficiency increase of 5.88% and a decrease in cogging torques of 75.22%.

3 Designed IPMSM Motor

A 5 HP motor is sufficient to irrigate 2 acres of regular crops. Moreover, at a 5 HP rating, three-phase induction motor and BLDC motor are easily available for cost benchmarking. Eventually, a 5 HP rating is being used for designing the motor. For the 5 HP motor, three-phase induction motor is used for submersible application. Below this rating, a single-phase induction motor is used. So, for comparison, a similar rating is used for designing of motor, i.e., 5 HP with 415 V as the rated voltage. Table 2 presents the various parameters and their calculated values for the designing of an IPMSM motor of 5 HP rating.

In the designed permanent magnet synchronous motor, the wire selected is 1/1.42 from the KEI catalog which is polywrapped winding wire.

It confirms the IS 8783 (Part 4/ Sect. 3): 1995 solid copper conductor. Three design variables for IPMSM are magnet thickness, magnet position, and magnet pole angle.

Table 2 Parameters of the designed 5 HP permanent magnet synchronous motor

Parameters	Values	Units	Conductor/slot	33.25	
Power	5	HP		33	
Voltage	415	V	Slot area	98	mm^2
Frequency	100	Hz	Wire dia insulated	1.42	mm
Rotor dia	40	mm	Conductor area	52.26	mm^2
Pack length	250	mm	SFF	53.33	%
Power factor	0.95				
Efficiency	92	%	Width of the teeth	3	mm
Current/Phase	5.97	A	Flux density at teeth	1.21	T
Parallel paths	1		Core depth	5	Mm
Current/path	5.97	A	Flux density at core	1.63	T
Conductor in parallel	1				
Wire selected	1/1.42 mm		Conductor	33	
Wire	1	mm	Turns/phase	132	
Area	0.79	mm^2	Lmt	0.81	m
Current density	7.56	A/mm^2	Conductor dimensions	1,1.42	mm
Back-EMF per phase	230.9	V	Group in parallel	1	
Bg	0.52	T	Calculated resistance	2.46	Ω
Flux per pole	0.00408407	Wb	Total calculated length	321.65	m
Turns/phase	133		Connections	Star	

As the researches show a lot of contradictions in the determination of rotor design, so no analytical calculation was found sufficient for reaching a viable result. Therefore, genetic algorithm was used for determining the values and finalizing the rotor design. Initial calculations have been carried out, and optimization is applied to it for finding the best design [2]. The genetic algorithm parameters are selected to maximize the efficiency. The goal is set for maximization of efficiency with magnet thickness, rib, and back iron as parameters. Optimization of three motor designs was done which is shown in Fig. 1.

4 Results of Rotor Design

During the simulations, the three configurations were optimized. First, the basic model of the bar magnet was taken and then optimized. It was found that after final optimization the magnet thickness of 2.65 mm, rib of 1.9 mm, and back iron of 4 mm has given the best efficiency of 87.31%. Then, similarly a basic design for V and U design was made and optimized for the best model. The best model efficiency was calculated, and it was found that V-shaped rotor construction was the most efficient

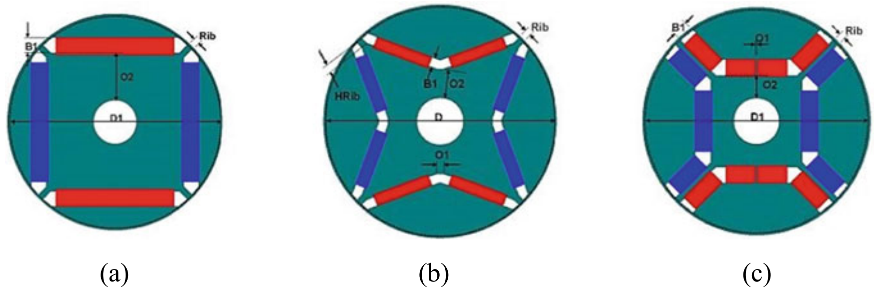

Fig. 1 Parameters used for designing and optimization, **a** bar magnet, **b** V-shaped magnet, **c** U-shaped magnet

Table 3 Results with optimization models for rotor designs of PMSM

Design	Bar magnet	V-shaped magnet	U-shaped magnet
Output power (W)	3730.6	3742.41	3730.02
Input power (W)	4272.89	4056.87	4173.5
Efficiency (%)	87.3086	92.2486	89.3737
Rated torque (N.m)	11.8749	11.9125	11.873
Fundamental RMS phase back-EMF (V)	147.17	173.665	136.53
Rated speed RPM	3000	3000	3000

model. The magnet dimensions were 20 × 2.4 mm with lengths of 50 mm. Stack of 50 mm is formed and combined to make the final length dimensions. The bridge is 2 mm thick. Table 3 indicates the efficiency-related results of the optimization models of the three types of rotor design [2].

5 Cost Comparison

The cost comparison of the permanent magnet synchronous motor (PMSM) has been done on the basis of the weights of its material and magnet cost. The laminations which can be used for motor development vary with thickness and core loss. IS 648 specifies the CRNO laminations grades. For industrial motors, the laminations can be 50C400, 50C470, 50C600, 50C700, 50C800, 50C1000, 65C470, 65C600, 65C700, 65C800, and 65C1000. The cost of the related lamination materials curve is shown in Fig. 2.

The material chosen is 50C470, which costs approx. ₹ 375/kg. The winding used for the submersible motor is PVC-wrapped copper wire of KEI. The cost is approx. ₹870/kg. The VFD used for PMSM and BLDC and Star-Delta starter used for IM cost are dependent on the quotations received for SIEMENS. Also, the solar panel

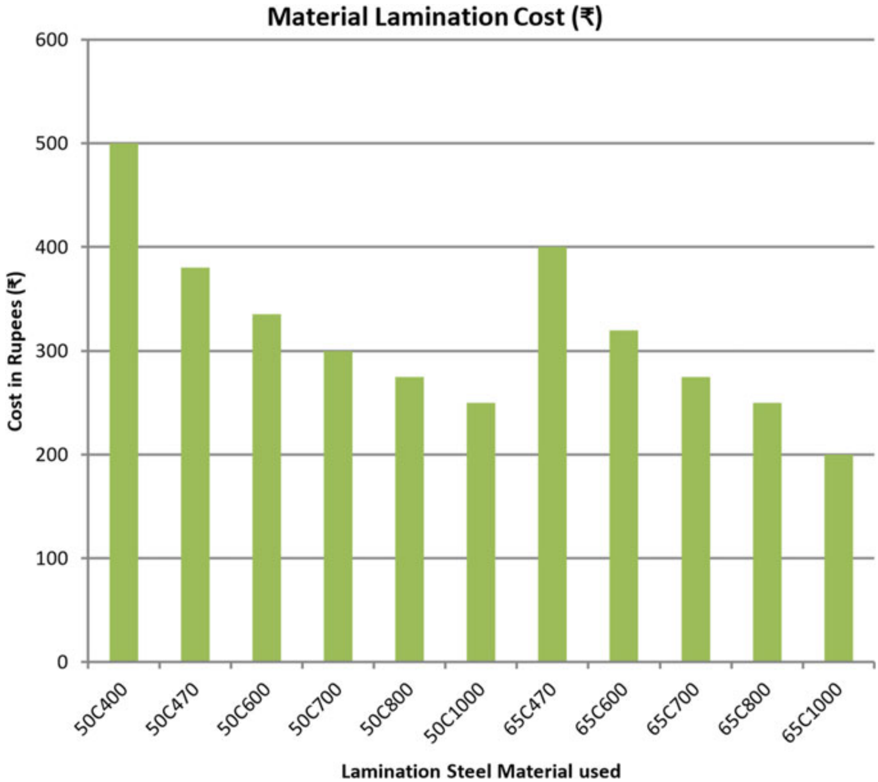

Fig. 2 Cost of various steel laminations

used for producing the motor output of 5 HP depends on the motor input. So, the solar panel required depends upon the motor and controller efficiency. In the design of the solar pumping system, the total setup cost is evaluated accordingly.

6 Solar System Costing

A rating of 540 Wp of a "Waaree Company" is considered for costing. As per its data, the cost is ₹55.5/W with solar panel, circuit breakers, wiring, erection, planning, and commissioning, with the metalling structure used for erection. Table 4 presents the cost of solar water pumping systems for different motors.

The cost of an efficiently designed motor is ₹ 2,32,977/-, which is lesser than the cost of a solar pumping system driven by an induction motor and BLDC motor. Figure 3 shows the comparison in terms of the cost of different motors in the water pumping system. The total system cost is categorized into solar PV panel cost, stator conductor cost, stator steel cost, and rotor cost with magnets.

Table 4 Solar pumping system cost comparison with different motors

Motor	Induction	BLDC	PMSM
Efficiency	78%	86%	92%
Solar required for 5 HP motor output (kW)	4.74	4.31	4.01
Solar cost/W (panel including EPC)	55.5	55.5	55.5
Solar panel cost (₹)	263,168.01	239,335.6	222,481.04
Armature conductor weights (kg)	2.27	1.41	1.68
Length of conductor used (m)	45	26	35
Conductor cost/meter	50	50	50
Total conductor cost	2250	1300	1750
Stator steel lamination (kg)	9.59	3.47	5.55
Rotor steel lamination weight (kg)	2.31	1.39	1.61
Lamination steel 50C470 cost/kg (₹/kg)	350	350	350
Total steel cost (₹)	4165	1701	2506
Rotor copper weight (kg)	1.018	–	–
End ring copper weight (kg)	0.09	–	–
Total copper weight (kg)	1.10	–	–
Rotor copper cost/kg (₹/kg)	800	–	–
Total copper cost in rotor (₹)	887.39	–	–
For PMSM and BLDC, rotor has to be divided into 50 mm stacks as producing a long magnet of 200 mm and 250 mm is difficult and costly. So BLDC has 8 poles, i.e., 8 poles × 2 magnets × 4 segments = 64 magnets. For PMSM, it has 4 poles, i.e., 4 poles × 2 magnets × 5 segments = 40 magnets			
Rotor magnets number	–	64	40
Cost/Magnet as per quotation ($/piece)	–	1.1	2
(Costing has been done with Ni-Cu-Ni coating and supplier (NeoMagnet in China quotes has been used))			
$ to ₹	–	78	78
Total magnet cost (₹)	–	5491.2	6240
Total solar pumping system cost (₹)	270,470.41	247,827.86	232,977.04

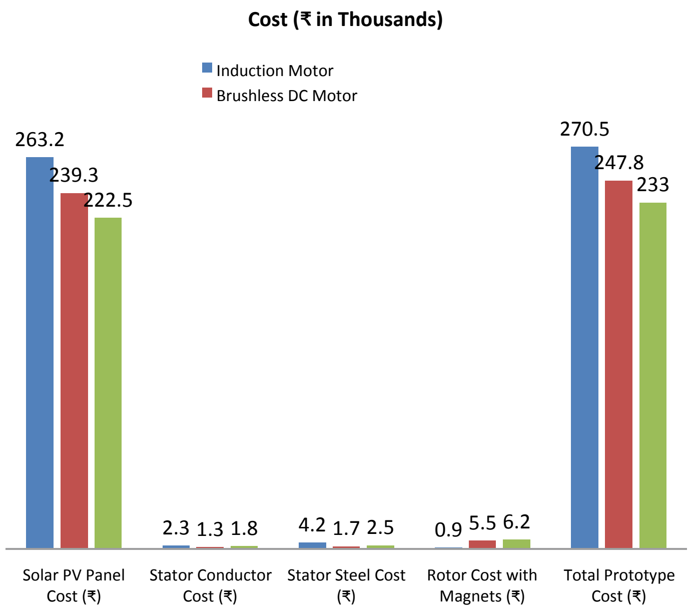

Fig. 3 Comparison of water pumping system cost based on different motors

7 Conclusion

From the results, it can be concluded that motor efficiency plays an important role in the cost-effectiveness of solar pumping systems. After the comparison, it was found that the designed highly efficient permanent magnet synchronous motor overall setup cost was found to be lesser than the induction motor and brushless DC motor as per the cost analysis. The PMSM motor was 6% lower in cost than the BLDC motor-driven solar pumping system and 16% lower than the induction motor-driven solar pumping system.

Future studies can be carried out with the design of motors that are less costly than BLDC and PMSM. This may be achieved with the development of synchronous reluctance motors for pumping applications. Since these motor does not have magnets, they can be cheaper and may be a better option in terms of efficiency and cost.

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Numerical Simulation of Primary Suspension in FIAT Bogie for Vertical Excitation

Namdev Latpate and Sachin Barve

Nomenclature

ICF	Integral coach factory
LHB	Linke Hofmann Busch
FIAT	Fabric Italina de Automobil Torino
DOF	Degree of freedom
CG	Centre of gravity
GC	Geometric centre
CAD	Computer-aided design
FEA	Finite element analysis

1 Introduction

Any country's economy is majorly influenced by its transport system, and in India, the Indian railway is the backbone of Indian transport system. Speed of transport and comfort during transport is the main domain where major research is going on. In Indian railways, ICF and LHB coaches are used in which 'LHB coaches are superior w.r.t passenger comfort, safety, speed, corrosion, maintenance, and aesthetics. These coaches are slightly longer as compared to ICF design resulting in more carrying capacity. FIAT bogies are used by LHB coaches' [1]. The function of the bogie is

N. Latpate (✉) · S. Barve
Mechanical Department, VJTI, Matunga, Mumbai, Maharashtra 400019, India
e-mail: nrlatpate_m20@me.vjti.ac.in

S. Barve
e-mail: ssbarve@me.vjti.ac.in

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to support the coach and minimise the effect of excitation due to track on the coach with the help of a suspension system.

Spring is the core element in suspension system. The function of spring is to absorb shock and vibration. There are several ways by which suspension system fail. Spring failure is one of them. Such a spring failure is observed in the outer spring of primary suspension in FIAT bogie. Indian railway follows maintenance schedule. At the time of third inspection, it is observed that the outer spring of primary suspension fails. Up to March 2019, total 144 failures observed [2]. The spring mainly fails at first or second coil. 'The failure investigation reports state that the fracture plane is inclined at 45 degrees to the axis of the rod' [2], and in this study, dynamic deflection of primary suspension in FIAT bogie is calculated for vertical track excitation.

Very little research on the spring of FIAT bogie is done, and till now, no research is done for dynamic or fatigue analysis of spring. But for ICF bogie spring and ground vehicle suspension spring failure, literature is available. Kumbhalkar et al. did a literature study of ICF bogie spring failure from 1998 to 2020 and find out that material investigation, static analysis, dynamic analysis, and fatigue analysis are the analysis used to find the spring failure. To do those analyses, spectroscopy, analytical method, experimental method, and finite Element method are used [3]. Prawoto et al. studied the failure of the automobile spring and found out that surface defects and corrosion are reasons for failure [4]. Singh et al. studied dynamic response for suspended equipment for LHB coach for this, and track data is collected using track recoding car. The random vertical irregularities of rail are the main source of vibration and lead to discomfort and noise [5]. Perichiyappan et al. studied primary suspension spring by considering weight, centrifugal couple, and gyroscopic couple for curved track and found outer spring fails under shear stress for chromium vanadium material [6]. Pavan Kumar et al. suggested chrome vanadium material of spring can be replaced by 60Si2MnA by considering analytical and ANSYS results [7]. Kumbhalkar et al. examined primary suspension spring failure for ICF bogie by considering two DOF mathematical model for the bogie and observed spring failure under dynamic loading [8].

Tugce et al. studied dynamics of high-speed railway using Simulink. They considered 10 DOF and 17 DOF models of a wagon to analyse vertical track irregularities by Simulink and observer; for vertical motion with the same phase for both rails, the 10 DOF and 17 DOF models give the same response [9]. From this, it is clear that the 4 DOF model is sufficient to analyse FIAT bogie for vertical track excitation. Hamed et al. analysed the effect on full vehicle model suspension performance by the stiffness of spring. The 7 DOF Simulink model is created and output that is acceleration and displacement is validated using experimental data [10].

The literature mainly focuses on dynamic analysis of ICF bogie and road vehicle. This study focuses on numerical simulation of primary suspension in FIAT bogie. So first mathematical modelling is done by considering FIAT bogie as a 4 DOF system, and its controllability is checked. The Simulink modelling of the mathematical model is done to check the response of primary suspension for track excitation.

2 Mathematical Modelling and Controllability Check

Mathematical modelling of a system is nothing but defining the system in the form of governing differential equations of equivalent spring mass damper system. The governing differential equations are then written in state space representation. Based on the state space, controllability of the system is checked.

2.1 Mathematical Modelling

The FIAT bogie has four primary suspensions and two secondary suspensions as shown in Fig. 1. The system is considered with 4 DOF and is shown in Fig. 2. Those are vertical and roll motion of secondary sprung mass represented by Z and θ and two vertical motion of the left and right primary sprung masses represented by Y and X. Due to eccentric sitting arrangement of passengers, the CG is shifted 31 mm from GC. Governing differential equations of these sprung masses are written as

$$\begin{aligned} Ms\ddot{z} &+ 2(Ks)z + (Ks*a - Ks*b)\theta - Ks*(y+x) \\ &+ (Cs+Cs)\dot{z} + (Cs*a - Cs*b)\dot{\theta} - Cs*(\dot{y}+\dot{x}) = 0 \end{aligned} \tag{1}$$

$$\begin{aligned} Iz\dot{\theta} &+ (Ks*a - Ks*b)z + \left(Ks*a^2 + Ks*b^2\right)\theta - Ks*a*y - Ks*b*x \\ &+ (Cs*a - Cs*b)\dot{z} + \left(Cs*a^2 + Cs*b^2\right)\dot{\theta} - Cs*a*\dot{y} - Cs*b*\dot{x} = 0 \end{aligned} \tag{2}$$

$$\begin{aligned} Mu\ddot{y} &- Ks*z - Ks*a*\theta + (2*Kp + Ks)*y - Cs*\dot{z} \\ &- Cs*a\dot{\theta} - (2*Cp + Cs)*\dot{y} = Kp*W1 + Kp*W2 \end{aligned} \tag{3}$$

$$\begin{aligned} Mu\ddot{x} &- Ks*z - Ks*b*\theta + (2*Kp + Ks)*x - Cs*\dot{z} \\ &+ Cs*b*\dot{\theta} - (2*Cp + Cs)*\dot{x} = Kp*W3 + Kp*W4 \end{aligned} \tag{4}$$

where.

'Ms = 25,324 kg (Secondary sprung mass),
Iz = 69,135.6 kg m^2 (Moment of inertia secondary sprung mass),
Mu = 1305.5 kg (Primary sprung mass),
Kp = 755,000 N/m (Primary spring stiffness),
Ks = 370,600 N/m (Secondary spring stiffness),
Cp = 14,167 Ns/m (Primary damping coefficient),
Cs = 17,500 Ns/m (Secondary damping coefficient)' [1, 11],
a = 0.805 m (Distance of CG from left side),
b = 0.867 m (Distance of CG from right side),

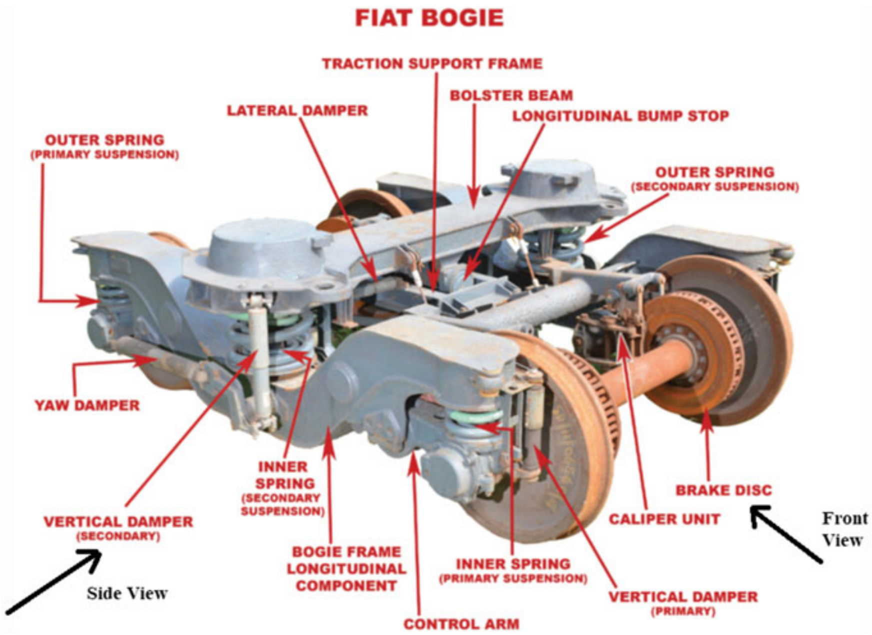

Fig. 1 FIAT bogie assembly [1]

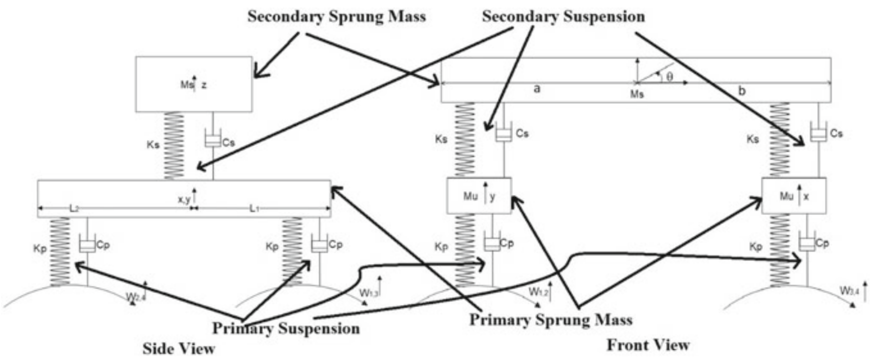

Fig. 2 Schematic representation of FIAT bogie

Wi = i = 1,2,3,4 (Track unevenness as input)

2.2 *State Space Representation and Controllability of System*

The state space representation of the system is a matrix representation of the dynamic system in the form of.

'State equation is X(t) = A (t) + B u(t).

Output equation is Y(t) = C X(t) + D u(t).

Controllability is defined as if a control vector u(t) exists that will transfer the system from any initial state $x(t_o)$ to some final state x(t) in a finite interval time' [12]. Kalman's test is used to check the controllability of the system that is rank of the control matrix [M] which is checked if the rank is equal to the number of state space variables then the system is controlled. The 'M' matrix is given by [12],

$[M] = [B: AB: A^2B:\ldots:A^{n-1}B]$.

The controllability of the system is checked in the MATLAB software, and the system is found to be continuous and controllable.

2.3 Static Deflection of Spring

The static deflection of primary spring is due to static weight of coach, secondary sprung mass, and primary sprung mass. Half mass of coach and secondary sprung mass is given by Ms. and its weight is given by Ws.

$$W_s = M_s * f = 243984.51 \text{ N} \tag{5}$$

As the coach is eccentric, weight of half coach and secondary sprung mass is acting more on one side which is given by Wu1.

$$\text{Wu1} = \frac{w_s * b}{a + b} = 126515.8913 \text{ N} \tag{6}$$

Total weight acting on one side of bogie on two primary spring is given as Wp.

$$\text{Wp} = \text{Wu1} + \text{Mu*g} = 139322.8463 \text{ N} \tag{7}$$

So, weight action on one spring is half of Wp, which is 69661.42315 N.

Static deflection of spring is given as δ_s

$$\delta_s = \text{Wp/Kp*2} = 92.27 \text{ mm} \tag{8}$$

3 Numerical Simulation

Numerical simulation tools are used to analyse the system efficiently. Here, for the study, MATLAB Simulink R2015a is used to analyse the system response for random road excitation.

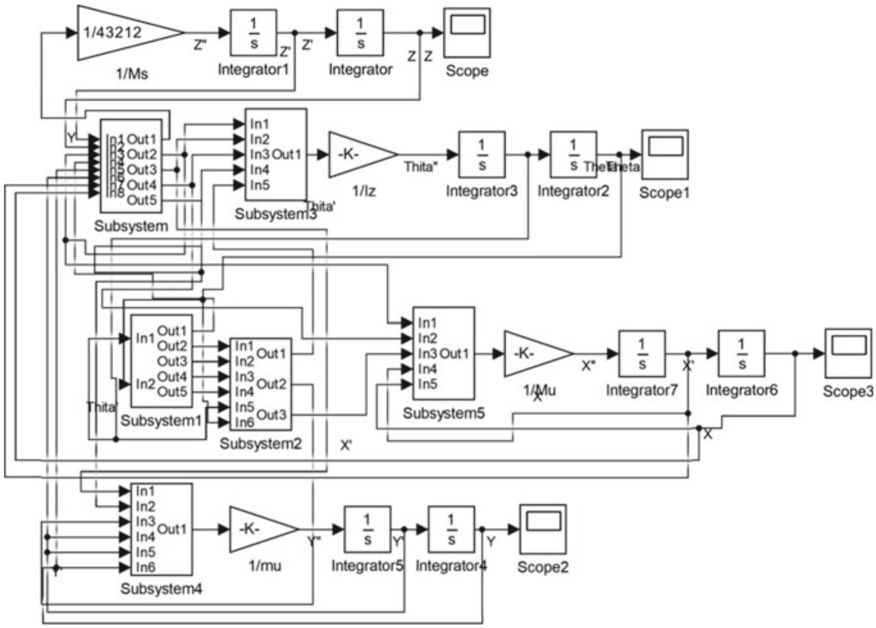

Fig. 3 Simulink model of FIAT bogie

3.1 Simulink Modelling

Simulink is the graphical representation of differential equations and is done using different blocks and signals. By creating such blocks and signals considering governing differential Eqs. 1–4, complete system is generated which is shown in Fig. 3.

Once the model is created in Simulink, then the system parameter values such as stiffness, damping, mass, and moment of inertia are provided to the model. For the analysis of response of system, track data is give as input to the model. The actual track data for 730 m is given [13].

3.2 Deformation of Spring

The spring has two types of deformations which are static and dynamic. The static deformation is a deformation of spring due to the weight of the coach and bogie. Total deflection is shown in Fig. 4.

As the CG of the bogie is shifted to one side, side spring will deform more. By considering a linear spring, the static deformation of the primary suspension spring is 92.3 mm. Dynamic deformation is the deformation of spring under running condition

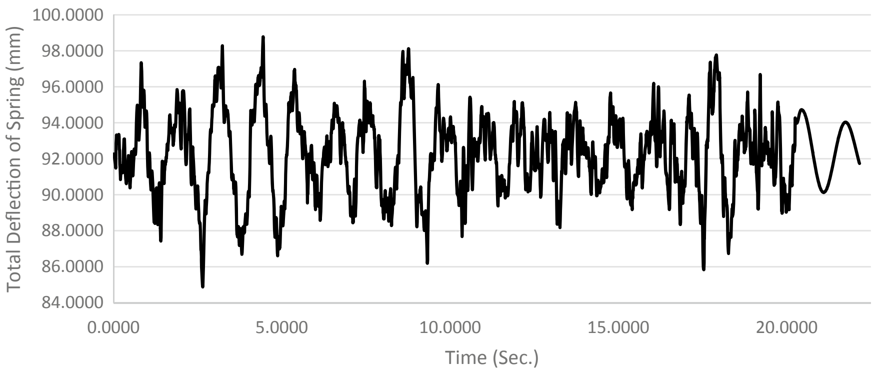

Fig. 4 Total deflection of spring with respect to time

due to track excitation which is the difference between primary sprung mass response and input track excitation. The total deformation of springs is the addition of static and dynamic deformation.

4 Conclusion and Scope

In this study, the deflection of outer spring in primary suspension in FIAT bogie is analysed by doing mathematical modelling and numerical simulation. Based on the study, following conclusions are inferred.

1. The rank of the M matrix is same as the number of state space variables, so the mathematical model of FIAT bogie is continuous and controllable.
2. The static deflection of the spring is 92.3 mm, and dynamic deflection is about 14 mm; this can lead to dynamic failure of the spring.

In the future, life of spring can be calculated from the dynamic deflection of the spring, and also using FEA method, location of maximum shear stress can be evaluated.

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