IFIP AICT 535

Ilkyeong Moon
Gyu M. Lee
Jinwoo Park
Dimitris Kiritsis
Gregor von Cieminski (Eds.)

Advances in Production Management Systems

Production Management for Data-Driven, Intelligent, Collaborative, and Sustainable Manufacturing

IFIP WG 5.7 International Conference, APMS 2018
Seoul, Korea, August 26–30, 2018
Proceedings, Part I

1 Part I

Springer

IFIP Advances in Information and Communication Technology 535

Editor-in-Chief

IFIP – The International Federation for Information Processing

IFIP was founded in 1960 under the auspices of UNESCO, following the first World Computer Congress held in Paris the previous year. A federation for societies working in information processing, IFIP's aim is two-fold: to support information processing in the countries of its members and to encourage technology transfer to developing nations. As its mission statement clearly states:

IFIP is the global non-profit federation of societies of ICT professionals that aims at achieving a worldwide professional and socially responsible development and application of information and communication technologies.

IFIP is a non-profit-making organization, run almost solely by 2500 volunteers. It operates through a number of technical committees and working groups, which organize events and publications. IFIP's events range from large international open conferences to working conferences and local seminars.

The flagship event is the IFIP World Computer Congress, at which both invited and contributed papers are presented. Contributed papers are rigorously refereed and the rejection rate is high.

As with the Congress, participation in the open conferences is open to all and papers may be invited or submitted. Again, submitted papers are stringently refereed.

The working conferences are structured differently. They are usually run by a working group and attendance is generally smaller and occasionally by invitation only. Their purpose is to create an atmosphere conducive to innovation and development. Refereeing is also rigorous and papers are subjected to extensive group discussion.

Publications arising from IFIP events vary. The papers presented at the IFIP World Computer Congress and at open conferences are published as conference proceedings, while the results of the working conferences are often published as collections of selected and edited papers.

IFIP distinguishes three types of institutional membership: Country Representative Members, Members at Large, and Associate Members. The type of organization that can apply for membership is a wide variety and includes national or international societies of individual computer scientists/ICT professionals, associations or federations of such societies, government institutions/government related organizations, national or international research institutes or consortia, universities, academies of sciences, companies, national or international associations or federations of companies.

More information about this series at http://www.springer.com/series/6102

Ilkyeong Moon · Gyu M. Lee
Jinwoo Park · Dimitris Kiritsis
Gregor von Cieminski (Eds.)

Advances in Production Management Systems

Production Management for Data-Driven, Intelligent, Collaborative, and Sustainable Manufacturing

IFIP WG 5.7 International Conference, APMS 2018
Seoul, Korea, August 26–30, 2018
Proceedings, Part I

Springer

Editors
Ilkyeong Moon
Seoul National University
Seoul
Korea

Gyu M. Lee
Pusan National University
Busan
Korea

Jinwoo Park
Seoul National University
Seoul
Korea

Dimitris Kiritsis
EPFL
Lausanne
Switzerland

Gregor von Cieminski
ZF Hungária Kft
Eger
Hungary

ISSN 1868-4238 ISSN 1868-422X (electronic)
IFIP Advances in Information and Communication Technology
ISBN 978-3-319-99703-2 ISBN 978-3-319-99704-9 (eBook)
https://doi.org/10.1007/978-3-319-99704-9

Library of Congress Control Number: 2018952244

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

We have already experienced three major industrial revolutions since the 18th century. These revolutions brought innovation in productivity for industry, the public, and individuals. Surprisingly, another new industrial revolution, the fourth one, has been rapidly approaching us in every sector of industry. Key components of the fourth industrial revolution include big data analysis, artificial intelligence, and virtual and augmented reality. These components also had a huge impact on the manufacturing sector and research on production management. Therefore, the 2018 Advances in Production Management Systems Conference played a leading role in the academic field. The core of our contributions strive to realize smart production management for data-driven, intelligent, collaborative, and sustainable manufacturing. Our topics of interest include Global Supply Chain, Knowledge-Based Production Management, Collaborative Networks, Sustainability and Production Management, Industry 4.0, and Smart City.

We welcomed leading experts from academia, industry, and research institutes from all over the world to the 2018 Advances in Production Management Systems Conference in Seoul, Korea, to exchange ideas, concepts, theories, and experiences. A large international panel of experts reviewed all the papers and selected the best ones to be included in these conference proceedings. In this collection of papers, the authors provide their perspectives along with their concepts and solutions for the challenges that industrial companies are confronted with, to offer great opportunities, new technologies, collaboration, and developments.

The proceedings are organized in two parts:

- Production Management for Data-Driven, Intelligent, Collaborative, and Sustainable Manufacturing (Volume 1)
- Smart Manufacturing for Industry 4.0 (Volume 2)

We hope that our readers will discover valuable new ideas and insights in these proceedings. The conference was supported by the International Federation of Information Processing (IFIP) and was organized by the IFIP Working Group 5.7 on Advances in Production Management Systems, the Korean Institute of Industrial Engineers (KIIE), and the Institute for Industrial Systems Innovation at Seoul National University. We would like to thank all contributors for their research and for their willingness to share ideas and results. We are also indebted to the members of the IFIP Working Group 5.7, the Program Committee members, and Organizing Committee members for their support in the review of the papers. Finally, we appreciate the generous support from both the Korean Federation of Science and Technology

Societies (KOFST) grant funded by the Korean government and Korea Land and Housing Corporation.

August 2018

Ilkyeong Moon
Gyu M. Lee
Jinwoo Park
Dimitris Kiritsis
Gregor von Cieminski

Organization

Honorary Co-chairs

Dimtris Kiritsis	EPFL, Switzerland
Jinwoo Park	Seoul National University, Korea

Conference Chair

Ilkyeong Moon	Seoul National University, Korea

Advisory Committee

Byung Kyu Choi	KAIST, Korea
Chi Hyuck Jun	POSTEC, Korea
Kap Hwan Kim	Pusan National University, Korea
Tae Eog Lee	KAIST, Korea
Young Hoon Lee	Yonsei University, Korea

Program Co-chairs

Gregor von Cieminski	ZF Hungária Kft, Hungary
Gyu M. Lee	Pusan National University, Korea

Program Committee

Bhaskar Bhandarkar	Indian Institution of Industrial Engineering, India
Chen-Fu Chien	National Tsing Hua University, Taiwan
Shuo-Yan Chou	National Taiwan University of Science and Technology, Taiwan
Xuehao Feng	Zhejiang University, China
Chin-Yin Huang	Tunghai University, Taiwan
Szu-Hao Huang	National Chiao Tung University, Taiwan
Takashi Irohara	Sophia University, Japan
Yasutaka Kainuma	Tokyo Metropolitan University, Japan
Harish Kutemate	Indian Institution of Industrial Engineering, India
Bo Lu	Dalian University, China
Hiroaki Matsukawa	Keio University, Japan
Koichi Nakade	Nagoya Institute of Technology, Japan
Izabela Ewa Nielsen	Aalborg University, Denmark
Taeho Park	San Jose State University, USA
Subrata Saha	Institute of Engineering and Management, India
Biswajit Sarkar	Hanyang University, Korea

Hongfeng Wang	Northeastern University, China
Ruiyou Zhang	Northeastern University, China

Organizing Committee

Jung Woo Baek	Chosun University, Korea
Tai-Woo Chang	Kyonggi University, Korea
Yoon Seok Chang	Korea Aerospace University, Korea
Taesu Cheong	Korea University, Korea
Hyunbo Cho	POSTECH, Korea
Yong–Chan Choi	KAIST, Korea
Byung Do Chung	Yonsei University, Korea
Kwanghun Chung	Hongik University, Korea
Byung–Hyun Ha	Pusan National University, Korea
Kyu Hwan Han	Seoul National University, Korea
Yoo Suk Hong	Seoul National University, Korea
Young Jae Jang	KAIST, Korea
Bong Ju Jeong	Yonsei University, Korea
Hong-Bae Jun	Hongik University, Korea
Changmuk Kang	Soongsil University, Korea
Yuncheol Kang	Hongik University, Korea
Jun-Gyu Kang	Sungkyul University, Korea
Byung-In Kim	POSTECH, Korea
Byung Soo Kim	Incheon National University, Korea
Dongsoo Kim	Soongsil University, Korea
Duck Young Kim	UNIST, Korea
Hwa–Joong Kim	Inha University, Korea
Chang Seong Ko	Kyungsung University, Korea
Chulung Lee	Korea University, Korea
Dong Ho Lee	Hanyang University, Korea
Kangbok Lee	POSTECH, Korea
Kyungsik Lee	Seoul National University, Korea
Taesik Lee	KAIST, Korea
Dug Hee Moon	Changwon National University, Korea
Sang Do Noh	Sungkyunkwan University, Korea
Kun Soo Park	KAIST, Korea
Kwangyeol Ryu	Pusan National University, Korea
Jong–Ho Shin	Chosun University, Korea
Eun Suk Suh	Seoul National University, Korea

International Advisory Committee

Erry Yulian Triblas Adesta	International Islamic University Malaysia, Malaysia
Erlend Alfnes	Norwegian University of Science and Technology, Norway
Thecle Alix	IUT Bordeaux Montesquieu, France

Susanne Altendorfer-Kaiser	Montanuniversität Leoben, Austria
Farhad Ameri	Texas State University, USA
Bjørn Andersen	Norwegian University of Science and Technology, Norway
Eiji Arai	Osaka University, Japan
Frédérique Biennier	INSA Lyon, France
Umit S. Bititci	Heriot Watt University, UK
Magali Bosch-Mauchand	Université de Technologie de Compiègne, France
Abdelaziz Bouras	Qatar University, Qatar
Jim Browne	University College Dublin, Ireland
Luis Camarinha-Matos	Universidade Nova de Lisboa, Portugal
Sergio Cavalieri	University of Bergamo, Italy
Stephen Childe	Plymouth University, UK
Hyunbo Cho	Pohang University of Science and Technology, Korea
Gregor von Cieminski	ZF Hungária Kft, Hungary
Catherine Da Cunha	Ecole Centrale de Nantes, France
Frédéric Demoly	Université de Technologie de Belfort-Montbéliard, France
Shengchun Deng	Harbin Institute of Technology, China
Melanie Despeisse	Chalmers University of Technology, Sweden
Alexandre Dolgui	IMT Atlantique Nantes, France
Slavko Dolinšek	University of Ljubljana, Slovenia
Heidi Carin Dreyer	Norwegian University of Science and Technology, Norway
Eero Eloranta	Helsinki University of Technology, Finland
Soumaya El Kadiri	Texelia AG, Switzerland
Christos Emmanouilidis	Cranfield University, UK
Åsa Fasth-Berglund	Chalmers University, Sweden
Jan Frick	University of Stavanger, Norway
Paolo Gaiardelli	University of Bergamo, Italy
Adriana Giret	Universidad Politécnica de Valencia, Spain
Bernard Grabot	INP-ENIT (National Engineering School of Tarbes), France
Samuel Gomes	Belfort-Montbéliard University of Technology, France
Gerhard Gudergan	FIR Research Institute for Operations Management, Germany
Thomas R. Gulledge Jr.	George Mason University, USA
Hironori Hibino	Tokyo University of Science, Japan
Hans-Henrik Hvolby	Aalborg University, Denmark
Dmitry Ivanov	Berlin School of Economics and Law, Germany
Harinder Jagdev	National University of Ireland at Galway, Ireland
John Johansen	Aalborg University, Denmark
Toshiya Kaihara	Kobe University, Japan
Dimitris Kiritsis	Ecole Polytechnique Fédérale de Lausanne, Switzerland

Tomasz Koch	Wroclaw University of Science and Technology, Poland
Pisut Koomsap	Asian Institute of Technology, Thailand
Gül Kremer	Iowa State University, USA
Boonserm Kulvatunyou	National Institute of Standards and Technology, USA
Thomas R. Kurfess	Georgia Institute of Technology, USA
Andrew Kusiak	University of Iowa, USA
Lenka Landryova	Technical University of Ostrava, Czech Republic
Jan-Peter Lechner	First Global Liaison, Germany
Ming K. Lim	Chongqing University, China
Hermann Lödding	Hamburg University of Technology, Germany
Marco Macchi	Politecnico di Milano, Italy
Vidosav D. Majstorovich	University of Belgrade, Serbia
Adolfo Crespo Marquez	University of Seville, Spain
Gökan May	Ecole Polytechnique Fédérale de Lausanne, Switzerland
Jörn Mehnen	Strathclyde University Glasgow, UK
Hajime Mizuyama	Aoyama Gakuin University, Japan
Ilkyeong Moon	Seoul National University, Korea
Dimitris Mourtzis	University of Patras, Greece
Irenilza de Alencar Naas	UNIP Paulista University, Brazil
Masaru Nakano	Keio University, Japan
Torbjörn Netland	ETH Zürich, Switzerland
Gilles Neubert	EMLYON Business School Saint-Etienne, France
Sang Do Noh	Sungkyunkwan University, Korea
Manuel Fradinho Duarte de Oliveira	SINTEF, Norway
Jinwoo Park	Seoul National University, Korea
François Pérès	Université de Toulouse, France
Fredrik Persson	Linköping Institute of Technology, Sweden
Selwyn Piramuthu	University of Florida, USA
Alberto Portioli-Staudacher	Politecnico di Milano, Italy
Vittaldas V. Prabhu	Pennsylvania State University, USA
Ricardo José Rabelo	Federal University of Santa Catarina, Brazil
Mario Rapaccini	Florence University, Italy
Joao Gilberto Mendes dos Reis	UNIP Paulista University, Brazil
Ralph Riedel	TU Chemnitz, Germany
Asbjörn Rolstadås	Norwegian University of Science and Technology, Norway
David Romero	Tecnologico de Monterrey University, Mexico
Christoph Roser	Karlsruhe University of Applied Sciences, Germany
Martin Rudberg	Linköping University, Sweden
Thomas E. Ruppli	University of Basel, Switzerland
Krzysztof Santarek	Warsaw University of Technology, Poland

John P. Shewchuk	Virginia Polytechnic Institute and State University, USA
Dan L. Shunk	Arizona State University, USA
Riitta Smeds	Aalto University, Finland
Vijay Srinivasan	National Institute of Standards and Technology, USA
Johan Stahre	Chalmers University, Sweden
Kathryn E. Stecke	University of Texas at Dallas, USA
Kenn Steger-Jensen	Aalborg University, Denmark
Volker Stich	FIR Research Institute for Operations Management, Germany
Richard Lee Storch	University of Washington, USA
Jan Ola Strandhagen	Norwegian University of Science and Technology, Norway
Stanislaw Strzelczak	Warsaw University of Technology, Poland
Shigeki Umeda	Musashi University, Japan
Marco Taisch	Politecnico di Milano, Italy
Kari Tanskanen	Aalto University School of Science, Finland
Ilias Tatsiopoulos	National Technical University of Athens, Greece
Sergio Terzi	Politecnico di Milano, Italy
Klaus-Dieter Thoben	Universität Bremen, Germany
Jacques H. Trienekens	Wageningen University, The Netherlands
Mario Tucci	Universitá degli Studi di Firenze, Italy
Gündüz Ulusoy	Sabancı University, Turkey
Bruno Vallespir	University of Bordeaux, France
Agostino Villa	Politecnico di Torino, Italy
Hans-Hermann Wiendahl	University of Stuttgart, Germany
Joakim Wikner	Jönköping University, Sweden
Hans Wortmann	Groningen University, The Netherlands
Thorsten Wuest	West Virginia University, USA
Iveta Zolotová	Technical University of Košice, Slovakia

Marco Garetti Doctoral Workshop

Co-chairs

Gyu M. Lee	Pusan National University, Korea
Ralph Riedel	TU Chemnitz, Germany

Academic Reviewers and Participants

Gregor von Cieminski	ZF Hungária Kft, Hungary
Paolo Gaiardelli	University of Bergamo, Italy
Adriana Giret	Universidad Politécnica de Valencia, Spain
Gyu M. Lee	Pusan National University, Korea
Ming K. Lim	Chongqing University, China
Gökan May	Ecole Polytechnique Fédérale de Lausanne, Switzerland

Ralph Riedel	TU Chemnitz, Germany
David Romero	Tecnologico de Monterrey University, Mexico
Stanislaw Strzelczak	Warsaw University of Technology, Poland

Sponsors for APMS 2018

College of Engineering, Seoul National University
IFIP WG 5.7 Advances in Production Management Systems
Institute for Industrial Systems Innovation, Seoul National University
Korea Land & Housing Corporation
Korean Federation of Science and Technology Societies
Korean Institute of Industrial Engineers

Contents – Part I

Operations Management in Engineer-to-Order Manufacturing

Product-Service Systems Customer-Driven Innovation and Value Co-creation

Collaborative Networks

Global Supply Chain - Supply Chain Management

Knowledge Based Production Planning and Control

Knowledge Based Engineering

Contents – Part II

Manufacturing Performance Management in Smart Factories

Industry 4.0 - Digital Twin

Industry 4.0 - Smart Factory

Industry 4.0 – Collaborative Cyber-physical Production and Human Systems

Lean and Green Manufacturing

Reverse Logistics Route Selection Using AHP: A Case Study of Electronics Scrap from Pakistan

Fahad Mushtaq[1], Muhammad Shafiq[1,2(✉)], Matteo Mario Savino[2], Touqeer Khalid[1], Marialuisa Menanno[2], and Ali Fahad[1]

[1] Department of Industrial Engineering, University of Engineering and Technology, Taxila 47050, Pakistan
shafiqaatirl@gmail.com
[2] Department of Engineering, University of Sannio, 82100 Benevento, Italy

Abstract. Selection of optimal route among available choices in the presence of various factors has been a prime focus in logistics. In this paper, Analytical Hierarchy Process (AHP) is used for selection of optimum route among available options for revere logistics of electronics scrap from Pakistan to the industry using End of Life (EOL) products as there raw material. The main objective of this study is to find out the optimal reverse logistic path for electronic scrap considering: cost of transportation, time of transportation, volume of goods to be transported, nature of goods (refurbished, recyclable or scrap), and financial value of the goods being transported. Recently developed China Pakistan Economic Corridor named as CPEC is also considered among available routes which are being analyzed. The results show that CPEC is the best possible route. In addition, the proposed mechanism also provides hierarchical list for the possible route preferences which helps in finding an alternate in case the best/better route isn't available due to some unavoidable factors.

Keywords: Reverse logistics · Supply chain
China Pakistan Economic Corridor (CPEC)
Analytical Hierarchy Process (AHP)

1 Introduction

Logistics management has established to be a key factor in supply chains. Realization of customers' value has increased the role of reverse logistics (RL) as it can play a key role in customers' satisfaction. RL has not only been used by companies for returning of goods for the purpose of recycling/remanufacturing but also useful in warranty claims and rejections.

Over past few decades, the World is digitized and use of electronic gadgets has increased exponentially. This development has given birth to an anti-climactic waste element known as electronic scrap [1]. The most interesting thing that differentiate such type of scrap from other industrial scrap is that it consists of hazardous but expensive metals. The recovery of these metal can be useful. Pakistan being more close to china and a good consumer market for electronic appliances and gadgets is facing

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 3–10, 2018.
https://doi.org/10.1007/978-3-319-99704-9_1

environmental issues [2]. In China, there are various facilities that can recycle this electronic scrap and reuse it as raw material, thereby, saving cost and making environment clean. China is the major producer of electronic products so it is also largest user of all raw and auxiliary materials in the electronic industry [3, 4]. In this way, China is responsible for almost 70% of the electronic waste. Chinese goods are supplied using different trade routes. CPEC is the latest development in one-belt-one-road initiative. This is indeed the shortest way, however, mostly used for downstream transportation of goods. There is a huge potential to use this route for upstream transportation of electronic wastes, back to China [5].

In this paper, optimal reverse logistics route is determined for electronic scrap using AHP. Reverse logistics is upstream movement of products that can be due to warranty claim, repair, reclaimed or remanufactured. In few cases, parts of products are reused to save cost. Concept of disposable, especially, for electronic scrap is a major issue being faced by many countries. Pakistan being a developing country is facing this issue at highest possible level as it has become a dumping state for used electronics from all over the world (USA, EUROPE, and GULF). Cheaper Chinese products are another source of huge amount of Electronic waste. This paper focuses on finding optimal route for transportation of these products to proper disposed-off destinations for maximum gain.

2 Literature Review

Return type in reverse logistics is important because it shows interest of the repairing, refurbishing or remanufacturing industry. Obsolete market (ebay.com, taobao.com etc.) resell huge amount of used, obsolete parts and their buyer are present all over the world. Major return types categories are: (i) end of life, (ii) end of use, and (iii) reusable returns [6]. *End of life return (EOL)* is the equipment and machinery used up to a specified time and dispose either at end of documented life or when there is an up gradation to latest versions [4]. *End of use return* is used when instead of buying machinery or equipment some companies prefer to get it on lease or rent and after specified period they need to be returned, e.g., construction industry [7, 8]. *Reusable items* are reusable parts of the scrapped machinery is scrapped [9]. Recovery of parts started right from where the machinery is scrapped. The requirements of the firms are usually different. For instance, those who are interested in metallic scrap are not bothered about electrical items. Those interested in instrumentation don't consider metallic scrap. Another important aspect is condition of the items which includes both working and cosmetic conditions [1].

Secondary markets for used products are subdivisions of the primary market and are intertwined. Pakistan can be termed as secondary market as for as electronics items are concerned. Used laptops, industrial products, control and instrumentation is largely being imported as scrap for saving cost of imports [7]. When collection is made at primary market and buyer is spread all over the world then secondary market is needed. The secondary market sell this scrap at a reasonably good price [6].

Reverse logistics lacks due attention in extant body of literature. More research work is required to solve problems related to reverse logistics [10]. The general processes associated with reverse logistics are described as follows. *Collection*: The process of collecting used products at fixed locations for further processing is called collection. This includes purchasing of scrap, plant, machinery, and parts [11]. *Inspection/separation*: Process comprising segregation of goods and their classification as reusable, repairable, reclaimable etc. This helps us in assigning next destination to the products. At this stage: separation, disassembly, testing and then storage is carried out. Scrap is shredded and compressed to less volume for transportation ease [11]. *Re-processing*: The process of making a used product reusable, it can be in the form of: repair, part replacement, remanufacturing of parts, reassembly etc. [12]. *Disposal*: Finally, few products cannot be used due to less market value or huge maintenance cost (more than new in some cases) and need to be disposed. Disposal may include transportation, land filling and burning etc., keeping in view environmental safety regulations [13, 14]. *Re-distribution*: The process of transporting the recovered or repaired goods to its users is called re-distribution. This may include sales, transportation and storage activities [15, 16].

Reverse logistics is upstream movement of goods from end users to OEM [17]. Srivastava [18] defined reverse logistics as a process to plan, implement, and control the flow of returned products in order to recover value [19]. In short, reverse logistics is a process of returning products from the end user to supplier. The return can be because of warranty, incorrect delivery, end-of-lease or end-of-life [20].

The core activity of reverse logistics is collection of end of life products, faulty products, and scrap from market. Electronic products have huge number of users so collection of these items is complex as compare to the collection of equipment and machinery. Currently, majority of electronic products are being recovered by conventional means and repair/cannibalization industry is the largest source of electronic scrap collection from end users. As per environmental protection agency (EPA), "Professionals approximate a recovery of 24 kg (50 lb) of gold, 250 kg (550 lb) of silver, 9 kg (20 lb) of palladium, and more than 9,000 kg (20,000 lb) of copper from reprocessing 1 million cell phones" [19, 20].

The amount of gold which can be recovered from one metric ton electronic scrap of personal computers is more than 17 ton of gold ore. In 1998, United States recovered an equivalent amount of gold from electronic scrap to the amount recovered from 2 million metric tons (Mt) of gold ore and waste [21, 22].

Effect on environment due to electronic industry is huge as compare to other household products. A study conducted by United Nation Organization (UNO) established that the making of a computer and display screen takes at least 240 kg (530 pounds) of fossil fuels, 22 kg (48 pounds) of chemicals and 1.5 tons of water which is more than the weight of a rhinoceros or a car [23]. Recycling process of used aluminum saves 90% of energy required to mine fresh aluminum.

For a successful model of reverse logistics, it is necessary that there is a proper system of collection and upstream transportation. An algorithm that saves time and cost should be employed for the success of the model. The same can be studied from courier/cargo services being used in e-commerce and online shopping [24]. Electronic waste has many materials which are costly (such as silver, gold) and also hazardous material for the environment (lead, tin etc.). The purpose is to recover all these materials to protect environment as well as to reduce cost of future products [25]. Recovering precious metals like Gold, Silver etc. is cheaper and environmental friendly [23, 26].

3 Methodology

The scope of reverse logistics isn't limited to get back defected and warranty products. Rather the aim green supply chain in reverse logistics is to deal with disposal of products and protect environment from hazardous chemicals during product disposal [27]. Hierarchy of reverse logistics for electronics waste is: (i) reuse, (ii) remanufacture, (iii) recycle, and (iv) disposal [28]. However, this hierarchy isn't fixed for all types of products and may vary accordingly.

China Pakistan Economic Corridor (CPEC)

CPEC is a roadmap of regional linkage, the benefit of which is not only limited to China and Pakistan. The development of geographical connections have upgraded road, rail and air transportation system with recurrent and free exchanges of growth and contact. As a result, the exchange rate has been increased in terms of education, knowledge, culture, and business, resulting in peace, harmony, and development.

Figure 1 shows various international routes those can be used as an option for reverse logistics of electronics scrap from Pakistan. Indeed, we have five available routes, which are named Route 1 to Route 5. We will assign different weights to these routes based on decision parameters. The five decision parameters selected to conduct this study are [31, 32]: (i) cost of Transportation, (ii) transportation time, (iii) volume of goods, (iv) nature of goods (Refurbished, Recyclable or Scrap), and (v) financial value of goods.

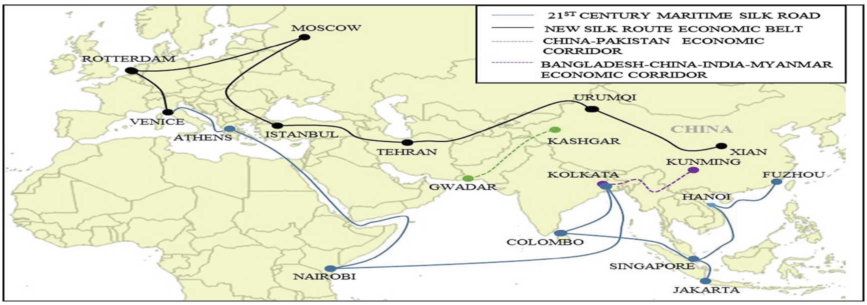


Fig. 1. Possible routes

Assigning suitable weights, which are learned from the view of expert and literature, we may estimate preference value of the routes [33, 34]. AHP is used to carry out analysis. AHP is useful and requires to draw a diagram by connecting dependent and independent nodes as shown in Fig. 2. The next step is to assign relative weights to the routes which are either based on data or experts' opinion.

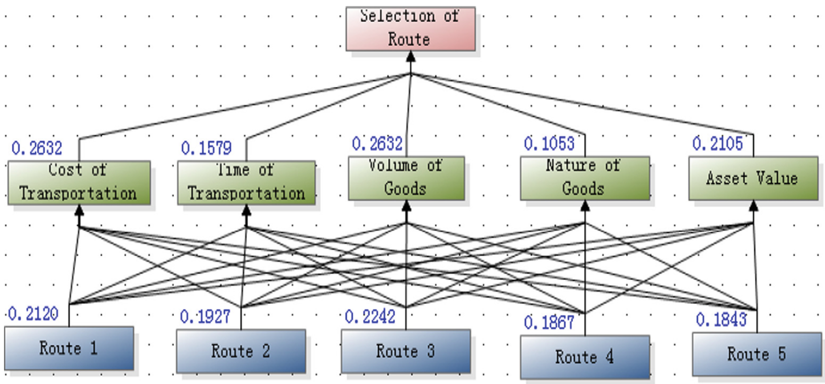


Fig. 2. Value of different routes for reverse logistics

4 Results and Discussion

Five factors have been considered in making decision using AHP to analyze different transportation routes. The weights/factors are provided by past data and opinion of the experts. The value for each routes using proposed AHP based mechanism is given in Table 1.

Table 1. Ranking weights of decisions

Sr. #	Alternative	Calculated weight
1	Route 1 (Green)	0.2242
2	Route 2	0.2120
3	Route 3	0.1927
4	Route 4	0.1867
5	Route 5	0.1843

Here, we can see that value of Route 1 (CPEC Route) is highest. CPEC has various advantages and drawbacks as compare to other routes. One major drawback is that the products might have to travel more in China main land than in Pakistan. However, China is planning to develop western region which is close to Pakistan.

Transportation cost and time are two major factors that give edge to CPEC over other routes. In case of other routes, the volume of goods being reverse transported may be large as those routes are well established. However, time and transportation cost of CPEC is much lower than other routes [29, 30]. With maturity of the CPEC system and increase in forward logistics, the amount and types of the products available for reverse logistics will further increase which ultimately, increases the benefits of reverse logistics through CPEC.

Similarly, the weights of decision factors are tabulated below that are received after analysis using AHP. These are actually the advantages that CPEC provides for different decision parameters. With the development of western part of China, these decision parameters will be having higher values, i.e. become more advantageous.

Table 2. Ranking weights of the elements in first intermediate layers

Sr. #	Alternative	Calculated weight
1	Volume of goods	0.2632
2	Cost of transportation	0.2632
3	Asset value	0.2105
4	Time of transportation	0.1579
5	Nature of goods	0.1053

From Table 2, it is clear that volume of goods and cost of transportation have equal value. It means that CPEC with current assigned weights and decision parameters give equal importance to cost and weight. The more is the weight, more will be the transportation cost but in some situations this is not true. For bigger volume of goods and less weights, we ignore weights and cost is calculated based on volume. The table also explains that how closely different decision parameters are linked with each other.

The same model can be applied if we have more options of routes with different decision parameters. The decision parameters can vary based on type of goods to be transported. We can also use AHP-TOPSIS mixed approach for the calculation of preferred routes hierarchy. If available supply tracks for competitive market are unpredictable, the most feasible strategy to mitigate risk is to hold “emergency stock”. However, if there exists a reliable path among available supply tracks to serve a competitive market, the superior risk mitigation strategy would be the economic (least costly) one.

5 Conclusions and Recommendations

This study addressed the design of a resilient supply chain network that targets to find out optimal route among the available options considering: (i) cost of transportation, (ii) time of transportation, (iii) volume of goods to be transported, (iv) nature of goods (refurbished, recyclable or scrap), and (v) financial value of goods to be transported. The main focus is to minimize the cost of transportation and time required for transportation. This study not only provide us an optimal path but also present results in such an order that all given options can be used in case of any unexpected situation. AHP is just an evaluation tool and the inputs or decision tables which compare different factors with each other are truly derived from past data and experts’ opinion. As for CPEC, we don’t have any past data, experts’ opinions are used as input to find best possible solution.

The reverse and green logistics will help Pakistan to get rid of electronic waste in most productive way. In different cities of Pakistan, people are already working on electronic wastes and trying to recover as many components as they can. These recovered components are precious metals like gold, aluminum and other super conductor elements. Pull out electronic component market is very popular in Pakistan. This is another use of electronic scrap to recover good quality and cheaper electronic components.

The future of the world is moving towards electric vehicles (Computer on the wheels) and we are heading towards a huge amount of waste in the form of electronic gadgets and, especially, batteries being used in cars and other similar vehicles like electric bikes etc. So a special study for reverse logistics of batteries will not only help us in getting rid of scraps but cost saving as well. Another extension of this research can be AHP-TOPSIS based methodology considering additional factors. This will increase validity of results and interdependency of results can be verified.

References

1. Kersten, W., Blecker, T., Ringle, C.M.: Sustainability in logistics and supply chain management. In: Proceedings of the Hamburg International Conference of Logistics (HICL). epubli (2015)
2. Olariu, I.: Conceptual issues regarding reverse logistics. Stud. Sci. Res. Econ. Ed. **18**, 326–331 (2013)
3. Ni, H.-G., Zeng, E.Y.: Law Enforcement and Global Collaboration are the Keys to Containing E-Waste Tsunami in China. ACS Publications (2009)
4. Kahhat, R., Kim, J., Xu, M., Allenby, B., Williams, E., Zhang, P.: Exploring e-waste management systems in the United States. Res. Conserv. Recycl. **52**(7), 955–964 (2008)
5. Ninlawan, C., Seksan, P., Tossapol, K., Pilada, W.: The implementation of green supply chain management practices in electronics industry. In: Proceedings of the International Multiconference of Engineers and Computer Scientists (2010)
6. Sarkis, J.: How green is the supply chain? Practice and research. Graduate School of Management/Clark University, Worchester, pp. 1–40 (1999)
7. Wang, M., Liu, J., Wang, H., Cheung, W.K., Xie, X.: On-demand e-supply chain integration: a multi-agent constraint-based approach. Expert Syst. Appl. **34**(4), 2683–2692 (2008)
8. Stock, J.R.: Development and implementation of reverse logistics programs. In: Annual Conference Proceedings, Council of Logistics Management (1998)
9. Kumar, N., Chatterjee, A.: Reverse supply chain: completing the supply chain loop. In: Cognizant 20-20 Insights (2011)
10. Baldé, C.: The global e-waste monitor 2014: quantities, flows and resources (2015)
11. Yang, H., et al.: The impact of customer returns in a supply chain with a common retailer. Eur. J. Oper. Res. **256**(1), 139–150 (2017)
12. Xu, S., Liu, Y., Chen, M.: Optimisation of partial collaborative transportation scheduling in supply chain management with 3PL using ACO. Expert Syst. Appl. **71**, 173–191 (2017)
13. Sauer, P.C., Seuring, S.: Sustainable supply chain management for minerals. J. Clean. Prod. **151**, 235–249 (2017)
14. Ali, M.M., Babai, M.Z., Boylan, J.E., Syntetos, A.A.: Supply chain forecasting when information is not shared. Eur. J. Oper. Res. **260**(3), 984–994 (2017)
15. Sheu, J.B., Kundu, T.: Forecasting time-varying logistics distribution flows in the One Belt-One Road strategic context. Transp. Res. Part E: Logist. Transp. Rev. (2017)

16. Aljazzar, S.M., Jaber, M.Y., Moussawi-Haidar, L.: Coordination of a three-level supply chain (supplier–manufacturer–retailer) with permissible delay in payments and price discounts. Appl. Math. Model. **48**, 289–302 (2017)
17. Rogers, D.S., Tibben-Lembke, R.: An examination of reverse logistics practices. J. Bus. Logist. **22**(2), 129–148 (2001)
18. Marulanda, J.M., Srivastava, A.: Carrier density and effective mass calculations in carbon nanotubes. Physica Status Solidi (b) **245**(11), 2558–2562 (2008)
19. Yuksel, H.: An analytical hierarchy process decision model for e-waste collection center location selection. In: Computers & Industrial Engineering, CIE 2009 (2009)
20. Zhang, Y., Feng, Y.: A selection approach of reverse logistics provider based on fuzzy AHP. In: Fourth International Conference on Fuzzy Systems and Knowledge Discovery (2007)
21. Nnorom, I.C., Osibanjo, O.: Electronic waste (e-waste): material flows and management practices in Nigeria. Waste Manag. **28**(8), 1472–1479 (2008)
22. Lipan, F., Govindan, K., Chunfa, L.: Strategic planning: design and coordination for dual-recycling channel reverse supply chain considering consumer behavior. Eur. J. Oper. Res. **260**(2), 601–612 (2017)
23. Schwarzer, S., De Bono, A., Giuliani, G., Kluser, S., Peduzzi, P.: E-waste, the hidden side of IT equipment's manufacturing and use (2005)
24. Pochampally, K.K., Gupta, S.M.: A business-mapping approach to multi-criteria group selection of collection centers and recovery facilities. In: IEEE International Symposium on Electronics and the Environment (2004)
25. Streicher-Porte, M., Widmer, R., Jain, A., Bader, H.P., Scheidegger, R., Kytzia, S.: Key drivers of the e-waste recycling system: assessing and modelling e-waste processing in the informal sector in Delhi. Environ. Impact Assess. Rev. **25**(5), 472–491 (2005)
26. Babazadeh, R.: Optimal design and planning of biodiesel supply chain considering non-edible feedstock. Renew. Sustain. Energy Rev. **75**, 1089–1100 (2017)
27. Wu, X., Zhou, Y.: The optimal reverse channel choice under supply chain competition. Eur. J. Oper. Res. **259**(1), 63–66 (2017)
28. Chung, H., Lee, E.: Asymmetric relationships with symmetric suppliers: strategic choice of supply chain price leadership in a competitive market. Eur. J. Oper. Res. **259**(2), 564–575 (2017)
29. Chen, J., Liang, L., Yao, D.Q., Sun, S.: Price and quality decisions in dual-channel supply chains. Eur. J. Oper. Res. **259**(3), 935–948 (2017)
30. Rezapour, S., Farahani, R.Z., Pourakbar, M.: Resilient supply chain network design under competition: a case study. Eur. J. Oper. Res. **259**(3), 1017–1035 (2017)
31. Tostivint, C., de Veron, S., Jan, O., Lanctuit, H., Hutton, Z.V., Loubière, M.: Measuring food waste in a dairy supply chain in Pakistan. J. Clean. Prod. **145**, 221–231 (2017)
32. Feitó-Cespón, M., Sarache, W., Piedra-Jimenez, F., Cespón-Castro, R.: Redesign of a sustainable reverse supply chain under uncertainty: a case study. J. Clean. Prod. **151**, 206–217 (2017)
33. Fahimnia, B., Jabbarzadeh, A., Ghavamifar, A., Bell, M.: Supply chain design for efficient and effective blood supply in disasters. Int. J. Prod. Econ. **183**, 700–709 (2017)
34. Chowdhury, M.M.H., Quaddus, M.: Supply chain resilience: conceptualization and scale development using dynamic capability theory. Int. J. Prod. Econ. **188**, 185–204 (2017)

Digital Lean Cyber-Physical Production Systems: The Emergence of Digital Lean Manufacturing and the Significance of Digital Waste

David Romero[1(✉)], Paolo Gaiardelli[2], Daryl Powell[3], Thorsten Wuest[4], and Matthias Thürer[5]

[1] Tecnológico de Monterrey, Monterrey, Mexico
david.romero.diaz@gmail.com
[2] University of Bergamo, Bergamo, Italy
paolo.gaiardelli@unibg.it
[3] Norwegian University of Science and Technology, Trondheim, Norway
daryl.j.powell@ntnu.no
[4] West Virginia University, Morgantown, USA
thwuest@mail.wvu.edu
[5] Jinan University, Guangzhou, China
matthiasthurer@workloadcontrol.com

Abstract. This paper explores the emergence of the next cyber/digital frontier for lean manufacturing practices. It focuses on (a) the new capabilities of information and operational technologies (ITs/OTs) for proactively detecting and eliminating potential 'physical waste' in production processes, preventing its manifestation in the real world through powerful virtual models and simulations as well as real-time performance monitoring systems based on advanced data analytics, and (b) on identifying and eliminating 'digital waste' that may come into existence in the cyber world due to the non-use (e.g. lost digital opportunities) and/or over-use (e.g. abused digital capabilities) of new digital/smart manufacturing technologies.

Keywords: Digital manufacturing · Smart manufacturing
Lean manufacturing · Digital Lean Manufacturing · Digital Lean Enterprise
Cyber-Physical Production Systems · Industry 4.0 · Waste · Digital waste

1 Introduction

Lean Manufacturing (LM) is a systematic approach to waste minimization within a production system [1]. *Lean* is a toolbox that assists in the identification and elimination of waste. By eliminating *waste*, quality improves while production time and cost are reduced [1]. Seven forms of waste have traditionally existed within the real "physical" world of lean: defects, overproduction, waiting, transportation, inventory, motion and over-processing, plus a recent one: not-utilizing talent [2]. These 7 + 1 traditional *physical waste* types can nowadays be better identified and eliminated

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 11–20, 2018.
https://doi.org/10.1007/978-3-319-99704-9_2

through new *Digital/Smart Manufacturing (D/SM) technologies* [3, 4] (e.g. Big Data, Industrial Internet of Things (IIoT) and Advanced Analytics) as mechanical/physical production systems evolve into *Cyber-Physical Production Systems (CPPSs)* [5]. Here, established *lean methods* gain a new *digitally-enabled edge* [4, 6], hereby referred to as *"Digital Lean Manufacturing (DLM)"*.

While the principles of *traditional lean manufacturing* will remain valid, DLM will (a) facilitate the application of these principles, and (b) enhance its scope and direction. For instance, DLM will the introduce new capabilities of information and operational technologies, such as powerful virtual models and simulations as well as real-time performance monitoring systems based on advanced data analytics that have the ability to proactively detect and eliminate 'traditional' *physical waste* in (physical) production processes.

However, new forms of *digital waste* may come into existence in the virtual/digital "cyber" world due to the new "cyber-physical" nature of production systems. Therefore, DLM will require new techniques for identifying and eliminating *digital waste* that may come into existence in the cyber world due to, for example, the non-use (e.g. lost digital opportunities) and/or over-use (e.g. abused digital capabilities) of new D/SM technologies. In this context, *digital waste* will be defined as any non-value adding digital activity to women/men, materials, machines, methods and measurements (5 M) in the *Digital Lean Enterprise.* This includes, for example, the creation of redundant and/or unnecessary data that is collected, managed, transmitted or stored for no tactical, operational or strategic reasons. In this case, these artefacts create unwanted and wasteful data congestion in a decision-making process [7]. On this premises, this 'position paper' explores the emergence of the next cyber/digital frontier for lean manufacturing practices, introducing a first definition of *digital waste,* and providing a typology for it in order to support the elimination of physical waste and at the same time the avoidance and the prevention of *digital waste* in the digital lean smart factory.

2 The Emergence of Digital Lean Manufacturing

Digital technologies have given rise to a new era of lean manufacturing, which extends the *lean philosophy* to the cyber world (e.g. *lean automation* [5] manifested as *Jidoka & Heijunka 4.0 systems* [8]); for example by making 'physical-to-digital' conversions, known as 'digital transformations' or 'digitalization', of value adding activities in order to pursue new *digital manufacturing levers* to eventually realize higher productivity levels, higher quality, optimized resources usage and increased production throughput.

DLM builds on new data acquisition, data integration, data processing and data visualization capabilities [9] to create different descriptive, predictive and prescriptive analytics applications [10] to detect, fix, predict and prevent unstable process parameters and/or avoid quality issues inside defined tolerance ranges that may lead to any type of waste within the cyber-and physical-worlds. Hence, *Digital Lean CPPSs* will aim to support the operation of *digital lean smart factories* towards (near) zero physical and digital waste. This will be achieved, for example, by a *synchronized production environment* [11] (viz. digital twins [12]) between virtual models and simulations representing the virtual factory [13] that will help to design, engineer, verify and validate waste-free production operations in the cyber world before their release and ramp-up in the real factory. *Digital Lean CPPSs* will also help to monitor real-time performance in the physical world in order to assess whether production operations are actually being performed at their highest possible productivity level and quality standard, as planned, or if there remain opportunities for improvement *(Kaizen).*

Moreover, when adopting D/SM technologies to 'digitize-to-connect' and pursue vertical and horizontal factory big data integration [14] will contribute to minimize waste in the process of creating *digital lean capabilities* such as: (a) data visibility (e.g. new generation *Andon* systems and digital dashboards), (b) information transparency (e.g. real-time production monitoring and communication systems), and (c) (critical) events forecasting (e.g. predictability charts for continues improvement) of production operations conducted by humans, machines and computer systems on the shopfloor.

3 The Meaning of Digital Waste

Waste has traditionally been defined by the lean community as 'any non-value adding activity' [15, 16]. However, according to the Merriam-Webster's online dictionary definition, waste can also mean: "the loss of something valuable that occurs because too much of it is being used or because it is being used in a way that is not necessary or effective; an action or use that results in the unnecessary loss of something valuable; a situation in which something valuable is not being used or is being used in a way that is not appropriate or effective". This etymological meaning is of great importance for the definition of 'digital waste' in DLM, since it highlights the need to consider two types of digital waste: (i) *passive digital waste* due to missing digital opportunities to unlock the power of (existing) data, and (ii) *active digital waste* as a result of a data rich manufacturing environment that lacks from the proper information management approaches to derive the right amount of information to be provided at the right time to the right person, machine or information system for decision-making (knowledge).

The next sub-sections will exemplify: How a – *digital lean philosophy* – and D/SM technologies can contribute to reduce waste in the physical world through virtual/digital assisting means as well as How passive digital waste can be avoided and How active digital waste can be prevented. These examples may work independently or together in order to reduce or eliminate one or more types and forms of *physical* and *digital waste.*

3.1 Eliminating Defects Waste: Digital Quality Management Lever

Digital Quality Management (DQM) refers to the semi-automated or automated digital governance of cyber-physical production assets like smart products, smart operators and smart machines, aimed at offering real-time tracking and reporting of such intelligent assets performance towards compliance with predefined quality standards and proactively alerting in case of potential deviations from them to prevent quality problems (viz. defects) before they materialize.

Eliminating Physical Waste. New technologies, such as IIoT and cloud storage, provide real-time data (as well as easy access to historical data) from the shopfloor of the digital lean smart factory. This triggered the evolution of QM from ‘sampling-based measurements’ to a ‘full coverage’ of wo/men and machines operations in a production system. This new data lake environment on the shopfloor, combined with real-time data analytics and *Advanced Process Control (APC)|Statistical Process Control (SPC)* systems, has enabled the possibility for real-time error corrections in operations to minimize rework and scrap (waste) – towards zero defects. For example, (a) real-time monitoring and performance management of machine operations that allow for manufacturing processes self-adjustments to keep a quality threshold (e.g. 100% First Pass Yield - FPY) or (b) real-time tracking of operator actions in assembly sequences based on ‘context-aware wearable computing’ by recognizing the operator’s actions/movements [17] and/or ‘mixed reality (i.e. Augmented & Virtual Reality) assistance systems’ [18] by showing virtual assembly instructions directly in the operator’s field of view (e.g. 100% Complete & Accurate tasks - % C&A). Both approaches act as a kind of *digital poka-yoke system.*

Avoiding Passive Digital Waste. Advancements in electronic data processing and interchange, (enterprise) information systems and data itself have long played an important role in manufacturing operational excellence (viz. product quality, process efficiency, assets and human reliability). Hence, passive digital waste in this context may refer to the potential loss of DLM opportunities by ‘quality engineers’ if not upgrading their traditional quality control methods to new available techniques based on *Machine Learning (ML)* [10] for advanced (big) data analytics. For example, the use of a *neural network* to learn from historical quality control data to identify defects and predict quality deviations with a high degree of accuracy, avoiding waste due to false defect detection.

Preventing Active Digital Waste. At the same time that QM becomes digitized and data-driven, more data will be created, processed and consumed on the shopfloor. This will require more storage, computer processing power and network bandwidth as well as the (human) talent provision (e.g. setup, integration and maintenance of IT/OT systems) to support DQM. In this sense, emerging ‘digital - quality engineers’ will need to pursue a *smart data vision* rather than a *big data vision,* aiming always to turn big data into actionable smart data with real-business value through its application to a business process to create insights and support in-the-moment/rapid decision-making (e.g. defects real-time detection). [19] have defined four categories of *waste (digital) data* to be managed, in this case in a DQM business process: (a) *unintentional data* created as a by-product of a process with no purpose, (b) *used data* that serves its purpose for a period of time and then is no longer useful, (c) *degraded data* that has lost its quality due to whatever reason and it is no longer useful, and (d) *unwanted data* that was created, but never useful for any purpose.

3.2 Eliminating Overproduction: Digital Kanban Systems Lever

Digital Kanban Systems (DKSs) refer to real-time digital ‘pull’ signalling systems that use a mix of digital technologies (e.g. smart tags, smart bins/boxes, smart dashboards and smart automation) to trigger the Just-In-Time (JIT) movement of materials and electronic information (e-Kanban cards) within a digital lean smart factory in order to eliminate overproduction by being responsive to the current demand instead of forecast.

Eliminating Physical Waste. DKSs can eliminate 'overproduction' through the synchronisation between production and (raw) materials demand (of a specific item, in specific quantities, to be delivered to a specific location (e.g. smart bin or smart dashboard)) at a smart workstation, or even forecast such demand need by means of *advanced data analytics,* to optimize material handling and transport time as well as the time and effort needed for *(e-)Kanban cards* handling thanks to electronic real-time communication (viz. faster signals transfer) through e-messaging and e-alerting (sub-) systems between the workstation and its supplier(s).

Avoiding Passive Digital Waste. By not migrating to DKSs, electronic records of pull requests, recipient timestamps and delivery acknowledgements will not be able to be recorded, stored (historical data), traced and used to be analysed to reveal weak points in the JIT management of a pull production process towards zero overproduction.

Preventing Active Digital Waste. Designing effective and efficient DKSs and their corresponding *e-Kanban cards* for the digital lean smart factory will require an emphasis on the engineering or re-engineering of input data systems (viz. smart tags and/or smart bins), processing data systems (viz. ERP + MES) and output data systems (viz. smart dashboards and smart automation (e.g. deliveries by AGVs/drones)) in order to orchestrate material and information flows JIT between workstations, warehouse(s) and intra-logistics activities and their associated information systems without synchronisation problems that may not allow to achieve a real-time material and information handling and transport system, and may cause overproduction.

3.3 Eliminating Waiting Waste: Cyber-Physical Systems Lever

Digital Lean CPPSs, or CPPSs-based *Jidoka & Heijunka* [8] production systems, refer to autonomous and cooperative human, machine and product 'smart entities' that co-create a networked socio-technical production environment, where all software, hardware and humanware sub-systems can sense, actuate and interoperate. This is facilitated via human-machine interfaces (HMI/H2M) and machine-to-machine (M2M) communication protocols, to enable vertical and horizontal value-added data flows for the provision of a range of intelligent functions, services and features for the design and engineering, warehouse and logistics, fabrication, assembly, quality and maintenance digital lean smart factory departments.

Eliminating Physical Waste. The context-awareness capabilities of D Lean CPPSs [20] enabled by means of smart sensors, actuators and adaptive controllers can allow the smart control of the entire production processes in order to avoid *waiting-times* by self-adapting (re-balancing) in real-time for maximum flexibility to manage excessive demand fluctuations *(Mura),* and overburden of machine & operators capacities *(Muri).*

Avoiding Passive Digital Waste. Thanks to new CPPSs-based *Heijunka systems,* all production resources (viz. wo/men, materials and machines) can be instrumented and networked in a social IIoT environment [21, 22] for supporting a 'truly holistic' production scheduling or re-scheduling in real-time and just-in-sequence logic for avoiding waste risk creation due to the lack of a systemic (re-)scheduling approach.

Preventing Active Digital Waste. When designing *D Lean CPPSs* environments, 'digital lean engineers' should avoid *over-engineering* the CPPS and adding unneeded 'complexity' to manufacturing, which may increase the potential of catastrophic, but also incremental, failure of the system. Moreover, the design principles for Industry 4.0 and CPSs [23, 24] in general advocate for decentralised structures and for small and simple-to-integrate modules (plug-and-play) in order to better manage their complexity as well as the complexity of the overall system.

3.4 Eliminating Transportation Waste: AGVs, Drones and 3D Printing Levers

Automated Guided Vehicle (AGV) Systems refer to material handling systems that use programmed AGVs – such as carts, pallets, trays or forklifts – for the transport of goods in order to support human-less intra-logistics activities at the digital lean smart factory. In a complementary way, *drones,* also referred as unmanned aerial vehicles (UAVs), aim to support other human-less intra-logistics activities such as visual inventory counts and searching for goods based on 'flying smart tag scanners' as well as acting as picking-and-delivery systems for goods located at the top levels of storage or shelving racks of high-rise warehouses. On the other hand, *3D printing* refers to rapid/on-demand manufacturing technology that can allow the fast production of needed items on-site.

Eliminating Physical Waste. By using *3D printing* for the production of low volume components on-site, reduction of transportation and even inventory waste can be realized. Furthermore, by automating pick-up, transport and delivery tasks on the shopfloor, operators can continue working at their workstations and conducting value-adding activities thanks to the support of *AGVs* and *smart conveyors*. Similarly, high-rise warehouses will benefit from the help of *AGVs* and *drones* as highly-efficient searching, picking and delivery systems.

Avoiding Passive and Preventing Active Digital Waste. Different AGVs, drones and 3D printing solutions exist nowadays in the market at different maturity and capability levels, therefore, proper benchmarking tools should be used to grade their performance in industrial environments in order to guarantee investments that live-up to their ROI.

3.5 Eliminating Inventory Waste: Digital Warehouse Operations Lever

Digital Warehouse Operations (DWOs) refer to the automation of warehousing activities with the support of auto-ID technologies, smart boxes, AGVs and real-time inventory optimisation strategies to manage the ideal levels of raw materials, work-in-progress (WIP) and finished product(s) inventories.

Eliminating Physical Waste. DWOs automate 'true JIT ordering' on the basis of stock reduction by the use of diverse sensors and smart bins/boxes to manage inventory levels in collaboration with digital Kanban systems and e-billing services.

Avoiding Passive Digital Waste. Auto-ID technologies (e.g. RFID) can provide the ability to automatically compare the characteristics of all raw materials received at the warehouse based on 'purchase order data' in order to control for discrepancies that may lead to inaccurate inventory keeping beyond simple units counting.

Preventing Active Digital Waste. When relying on 'smart sensors' for automated inventory control, their appropriate selection, use and maintenance will be vital for maximizing data accuracy and providing increased confidence in inventory reports.

3.6 Eliminating Motion Waste: New HMIs and Wearable Computing Levers

Human-Machine Interfaces (HMIs) refer to computer systems/technologies endowed with capabilities for enabling human-to-machine (H2 M) interactions by means of data/information interpretation from various sensory and communication channels. In a complementary way, *Wearable Computing (WC)* refers to a wearable computer capable of sensing, storing and processing data that is incorporated into a person's clothing.

Eliminating Physical Waste. Wearable Computing can enable the tracking of operators' movements in order to build a *spaghetti chart* in real-time and provide motion optimization functionality as well as support for better ergonomic postures and movements to avoid injury. Correspondingly, *smart workstations* can be re-configured on the basis of ergonomic requirements of the individual operator (e.g. working table height and shelving unit reaching distance).

Avoiding Passive Digital Waste. New HMIs (e.g. voice control) can help operators to become hands-free in certain activities/operations, helping them to reduce time and motion when completing their tasks and therefore, improve their productivity.

Preventing Active Digital Waste. New HMIs and wearable computing can reduce operator's physical workload, but their usage should not contribute to increase his/her cognitive workload due to complex human-machine interactions.

3.7 Eliminating Over-Processing Waste: Digital Mfg. Standards Lever

Digital Manufacturing Standards (DMSs) refer to the adoption of a 'common language' for ensuring the reliable and efficient integration or interoperability of very different systems, from visual management systems (interfaces) to electronic data interchanges.

Eliminating Physical Waste. Visual management systems should always comply with design standards in order to bring consistency and readability to visual monitors and visual controls in order to avoid misinterpretations and wrong actions.

Avoiding Passive and Preventing Active Digital Waste. Data interoperability standards (e.g. EDI) are a must in order to have a clear interpretation of the data shared among systems and avoid wrong actions based on such data misinterpretation.

3.8 Eliminating Not-Utilizing Talent Waste: Digital Presence Lever

Digital Presence (DP) refers to the use of augmented reality smart glasses and other hands-free wearable technology [17], including haptics, for 'see-what-I-see', 'hear-what-I-hear' and even 'feel-what-I-feel' real-time communication for collaborative problem-solving between remote operators and service engineers in the field.

Eliminating Physical Waste. DP can reduce downtimes and increase fix rates of new or complex problems (e.g. troubleshooting) by enabling the possibility to tap into the specialized expertise (talent) of any service engineer on-site anytime, anywhere.

Avoiding Passive Digital Waste. Trying DP first, may enable in some occasions the possibility to get a faster diagnose and solution to a problem thanks to real-time two-way audio, video and even kinetics communication between a remote operator and a service engineer, eliminating or reducing the costly expenses of moving skilled service engineers from site-to-site to troubleshoot.

Preventing Active Digital Waste. Advancements in DP related technologies have enhanced MRO practices, nevertheless, each troubleshooting case must not disregard the possibility of the need of the physical presence of the service engineer on-site.

4 Conclusions

Through the exploration of *D/SM technologies* supporting *DLM practices,* this position paper provides an analysis of the different types of digital waste that may come into existence in the cyber world due to lost digital opportunities and/or abused digital capabilities of new digital/smart manufacturing technologies. The proposed approach can be adopted to identify a set of rules, policies, standards and models to govern and define which and how data is collected and managed to avoid the redundancy of unnecessary datasets towards a development path to Digital Lean CPPSs, thus minimizing digital waste in the digitalization process and improve digital lean value.

References

1. Bicheno, J., Holweg, M.: The Lean Toolbox: The Essential Guide to Lean Transformation. PICSIE Books, Buckingham (2009)
2. Liker, J.K.: The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer. McGraw-Hill, New York (2004)
3. Sameer, M., Muztoba, K., Romero, D., Wuest, T.: Smart manufacturing: characteristics, technologies and enabling factors. J. Eng. Manuf. (2017). https://doi.org/10.1177/0954405417736547

4. Mora, E., Gaiardelli, P., Resta, B., Powell, D.: Exploiting lean benefits through smart manufacturing: a comprehensive perspective. In: Lödding, H., Riedel, R., Thoben, K.-D., von Cieminski, G., Kiritsis, D. (eds.) APMS 2017. IAICT, vol. 513, pp. 127–134. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-66923-6_15
5. Kolberg, D., Zühlke, D.: Lean automation enabled by industry 4.0 technologies. In: IFAC Symposium on Information Control Problems in Manufacturing, vol. 48, no. 3, pp. 1870–1875 (2015)
6. Behrendt, A., et al.: Industry 4.0 Demystified - Lean's Next Level. McKinsey & Co., New York (2017)
7. Loshin, D.: Business intelligence and information exploitation. Business Intelligence, 2nd edn., pp. 1–13. Morgan Kaufmann Publishers, USA (2012). Chapter 1
8. Żywicki, K., Rewers, P., Bożek, M.: Data analysis in production levelling methodology. In: Rocha, Á., Correia, A.M., Adeli, H., Reis, L.P., Costanzo, S. (eds.) WorldCIST 2017. AISC, vol. 571, pp. 460–468. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-56541-5_47
9. Kusiak, A.: Smart manufacturing must embrace big data. Nature **544**(7648), 23–25 (2017)
10. Wuest, T., et al.: Machine learning in manufacturing: advances, challenges, and applications. Prod. Manuf. Res. **4**(1), 23–45 (2016)
11. Stjepandic, J., Wekerle, T., Pfouga, A.: Advancing smart factories with synced factory twins approach: representation and scenarios for synchronized digital and real factories. In: Symposium on Tools and Methods of Competitive Engineering (2018)
12. Tao, F., et al.: Digital twin-driven product design, manufacturing and service with big data. Int. J. Adv. Manuf. Tech. **94**, 3563–3576 (2017)
13. Pedrazzoli, P., Sacco, M., Jönsson, A., Boër, C.: Virtual factory framework: key enabler for future manufacturing. In: Cunha, P.F., Maropoulos, P.G. (eds.) Digital Enterprise Technology, pp. 83–90. Springer, Boston (2007). https://doi.org/10.1007/978-0-387-49864-5_9
14. Santos, M.Y., et al.: A big data analytics architecture for industry 4.0. In: Rocha, Á., Correia, A.M., Adeli, H., Reis, L.P., Costanzo, S. (eds.) WorldCIST 2017. AISC, vol. 570, pp. 175–184. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-56538-5_19
15. Thürer, M., Tomašević, I., Stevenson, M.: On the meaning of 'waste': review and definition. Prod. Plan. Control **28**(3), 244–255 (2017)
16. Tamás, P., Illés, B., Dobos, P.: Waste reduction possibilities for manufacturing systems in the industry 4.0. In: 20th Innovative Manufacturing Engineering and Energy Conference (2016)
17. Perera, C., Liu, C.H., Jayawardena, S.: The emerging internet of things marketplace from an industrial perspective: a survey. IEEE Trans. Emerg. Top. Comput. **3**(4), 585–598 (2015)
18. Rodriguez, L., Quint, F., Gorecky, D., Romero, D., Siller R.: Developing a mixed reality assistance system based on projection mapping technology for manual operations at assembly workstations. Procedia Comput. Sci. **75**, 327–333 (2015)
19. Hasanand, R., Burns, R.: The life and death of unwanted bits: towards proactive waste data management in digital ecosystems. In: 3rd International Conference on Innovative Computing Technology, London (2013)
20. Scholze, S., Barata, J.: Context awareness for flexible manufacturing systems using cyber physical approaches. In: Camarinha-Matos, L.M., Falcão, A.J., Vafaei, N., Najdi, S. (eds.) DoCEIS 2016. IAICT, vol. 470, pp. 107–115. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-31165-4_11
21. Li, H., Parlikad, A.K.: Social Internet of industrial things for industrial and manufacturing assets. In: 3rd IFAC Workshop on Advanced Maintenance Engineering, Service and Technology, vol. 49, no. 28, pp. 208–213 (2016)

22. Romero, D., Wuest, T., Stahre, J., Gorecky, D.: Social factory architecture: social networking services and production scenarios through the social internet of things, services and people for the social operator 4.0. In: Lödding, H., Riedel, R., Thoben, K.-D., von Cieminski, G., Kiritsis, D. (eds.) APMS 2017. IAICT, vol. 513, pp. 265–273. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-66923-6_31
23. Hermann, M., Pentek, T., Otto, B.: Design principles for industrie 4.0 scenarios. In: 49th Hawaii International Conference on System Sciences, pp. 3928–3937. IEEE (2016)
24. Lee, J., Bagheri, B., Kao, H.A.: Recent advances and trends of cyber-physical systems and big data analytics in industrial informatics. In: IEEE International Conference on Industrial Informatics (2014)

Effect of Prioritization on the Waiting Time

Yannic Jäger[1] and Christoph Roser[2(✉)]

[1] Locom Consulting, Karlsruhe, Germany
yannic.j@gmx.de
[2] Karlsruhe University of Applied Sciences, Karlsruhe, Germany
christoph.roser@hochschule-karlsruhe.de

Abstract. In industry, it is common to prioritize some orders over others. This is done to reduce the lead time and waiting time of these prioritized orders, hence the customer will get the order earlier than otherwise. However, whenever an order is prioritized, the remaining orders are de-prioritized, and their lead time and waiting time will increase. In industry, a rule of the thumb that no more than 30% of the orders should be prioritized is often used. This paper will verify this assumption using simulations for different conditions. It will show that this rule of thumb is generally a valid approach. The paper will offer more detail on the trade-off between prioritizing some orders and hence delaying other orders.

Keywords: Prioritization · Waiting time · Lead time

1 Introduction

The behavior of single-arrival single-server systems as shown in Fig. 1 is generally well understood, and relevant to most industries [1]. If an actual system can be observed, the lead time can easily be calculated using Little's law [2].

If the system is understood in more abstract terms, the Kingman equation (also known as Kingman formula or Kingman approximation) gives an approximation of the waiting time of the orders for a single process based on its utilization and variance [3]. Other calculations and approximations exist like [4–6] or [7]. These equations are valid over a wide range of assumptions and estimate the behavior of a steady state system quite well.

In industry, it is common practice to prioritize some orders over others to reduce the lead time and waiting time of the prioritized orders at the cost of an increased lead time and waiting time of the non-prioritized orders. Examples include the food industry with its limited product lifespan [8], maintenance tasks [9] or other resources [10], as well as general throughput improvements [11]. It is important to note that as long as the average system behavior does not change, the equations in [2–6] and [7] are still valid. Even if some orders are prioritized and accelerated, the slowdown of the not-accelerated orders will cause the overall system to keep a constant average lead time and waiting time.

Take for example Little's law [2]. Little's law is "not influenced by the arrival process distribution, the service distribution, the service order, or practically anything else" [12]. As prioritization does nothing but change the "service order," prioritization

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 21–26, 2018.
https://doi.org/10.1007/978-3-319-99704-9_3

Fig. 1. Illustration of a single-arrival single-queue single service system

has no effect on the average lead time. It does, however, affect the distribution of this lead time. As some orders are accelerated at the expense of others, the width of the distribution of the lead times and waiting times will increase, even though the mean remains unchanged.

Please also note that this paper uses orders as the item processed in the single-server single-queue system. However, the wide application of this prioritization makes the following simulations, discussions, and calculations equally valid for a system processing parts (as for example a machine), customers (for example in a supermarket, a hospital, or a call center), products (as for example a shipping warehouse), or many other applications.

2 System Outline

The system simulated is a single-arrival single-server system as a simplification of more complex production systems. The arrival times and service times are randomly distributed. For the arrival times, we used an exponential distribution, as this is the most commonly used distribution to model inter-arrival times [13, 14]. The service times are modeled using a lognormal distribution, which is also commonly used for service times [13, 15]. The exponential distribution has only one parameter, which was used to adjust the mean value. The lognormal distribution has two parameters, hence besides the mean, it is also possible to influence the standard deviation. During this analysis, the standard deviation was set to be 25% of the mean value (i.e., the coefficient of variation is 25% for the service times). This is within the range of common values in the industry.

The utilization of the system has a major influence on the waiting time. Hence different systems were simulated using different utilizations. Table 1 gives an overview of the different settings to achieve different utilizations. Please note that the units of the mean times are here only for a complete understanding of the set-up, but does not influence the results. The lot size of arrivals and processing is both one. For simplicity, we also did not model any set-up changes, breakdowns, or other interruptions. Transport times were also assumed instantaneous.

During the simulations, we measured the mean waiting time for each order type as well as the joint mean waiting time. We also measured the standard deviation of the waiting time for order types A and B individually as well as jointly. The 95% confidence interval of all of these was also determined. Each simulation experiment had a duration of 120,000 min, representing 20,000 orders processed or around one year of simulated time. Each simulation was repeated thirty-nine times to calculate the 95% confidence interval. For details on the set-up, see [16].

Table 1. Overview of the mean inter-arrival times and service times to achieve different utilizations

Utilization	Mean inter-arrival time (min)	Mean service time (min)
75%	6	4.50
80%	6	4.80
85%	6	5.10
90%	6	5.40
95%	6	5.70

2.1 Un-prioritized Baseline System

As a baseline reference, we used a system without prioritization, using a simple first-come-first-served approach for the arriving orders. The layout is shown in Fig. 1.

2.2 Prioritized System

The main part of the analysis is the prioritized system. Two different order types were simulated, order type A and B. Order type A always has priority over order type B. This is simulated by having two different waiting queues, both of which have an independent first-in-first-out logic. Orders in the B queue are only processed if there are no more orders waiting in the A queue. The service time for both order types is identical and depending on the selected utilization as shown in Table 1 (Fig. 2).

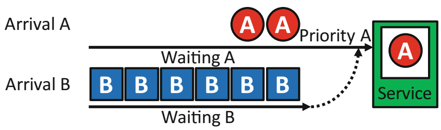


Fig. 2. Illustration of a prioritized system with a double-arrival double-queue single-service system

The percentage of prioritized orders was modified from 0.1% to 99.9% as shown in Table 2. The exponentially distributed inter-arrival times were adjusted accordingly to maintain a joint mean inter-arrival rate of 6 min between orders. Combining the 11 different percentages A with the 5 different utilizations gives a total of 55 simulation experiments in addition to the 5 utilizations of the baseline system.

3 Simulation Results

3.1 Baseline System

As expected and predicted by theory, the waiting time of the queue of the baseline system was influenced by the utilization. The exponential relation is shown in Fig. 3.

Table 2. Mean inter-arrival times for order A and B for different percentages of A

%A	Mean inter-arrival time A (min)	Mean inter-arrival time B (min)	Joint mean inter-arrival time (min)
0.1%	6000	6.006	6
10%	60	6.666	6
20%	30	7.5	6
30%	20	8.571	6
40%	15	10	6
50%	12	12	6
60%	10	15	6
70%	8.571	20	6
80%	7.5	30	6
90%	6.666	60	6
99.9%	6.006	6000	6

For a utilization of 100%, the average waiting time would approach infinity. These values serve as our baseline system.

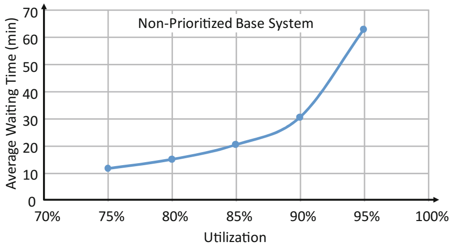


Fig. 3. Waiting times in dependence of the utilization of the un-prioritized baseline system

3.2 Prioritized System

Figure 4 shows the behavior of the systems under different utilizations and percentages of prioritized orders. For simplification, the percentage improvement of orders A and the percentage worsening of orders B compared to the baseline waiting time from Fig. 3 is shown. It is clearly visible that for low percentages of A, there is a substantial benefit for orders A with an up to 90% reduction in waiting time without much disadvantage for orders B. However, as the percentage of A increases, this benefit for A shrinks, whereas the disadvantage for orders B becomes exponential, with the waiting time being a multitude of the baseline.

Figure 5 shows the impact on the coefficient of variation of the waiting time. For both orders A and B, this increases as the percentage of prioritized orders A increases. Hence, not only does the average waiting time increase, but the range of the fluctuations also increases. The full data including the confidence intervals can be found in [16].

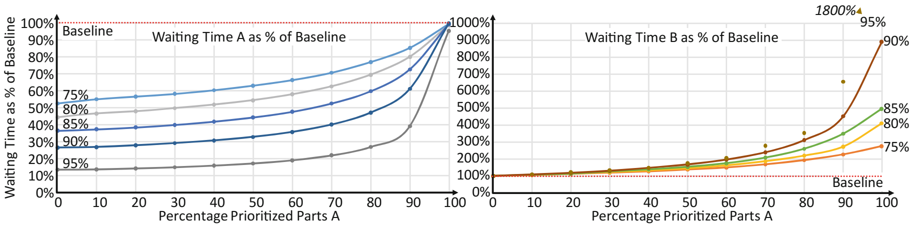


Fig. 4. Waiting times relative to the baseline in dependence of the utilization and percentage prioritized orders of the prioritized system

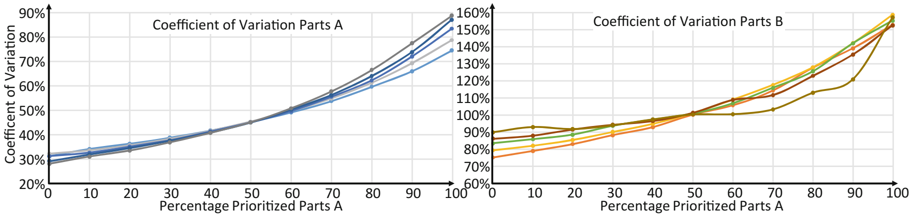


Fig. 5. Coefficient of variation of the waiting times in dependence of the utilization and percentage prioritized orders of the prioritized system

4 Conclusions

Overall, prioritizing important orders can have a significant benefit as long as it is done in moderation. In industry, often a general rule of thumb is used, recommending to prioritize no more than 30% of the workload. Since this number originates in industry, there is no academic reference for this that we are aware of. While this rule is an oversimplification, Fig. 4 shows that this is a workable assumption without having a too much negative effect on the not-prioritized orders. However, this is not a hard cut off, but rather a sliding scale, and prioritizing 35% or even 40% may also be possible, although the benefit shrinks and the disadvantages grow. It boils down to the tradeoff that has to be made between benefitting the prioritized products while disadvantaging everything else.

However, prioritizing an excessive number of orders will diminish the effect of this prioritization. The negative effect on the not-prioritized orders will multiply and become significant. Even worse, the range of the fluctuations increases faster than the mean waiting time. If the products are made to order (MTO), this means a prediction of a delivery date will become more difficult, as the actual delivery dates become more erratic. For a reasonable delivery performance, the promised delivery date now has to be much later, as this not only has to include the mean but also a substantial share of the outliers. If 95% of the true delivery dates should be within the estimate, the estimated delivery date needs to be the 95th percentile of the actual delivery dates.

Similarly, for made-to-stock (MTS) items, if the waiting and process time would always be constant, it would be sufficient to have one item in stock plus the coverage for the customer behavior. As the fluctuations of the waiting time and delivery time increase, more stock is needed to cover for these fluctuations. Again, if a 95% delivery performance is promised, there needs to be stock covering at least 95% of the shortest waiting times and processing times in addition to the customer behavior.

Overall, prioritizing too many orders will drastically push the promised delivery dates to the future (for MTO) or require significant increases in inventory (for MTS), or have a significant negative impact on the delivery performance (for both cases). Practitioners are strongly advised to prioritize no more than 30% of their order volume!

References

1. Tom, G., Lucey, S.: A field study investigating the effect of waiting time on customer satisfaction. J. Psychol. **131**(6), 655–660 (1997)
2. Little, J.D.C.: A proof for the queuing formula: L = λW. Oper. Res. **9**(3), 383–387 (1961)
3. Kingman, J.F.C.: The single server queue in heavy traffic. Math. Proc. Camb. Philos. Soc. **57**(4), 902–904 (1961)
4. Bhat, U.N.: The general queue *G*/*G*/1 and approximations. An Introduction to Queueing Theory. SIT, pp. 169–183. Birkhäuser, Boston (2008). https://doi.org/10.1007/978-0-8176-4725-4_9
5. Adan, I.: Queueing theory: Ivo Adan and Jacques Resing. Department of Mathematics and Computing Science, Eindhoven University of Technology (2001)
6. Marchal, W.G.: An approximate formula for waiting time in single server queues. E Trans. **8**(4), 473–474 (1976)
7. Krämer W., Lagenbach-Belz, M.: Approximate formulae for the delay in the queueing system GI/G/1. In: Proceedings of the 8th International Teletraffic Congress, Melbourne, pp. 235.1–235.8 (1976)
8. Akkerman, R., van Donk, D.P.: Product prioritization in a two-stage food production system with intermediate storage. Int. J. Prod. Econ. **108**(1), 43–53 (2007)
9. Li, L., Ni, J.: Short-term decision support system for maintenance task prioritization. Int. J. Prod. Econ. **121**(1), 195–202 (2009)
10. Gupta, S., Bhattacharya, J., Barabady, J., Kumar, U.: Cost-effective importance measure: a new approach for resource prioritization in a production plant. Int. J. Qual. Reliab. Manag. **30**(4), 379–386 (2013)
11. Pascual, R., Godoy, D., Louit, D.M.: Throughput centered prioritization of machines in transfer lines. Reliab. Eng. Syst. Saf. **96**(10), 1396–1401 (2011)
12. Simchi-Levi, D., Trick, M.A.: Introduction to 'Little's Law as viewed on its 50th anniversary. Oper. Res. **59**(3), 535 (2011)
13. Law, A.M., Kelton, D.W.: Simulation Modeling & Analysis, 3rd edn. McGraw Hill, Maidenherd (2000)
14. Domschke, W., Drexl, A.: Einführung in Operations Research, 7th edn. Springer, Berlin (2007). https://doi.org/10.1007/978-3-662-48216-2
15. Kühn, W.: Digitale Fabrik: Fabriksimulation für Produktionsplaner. Carl Hanser Verlag GmbH & Co. KG, München (2006)
16. Jäger Y.: Einfluss von Priorisierung auf das Verhalten eines Produktionssystems. Master thesis, Karlsruhe University of Applied Sciences, Karlsruhe, Germany (2017)

A Small Dice Game for the Kingman Formula

Christoph Roser[1(✉)] and Masaru Nakano[2]

[1] Karlsruhe University of Applied Sciences, Karlsruhe, Germany
christoph.roser@hochschule-karlsruhe.de
[2] Graduate School of System Design and Management, Keio University, Yokohama, Japan

Abstract. There are three main factors influencing the waiting time of a single-arrival single-process system: the utilization, the fluctuation of the arrival, and the fluctuation of the process time. The influence of these is not linear, and the combination of these effects is worse than the individual sums. Different approximations exist for this relation, the most popular one being probably the Kingman equation. Now it is one thing to understand this in theory, but experiencing this in practice makes it much easier to understand and will prepare practitioners much better for its effect. This paper describes a quick and easy game to have the practitioners experience the individual and combined effects of both utilization and fluctuation.

Keywords: Kingman equation · Utilization · Variation · Waiting time

1 Introduction

In manufacturing, or actually in most processing systems, the waiting time for the objects to be processed is often significant. In a supermarket, the waiting time of the customer is relevant for customer satisfaction [1]. In manufacturing, the waiting time of parts is a major contributor to the lead time. Most real live systems have a network of multiple processes and parts with varying utilizations and fluctuations. Often, the distribution of the inter-arrival time is the result of the output behavior of the preceding processes. Such complex systems can be simulated, but their relations are often difficult to grasp by humans and usually also difficult to analyze in queueing theory.

However, to understand the principles behind it, it is helpful to look in more detail at single-arrival single-departure processes, also known as single-server queue. This is often abbreviated as G/G/1 queue in Kendal's notation, where the G stands for a generally random distribution of the inter-arrival and service time, and 1 stands for a single process or server [2]. Such a system is visualized in Fig. 1.

Exact solutions of the relation between arrivals, departures, and waiting time are available for selected random distributions. Best known is the M/M/1 queue with exponentially distributed inter-arrival and service times. The average waiting time *E (W)* for a steady state system is a function of the parameter of the arrival distribution p and the service distribution μ as shown in Eq. (1) if the mean inter-arrival time exceeds the mean process time [3].

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 27–33, 2018.
https://doi.org/10.1007/978-3-319-99704-9_4

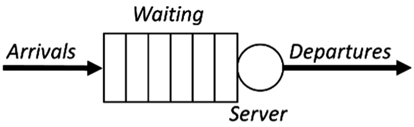


Fig. 1. Illustration of the general G/G/1 queue with arrivals, waiting objects, and server

$$E(W) = \frac{\frac{p}{\mu}}{1 - p} \tag{1}$$

For the general G/G/1 queue, there exist different approximations. The most common one is the Kingman approximation as shown in Eq. (2). Here, p stands for the utilization of the server (i.e., the mean arrival time µA divided by the mean service time µS). CA and CS are the coefficients of variation (standard deviation divided by the mean) of the arrival distribution and the service distribution [4].

$$E(W) = \frac{p}{1 - p} \cdot \left(\frac{C_A^2 + C_S^2}{2} \right) \cdot \mu_s \tag{2}$$

Please note that this is only an approximation, with the restrictions that it is only valid for higher utilization, that the utilization is below 100%, and that the arrival and service times need to be independently distributed. Other approximations exist like [5] or [6], but for our purposes, the Kingman equation will suffice, especially since it shows the main effects clearly.

1.1 Effect of Utilization

The effect of utilization on the waiting time is represented by the first part of Eq. (2). As the utilization p approaches 100%, the waiting time approaches infinity. Please note that this is not a linear effect. This is also graphically visualized in Fig. 2. Please note

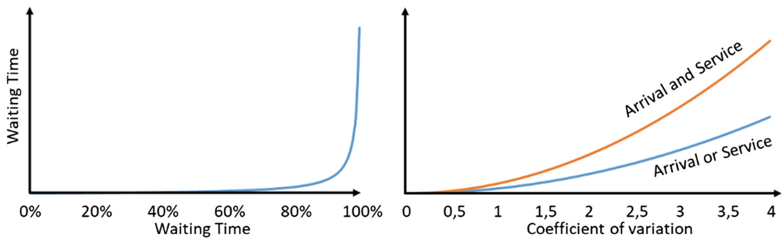


Fig. 2. Illustration of the general behavior of the effect of utilization and coefficient of variation on the waiting time

that the y-axis has intentionally no labels, as this would depend on a specific situation. Please also note that the Kingman equation is not very accurate for low utilization.

1.2 Effect of Variance

The middle part of Eq. (2) represents the effect of the variance of the arrival and service times. The increase of the waiting time is also not linear but squared to the coefficient of variation. Figure 2 shows the effect of increasing the coefficient of variation of either the arrival or departures in the lower line. The effect of increasing both arrival and departure variation simultaneously is shown in the upper line, which is simply double of the lower line.

1.3 Joint Effect of Utilization and Variance

Please note that the joint effect of utilization and variance is not the sum but the product of the two individual effects. Hence, if both utilization and variance increase, the waiting time will increase significantly more.

2 Game Objectives

It is one thing to know the Kingman equation in theory. It is something else to experience this relation in practice. The exponential behavior of increasing either the variation or the utilization, and especially the multiplicative behavior of a joint increase, is hard to internalize for practitioners.

The target group is people who are working or will be working with process systems. This includes shop floor supervisors, production planning staff, managers, and students of engineering or management. The game aims to teach its participants the severity of the problem of having both high utilization and high waiting time. During the game, the participants will guess the magnitude of the change due to an increase in utilization or variation. The resulting actual outcome usually far exceeds these estimates, improving the learning experience.

3 Game Outline

The game is an extended version of the number game found in [7], which shows the effect of utilization. In this original game, the effect of increasing utilization onto the system is experienced using normal six-sided (D6) dice. This game extends the original game to also show the effect of variation and the combined effect.

The game can be performed within thirty minutes and is hence a good warm-up for, as an example, a full-day or multi-day training. The game can handle a wide range of participants but ideally has around six to thirty participants split into groups of two. In each group one person represents the arrival, the other represents the service. Depending on the industry, these can be renamed as supplier and customer for manufacturing, customer and check out for supermarket cash registers, etc. as needed. The randomness is represented by dice throws. To model different variations, dice with different numbers are needed as shown in Fig. 3. The game will be explained using four-sided, twelve-sided, and twenty-sided dice, abbreviated ad D4, D12, and D20, but

Fig. 3. Dice with different numbers. Top row from left to right D4, D6, D8, bottom row D10, D12, and D20. D30 dice are also commercially available.

this can easily be adapted to other dice sizes. For each number, multiple dice are needed throughout the game. Ideally, there is one dice available in each size per person, but if there are not enough dice, one dice per team is also sufficient.

3.1 First Game: Baseline System

The game is played in a total of six games, each with twenty rounds between the arrival and the service. In the first game, the player uses D4 dice. Since not everybody may be familiar with the unusual shape of the dice, inform the participants that the number on top is the number of the throw. In Fig. 3, this would be a 4. Both the arrival and the service process throw the dice. The arrival adds 8 to the throw, and the service adds 10. This is a Δ of 2. Since the average throw of a D4 is 2.5, this means that in each round, 10.5 items are arriving and 12.5 items can be processed. This gives an average utilization of 84%.

If by chance more parts are arriving than can be serviced, the remaining parts are the queue. This is written down on a data sheet as shown in Fig. 4 on the left. In the first round, the service exceeded the arrival. In the second round, arrival threw a 4 and service a 1, hence one item remained in the queue to be processed at the next round. Since arrival and service threw 4 and 2 respectively, the queue remained at length 1. Only in the fourth round was the service able to reduce the queue to zero again. This is repeated for twenty rounds, and the sum, as well as the average of the queue length, is calculated.

The expected outcome based on two hundred simulations is around 0.06 with a standard deviation of also 0.06. The results of your game will, of course, be a different number for each team, somewhere in that range. In the game, however, you do not know the exact numbers but merely get a slightly different result from every team. The results of every team are marked on a chart to convey an idea of the range of expected results, and an estimated mean of the results is highlighted. Please be aware that the numbers will become quite high as indicated in Fig. 4. Yet, adding a scale from the beginning gives participants clues on the expected result and diminishes the learning experience.

Round	1	2	3	4	5	6
Dice	D4					
+Arriving	8					
+Check Out	10					
1	0					
2	1					
3	1					
4	0					
5	0					
6	0					
7	0					
8	0					
9	0					
10	1					
11	1					
12	0					
13	0					
14	0					
15	0					
16	1					
17	0					
18	0					
19	0					
20	0					
Sum	5					
Ø	0-25					

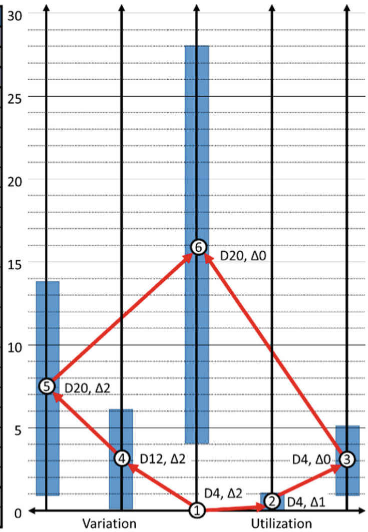


Fig. 4. Datasheet for the dice game with the first column filled out on the left and expected mean results for the six games with boxes for ± 1 standard deviations on the right

3.2 Second Game: Increase Utilization

In the next round, we keep the D4 dice but reduce the Δ to 1. Arrival adds 8, but service only adds 9. The expected utilization is now 91.3%. Repeating the twenty rounds will result in an average queue length of 0.5 with a standard deviation of 0.5. Again the results of the different teams are added to the chart.

3.3 Third Game: Increase Utilization to 100%

In the next game, we keep the D4 dice but reduce the Δ to 0. Both arrival and service add 8. The expected utilization is now 100%. Before playing this game, the participants should guess the expected outcome. Most will assume some linear relationship and guess around 1, vastly underestimating the true outcome. In the long term this would result in an infinite queue, but since in this game we play only twenty rounds, we expect an average queue length of 3 with a standard deviation of 2.2. Emphasize the nonlinear relationship by adding a curve through the tree means.

3.4 Fourth Game: Increase Variation by Using D12

In this game, we now use a D12 dice and add 4 to the arrival and 6 to the service. The Δ is now again 2 as in the first game. The expected mean value of a D12 is 6.5, hence there will be in average 10.5 parts arriving and 12.5 serviced. Please note that these averages are identical with the first game, and the utilization is therefore also 84%. Only the variation around the mean has increased. After twenty rounds again, the results of the teams are added to a chart. The results are expected to have a mean of 3.2 with a standard deviation of 3.2.

3.5 Fifth Game: Increase Variation by Using D20

The fifth game uses a D20. To get the same average arrivals of 10.5 and service of 12.5 with a utilization of 84% as in game 1 and 4, we add nothing to the arrivals and 2 to the service dice throw. Before playing the game, have the participants guess the expected outcome. Most of them again would assume a linear relationship and vastly underestimate the actual results, which are expected to have a mean 7.6 with a standard deviation of 6.06. Again, highlight the nonlinear relationship in the graph.

3.6 Sixth Game: Increase Variation to D20 and Utilization to 100%

In the last game, we combine the high variance with a high utilization. Both the arrival and the service get a D20 dice and cannot add anything to their dice throw, giving a Δ of 0 and hence a utilization of 100%. The participants should guess the expected outcome. Again, the participants vastly underestimate the outcome due to the multiplicative relationship of the effects. The results are expected to have a mean of 15.9 with a standard deviation of 11.9.

4 Discussion

To emphasize the key learnings of the nonlinear effect of both the utilization and the fluctuations and especially the multiplicative effect of both the game is closed with a discussion and review round. The moderator should emphasize and point out this nonlinear effect, and how the continuously larger numbers surprised the participants. Depending on the mathematical skills of the group, the Kingman equation can be introduced. Understanding this behavior is important for practitioners to define a production system. Often, inexperienced planners plan for a utilization of 100% and ignore the effect of variance. As a result, waiting times increase and therefore costs go up.

5 Participants Experience and Outcomes

This quick exercise is usually a surprising eye-opener for the participants, as shown by comments like “*I never though it would get so high*”. After the initial first game, participants consistently underestimate the effect of the changes. The participants usually assume a linear relation and underestimate the effect of the third game by estimating a queue length of less than 1 instead of the actual 3. The fifth game is usually only slightly underestimated with a predicted value of around 6 instead of the actual 7.6. For the combined effect of the sixth game, participants merely add the two effects and predict a queue of around 10, whereas the actual result is almost 16.

6 Summary

The game lets the participants experience the nonlinear effects of utilization, variation, and the nonlinear combination of both. Depending on the qualification of the participants, the Kingman equation may be introduced, but this is optional. We have played this game with different groups on different continents and have obtained consistent results of the participants being surprised by the magnitude of the effect. This game is a good warm-up for many trainings in the field of process optimization or lean manufacturing. Datasheets and more statistics can be downloaded at http://www.allaboutlean.com/dice-game-kingman-formula/.

References

1. Tom, G., Lucey, S.: A field study investigating the effect of waiting time on customer satisfaction. J. Psychol. **131**(6), 655–660 (1997)
2. Bhat, U.N.: The general queue *G*/*G*/1 and approximations. An Introduction to Queueing Theory. SIT, pp. 169–183. Birkhäuser, Boston (2008). https://doi.org/10.1007/978-0-8176-4725-4_9
3. Adan, I.: Queueing theory: Ivo Adan and Jacques Resing. Department of Mathematics and Computing Science, Eindhoven University of Technology (2001)
4. Kingman, J.F.C.: The single server queue in heavy traffic. Math. Proc. Camb. Philos. Soc. **57** (4), 902–904 (1961)
5. Marchal, W.G.: An approximate formula for waiting time in single server queues. E Trans. **8** (4), 473–474 (1976)
6. Krämer, W., Lagenbach-Belz, M.: Approximate formulae for the delay in the queueing system GI/G/1. In: Proceedings of the 8th International Teletraffic Congress, Melbourne, pp. 235.1–235.8 (1976)
7. Bicheno, J.: The Lean Games and Simulations Book. Picsie Books, Buckingham (2014)

Towards a Sustainable Innovation Process: Integrating Lean and Sustainability Principles

Myrna Flores[1,2(✉)], Doroteja Maklin[2], Billy Ingram[3], Matic Golob[2], Christopher Tucci[1], and Andrea Hoffmeier[4]

[1] École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland
myrna.flores@epfl.ch
[2] Lean Analytics Association, Carona, Switzerland
[3] Interface Inc., Atlanta, GA, USA
[4] SHERPA Sustainability Institute, Durango, CO, USA

Abstract. Many companies are heavily investing resources to innovate faster and smarter in order to gain or retain a competitive advantage. Nevertheless, defining and deploying a sustainable innovation vision still represents a challenge to most companies, as a deep change of mindset is required to reflect going beyond the design, development, production and distribution of new products, to also consider their disposal, recycling or reuse, as part of their end-to-end product life cycle. Therefore, this paper aims to: (1) highlight the relevance of including lean and sustainability principles in the early design and conceptualization phases, (2) explain how lean and sustainability can bring benefits when applied as an integrated system considering three axes: the economic, the social and the environmental, and (3) share a case study providing insights of a successful application.

Keywords: Sustainability · Green · Lean · Innovation · Product development

1 Introduction

Ever since humans evolved from Hominidae, we have constantly been looking for new products and services to evolve and solve day-to-day challenges. Companies, governments and users continuously strive for innovative products to make our lives simpler, more effective and easier. However, not many consider the effects such products/services have through their lifecycle and their impact on the economy, society and the environment. During the innovation process, products and services are designed to satisfy customer needs, and lean and sustainability thinking are a vital part of the process.

There are numerous successful and detailed examples of how companies have applied lean to eliminate waste and decrease costs both in manufacturing and services organizations. But only very few industrial cases show evidence of how lean and sustainability are applied in industrial settings since the very early stages of the conception of new products, thus taking into consideration the end-to-end life cycle.

The first thing that comes to mind when linking lean and sustainability is to eliminate waste or use less resources such as energy to reduce costs. However,

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 34–42, 2018.
https://doi.org/10.1007/978-3-319-99704-9_5

sustainable innovation brings much more than just economic benefits from waste reduction, since it also focuses on the impact on the environment and society in an integrated system.

2 Research Method

The Lean Analytics Association together with EPFL started the yearly Lean Product Development Best Practices Discovery Project in 2015. Eighteen companies have joined since, and company cases have been collaboratively developed, some of which were published in a book [5]. Through this paper, the authors aim to answer the following research questions:

1. **How are lean innovation and sustainability interconnected?**
2. **Which best practices can be identified in the industry that could increase awareness about the relevance of considering lean and sustainability when developing new products?**

The approach followed six main research steps. Firstly, the need was identified and the research question specified. Secondly, the state-of-the-art literature review was conducted. The literature review aimed to identify the lean and sustainability best practices applied in innovation process. Thirdly, the questionnaire was developed and interviews with the innovation leaders conducted. The interview answers were analyzed and documented to result in research publications. The last step aims to enable the industry and academia to learn from the findings and innovate greener.

3 Lean and Sustainability

3.1 Lean Thinking

The lean concept observed and explored in Japanese companies was expanded to a comprehensive philosophy by Womack and Jones [11]. In their book *Lean thinking: Banish waste and create wealth in your corporation*, they defined the five principles of lean thinking, as shown in Fig. 1.

Value	Specify what creates value from the customerís perspective (new product)
The value stream	Identify all the steps along the process chain
Flow	Make the value process flow: eliminate waste
Pull	Make only what is needed by the customer
Perfection/ Continuous Improvement	Strive for perfection by continually attempting to produce exactly what the customer wants

Fig. 1. Five lean principles (adapted from [10])

3.2 Lean Innovation

Lean innovation is the application of lean thinking to the End-to-End Innovation process, as shown in Fig. 2. It focuses on value creation, the provision of a knowledge environment and continuous improvement, which together encourage collaborative and sustainable innovation [5].

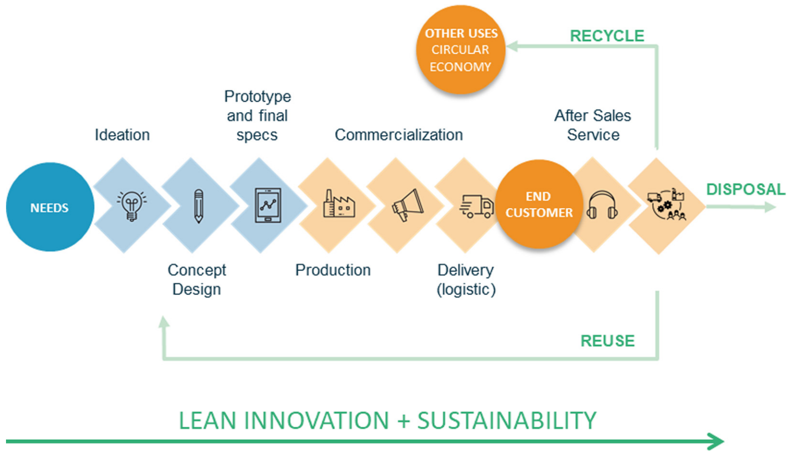


Fig. 2. Lean innovation and sustainability in the End-to-End innovation process

Lean efforts have focused mostly towards production and other transactional processes where waste was visible and savings in terms of cost were immediately noticeable. Figure 3 illustrates the significantly higher influence of the product design in comparison to the other phases. Therefore, if during the product design, the right decisions are made regarding design, processes and sustainability and the correct deliverables are forwarded, considerable waste will be avoided in the later stages and the whole process will become more efficient. Not only the efficiency but also the forecast of the entire product/service lifecycle with circular vision is determined at the design stage.

By incorporating Design for Sustainability principles, lean innovation supports and enables waste elimination through the entire value chain and it does not only bring economic benefits to companies, but also to the environment and society. The human factor and their skills are significant enablers towards lean and sustainable innovation. To be able to address sustainability challenges and design products for a green future, the employees in industry require training to develop a new mindset that enables them to integrate into their daily operations not only the economic aspect but also the environmental and social elements [4].

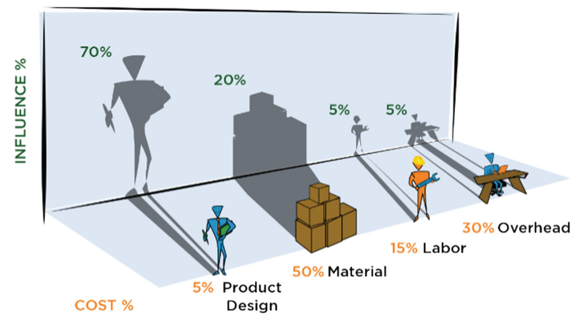


Fig. 3. Who casts the biggest shadow (adapted from [7])

3.3 Sustainability

Sustainability aims to develop and sustain the environmental, social and economic circumstances that enable humans to co-exist with nature in "productive harmony" both in the present and the future [1, 10]. A process where sustainability (environmental, social and economic as shown in Fig. 4) considerations are integrated into company systems from the idea generation through to research and development (R&D) and commercialization, is called *sustainable innovation*. This applies to products, services and technologies, as well as new business and organization models [2]. Furthermore, the definition of social responsibility (SR) was established in 2010 through the ISO 26000 and is foundational to our methods [3]. The SR Principle *"Respect for Stakeholder Interests"* is examined.

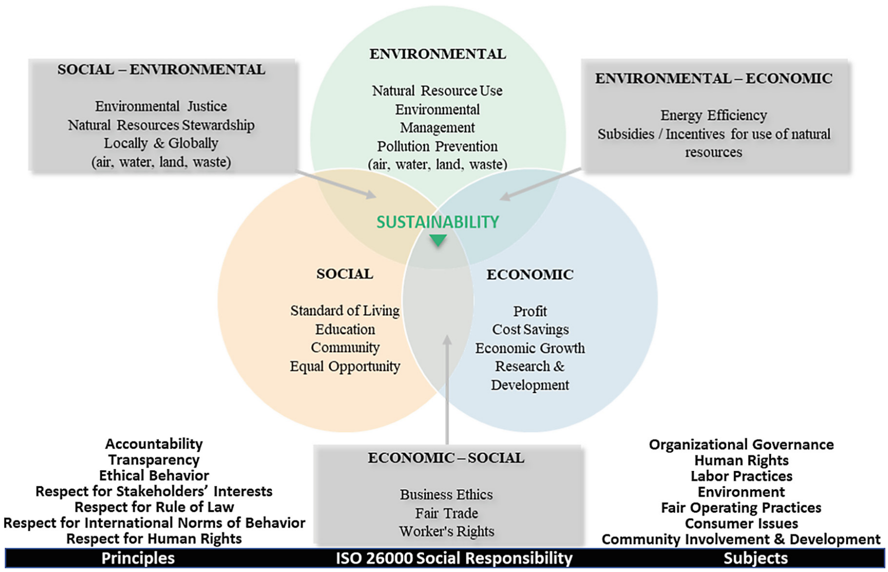


Fig. 4. Aspects of sustainability (adapted from [8]; addition of ISO 26000)

4 Lean Innovation Model Incorporating Sustainability Aspect

The Lean Innovation Model was developed to provide as a structured guide to create an integrated vision for the companies to start or continue their lean product development journey [5]. It is a framework that incorporates four main building blocks: 1. Strategy and Performance, 2. Skilled People and Collaboration, 3. Efficient Process and Knowledge-based Environment, 4. Continuous Improvement and Change. Each building block is represented by three enablers, giving a total of twelve enablers, as represented in Table 1. The model integrates both the technical enablers, as well as the "soft" aspects of skills, collaboration and leadership which are indispensable for a successful implementation. One of the important enablers is also *7. Sustainable Innovation Process*.

Table 1. The lean innovation model [5]

1. Strategy and performance	1. Customer value	**3. Efficient process and knowledge-based environment**	**7. Sustainable innovation process**
	2. Strategy and leadership commitment		8. Lean thinking tools and methods
	3. Track Performance		9. Co-create, share and reuse knowledge
2. Skilled people and collaboration	4. Human skills	**4. Continuous improvement and change**	10. Continuous improvement system
	5. Chief engineer		11. Internal and external partnerships
	6. Cross-functional collaboration		12. Communicate, manage and reward change

A truly sustainable lean innovation process is supported by activities during the whole End-to-end innovation phases. Table 2 outlines different innovation phases and which sustainability focused activity areas contribute to each one of them.

Table 2. Sustainable lean innovation phases and sustainability focus areas

Innovation phases	Sustainability focus areas
Engagement	- Stakeholder analysis *and respect for stakeholder interests*
Ideation	- *Considering stakeholder interests* throughout the entire product lifecycle: aiming to reduce CO_2 footprint & any harm end-to-end
Concept design	- Reusing some of the components or disposed products - Using recycled materials & reducing material use - Assessing social impact *on all stakeholders*

(*continued*)

Table 2. (*continued*)

Innovation phases	Sustainability focus areas
Prototype and final specs	- Creating a product that will produce minimal waste - Creating a product that will consume little energy - Ensuring health and safety requirements *for all stakeholders*
Production	- Reducing energy consumption and using renewable energy - *Considering workers as stakeholders* - Reducing production waste
Commercialization	- Green marketing [9] - Value-driven model *elevates stakeholders/society* - Consumer awareness of all types of impact (includes environment)
Delivery	- Using green logistics and reducing the CO_2 footprint - Promoting local sourcing: *engaging local stakeholders*
After sales service	- Promoting responsible use: repairs vs replacements
Disposal/Recycling/Reuse	- Encouraging users *and other relevant stakeholders* to recycle, safely dispose or reuse products

During the *Explore* and *Analyze* phases of the Best Practices Discovery research project carried annually by the Lean Analytics Association (LAA), lean innovation best practices have been identified and documented. In the third building block of the Lean Innovation Model, *Efficient Process and Knowledge Based Environment*, eleven best practices were consolidated from the 18 companies, six of which were categorized as "common" (well-known in the industrial innovation processes) and five as "emerging practices" (identified in less than five companies) as illustrated in Fig. 5. As observed, although the 18 interviewed companies have a clear product development process, there is currently poor integration of a sustainability strategy in innovation. Only three have so far integrated the sustainability vision into the product development practice. Therefore, sustainable innovation is still considered as one emerging best practice in lean innovation.

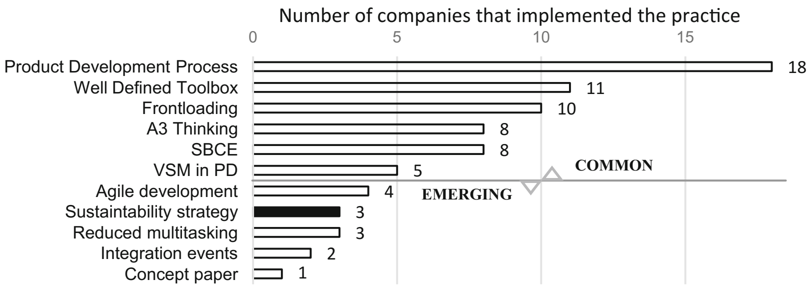


Fig. 5. Emerging and common best practices identified in *the Efficient Process and Knowledge Based Environment* building block of the Lean Innovation model (N = 18) [5]

The following section will provide more details about the practices of Interface, since it is the strongest of the three identified companies that continuously pursues the integration of its sustainability strategy into the innovation process.

5 Case Study: Interface Inc. - Implementing the Mission Zero Strategy

Interface is the world's largest manufacturer and marketer of modular carpet, headquartered in LaGrange, Georgia, USA. The company maintains its position among top sustainability leaders as a result of the company's focus on sustainability through its Mission Zero strategy which is aligned with the people, process, product, place and profits. Mission Zero was proposed under the leadership of Ray C. Anderson (1994) and its focus is "*to be the first company that, by its deeds, shows the entire industrial world what sustainability is in all its dimensions: people, process, product, place and profits—by 2020—and in doing so, to become restorative through the power of influence*" [6].

To accomplish this latter goal by 2020 and guide employees through the transformation, Interface developed the Mount Sustainability framework. Seven Fronts of Mount Sustainability were identified and placed on the mountain framework to remind employees of the fronts through which the company needs to pass to reach the top of the mountain before 2020 (Table 3).

Table 3. Interface Mount Sustainability's seven fronts and targets

Front 1: Eliminate waste	Eliminate all forms of waste in every area of the business - **$16 million in operational cost avoidance**
Front 2: Benign emissions	Eliminate toxic substances from products, vehicles and facilities **- $50 million inventory reduction**
Front 3: Renewable energy	Operate facilities with **100% renewable energy**
Front 4: Closing the loop	Redesign processes and products to close the technical loop using recycled and bio-based materials **- Recycled and bio-based raw material content increased from 50% to 75%**
Front 5: Efficient transportation	Transport people and products efficiently to eliminate waste and emissions **- Reduce transportation costs by 30%**
Front 6: Sensitizing stakeholders	Create a culture that uses sustainability principles to improve the lives and livelihood of all stakeholders **- Connect customers and vendors through Interface, positively influencing both**
Front 7: Redesign commerce	Create a new business model that demonstrates and supports the value of sustainability-based commerce - **Disrupt competitors and raise customer expectations in the industry. Sell 30% more at 15% higher margins**

The entire organization is committed to continuous improvement, and sustainability became a common vision which is deeply embedded in employees' behavior as part of their day-to-day focus. As a consequence, two key projects have shown the positive results and impact of Sustainable Innovation.

Net Works is a collaborative project between the Zoological Society of London, Aquafl (yarn producer) and Interface. An innovative, cross-sector initiative, was designed to tackle the growing environmental problem of discarded fishing nets in the world's coastal communities. Local fishermen in the Philippines usually discarded fishing nets that got tangled whilst out in the sea. The nets polluted the sea water and endangered the wildlife in the local area. The companies offer fishermen payment for the waste fishing nets, if they are brought onshore. Fishing nets are then recycled to produce yarn to be used for the production of new carpet tiles. Whilst benefiting the society by providing income for fishermen, the initiative helps educate the local society about the dangers of water pollution, and maintain the environment clean. Interface fulfils Mission Zero's goal to source 100% recycled materials for its carpet tiles. This can be referred to Circular Economy, in which one sector recycles the waste from another.

TacTiles® is Interface's carpet tile installation system that integrates lean thinking and sustainability to reduce waste and provide value to the customer. TacTiles are small adhesive-backed squares that connect carpet tiles securely to form a floor that "floats" for improved flexibility, easier replacement and long-term performance without permanent adhesion to the subfloor. TacTiles are a result of research and design using lean and sustainability concepts to reduce the environmental footprint and waste generated during the process, to save space and to cut transport costs compared to previously used glue adhesives. TacTiles have been imitated and adopted across the industry as a good practice of carpet tile installation, leading by example.

6 Conclusions

Although Lean and Sustainability have been applied in many organizations, their integration to design and develop new products still represents a challenge. The sustainable innovation approach will enable companies: (1) to develop new products and services, while not only envisioning economic returns, but also integrating the impact those innovations have on the environment and society, (2) to widen the scope, going from the ideation phase to the recycling, reuse or disposal of all products, (3) *to achieve innovative leaps by taking all stakeholders into consideration.* This paper provided evidence of a successful industrial case, in which a carpet producing company has defined and deployed a strategy that successfully integrates lean and sustainability considering the end-to-end innovation process providing economic returns but also impacting the environment and the society, taking care of the Earth's resources for future generations.

References

1. Ayman, A.E.O., Mayar, A.G., Nazirah, Z.A.: Lean principles: an innovative approach for achieving sustainability in the Egyptian construction industry. Organ. Tech. Manag. Constr. Int. J. **6**(1), 917–932 (2014)
2. Charter, M., Clark, T.: Sustainable innovation key conclusions from sustainable innovation conferences 2003–2006. The Centre for Sustainable Design University College for the Creative Arts (2007). www.cfsd.org.uk. Accessed 6 Apr 2018
3. Duckworth, H.A., Hoffmeier, A.: A Six Sigma Approach to Sustainability: Continual Improvement for Social Responsibility. CRC Press Taylor & Francis Group, Boca Raton (2015)
4. Flores, M., Canetta, L., Castrovinci, A., Pedrazzoli, P., Longhi, R., Boër, C.R.: Towards an integrated framework for sustainable innovation. Int. J. Sustain. Eng. **1**(4), 278–286 (2008)
5. Flores, M., Golob, M., Maklin, D., Tucci, C., Flores, K.: Lean Product Development Best Practices: 10 Industrial Success Stories. Lean Analytics Association, Carona (2017)
6. Ingram, B., Design Studio Team: Interviewed by Maklin, D. and Flores, M. in LaGrange, USA (2015)
7. Munro and Associates: Who has the Biggest Shadow? (1989). www.leandesign.com/history-of-lean-design. Accessed 14 Mar 2016
8. Rodriguez, M.A., Ricart, J.E., Sanchez, P.: Sustainable development and the sustainability of competitive advantage: a dynamic and sustainable view of the firm. Creativity Innov. Manag. **11**(3), 135–146 (2002)
9. United Nations Environment Programme: Design for sustainability. A Step-by-Step Approach. TU Delft and UNEP, Paris, France (2009)
10. USEPA: Basic Information The United States Environmental Protection Agency (USEPA). (2009) http://www.epa.gov/sustainability. Accessed 1 Apr 2018
11. Womack, J., Jones, D.: Lean Thinking: Banish Waste and Create Wealth in your Corporation. Simon & Schuster UK Ltd., London (1996)

Mathematical Modelling for Sustainable Agricultural Supply Chain Management Considering Preferences Between Farmers and Retailers

Takashi Hasuike[1(✉)], Tomoko Kashima[2], and Shimpei Matsumoto[3]

[1] Waseda University, 3-4-1 Okubo, Shinjuku, Tokyo 169-8555, Japan
thasuike@waseda.jp
[2] Kinki University, 1 Takaya Umenobe,
Higashi-Hiroshima City, Hiroshima 739-2116, Japan
kashima@hiro.kindai.ac.jp
[3] Hiroshima Institute of Technology,
2-1-1 Miyake, Saeki-ku, Hiroshima 731-5193, Japan
s.matsumoto.gk@cc.it-hiroshima.ac.jp

Abstract. This paper considers an agricultural supply chain management to find the best matching between farmers and retailers with contract according to their preferences. It is important to construct the agricultural production system to hold the win-win relationship considering transportation costs. Therefore, in this paper, a mathematical programming problem is formulated to find the optimal matching between farmers and retailers under several uncertainties. It is generally difficult to obtain the best solution directly in terms of multiobjectivity and uncertainty. Therefore, the flexible modeling and the efficient algorithm to obtain these optimal solutions are also developed using a data-driven approach using our proposed information system.

Keywords: Agricultural supply chain management
Mathematical programming · Data-driven approach

1 Introduction

For several years, Japanese farmers' surroundings have been drastically changed. Particularly, aging problem and globalization of food production are critical problems to give some negative impacts to Japanese agriculture. Therefore, various solution approaches to overcome these disadvantages are nowadays discussed. On the other hand, by using recent Information and Communication Technology (ICT), Japanese agriculture may have a big opportunity to change traditional system and to positively construct a new advanced system.

In the standard Japanese agricultural system, agricultural products were sold from farmers to a central wholesale market, to some suppliers, and finally sent to consumers. In this traditional system, it is difficult for consumers to get to know detailed production information of the purchased agricultural products. In addition, it is also difficult for

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 43–49, 2018.
https://doi.org/10.1007/978-3-319-99704-9_6

farmers to get their sufficient returns sustainably. In terms of information sharing between farmers and consumers, ICT-based agricultural systems are proposed all over the world (Holzworth et al. [2], Janssen et al. [3], Wright et al. [5]). Furthermore, some agricultural information systems dedicated to Japanese agriculture were also recently developed. Particularly, Kashima et al. [4] proposed Farmer's Information System (FIS) to improve Japanese traditional agriculture by ICT in terms of sustainable agricultural management. FIS can also adjust their farming schedule in a way that by the time they grow agricultural products, and their products are actually sought upon by consumers.

Thus, useful ICT-based agricultural systems have been proposed, but there are still few studies of quantitative and qualitative analyses of the agricultural supply chain management in terms of optimization. We [1] recently proposed a mathematical programming problem on the FIS-based agricultural system in terms of environmental load. However, our previous proposed model considered only minimizing the total discarding volume. In addition, the preferences between farmers and retailers are also not considered. In terms of sustainable development of Japanese agriculture, it is generally important to consider that both each farmer maximizes the profit and the retailers buy the needed high quality agricultural product to achieve the Win-Win relationship among them. Furthermore, a transportation cost from the farmer to the retailer is also one of the most important factors to maximize their profits. We could not introduce the transportation cost into our previous model, and do the sensitivity analysis directly. In order to achieve these objectives, we need to consider optimal matching between farmers and retailers considering their preferences.

FIS can collect POS data of the agricultural product, and hence, it is also important to formulate a sustainable agricultural supply chain with the optimal matching between farmers and retailers as a mathematical programming problem and to apply the data-driven approach based on FIS. Particularly, we consider that each farmer contracts to the retailer. The contract is that production volume of the agricultural product at the contract farmer is all shipped to the retailer, because farmer need not discard a large quantity of unsold agricultural product. On the other hand, this contract is that the burdens of retailers are increasing, and hence, in terms of risk aversion, the retailers order the cultivated filed to the contracted farmer considering consumers' demands.

From the above-mentioned, we extend our previous agricultural supply chain model to the risk sharing and optimal matching problem by introducing contracts and preferences of both farmers and retailers, and develop the efficient algorithm to obtain the optimal ordering cultivate field at each contracted farm. By integrating this paper's mathematical approach into FIS, an advanced agricultural system with both theoretical and practical evaluations can be constructed as an important application of this paper. In addition, in this future advanced agricultural system, both farmers and retailers will make grate efforts to raise preference levels, because to put the optimal matching each other into practice is directly related to achieve their target profits.

2 Mathematical Formulation

In terms of Win-Win relationship shown in Introduction, we focus on achieving each target profit to set all retailers and farmers as much as possible. In the case that the risk is considered as the total cost, the risk sharing is directly related to maximizing the total profit considering the cost at all farmers and retailers. We assume that n retailers purchase one agricultural product from m local farmers in terms of local production for local consumption. In order to do modeling our agricultural supply chain model, we assume the following situations.

– The production volume of the agricultural product at each farmer is given as a random variable, and the actual production volume is all shipped to the contracted retailers.
– Consumer's demand at each retailer is also random variable.
– Unsold volume at each retailer is discarded. The discarding cost is paid by each retailer.
– The decision variable is the cultivated field of the agricultural product at each contracted farmer.

Furthermore, the following assumption is introduced to ensure the target profit of each farmer.

– Each farmer initially sets the contract fee per cultivated field and minimum cultivated field considering the target profit.
– The objective is to maximize the total profit of all retailers satisfying the target profit of each retailer through the multiperiod.

2.1 Notation of Parameters

(For contract farmers)

m: Total numbers of farmers.

$\hat{C}_i$: Contract fee per cultivated field of the agricultural product at ith farmer. In this paper, the contract fee is the same to all retailers.

S_{ij} : Contract cultivated areas of the agricultural product from jth retailer to ith farmer (decision variable).

S_i^{min} : Minimum cultivated areas of the agricultural product of kth quality at ith farmer which is dependent on the contract fee. This parameter is initially set by each farmer as well as setting parameter C_i : according to target profit.

S_i^{max} : Maximum cultivated areas of the agricultural product at ith farmer which is the same as the total field owned by the ith farmer.

Q_i : Amount of the agricultural product per cultivated area for ith farmer. In the real-world agricultural system, Q_i is dependent on current weather and climate conditions, and hence, Q_i is assumed to be a random variable with mean value $\bar{Q}_i$ and variance σ_i^2 in this paper

(For retailers of our proposed model)

n: Total number of retailers.

p_j: Selling price of unit volume to the agricultural product at jth retailer.

s_j: Shortage cost to the agricultural product at jth retailer.

β_j: Discarding cost of unit unsold volume at jth retailer.

D_j: Consumers demand to the agricultural product at jth retailer which is assumed to be a random variable with mean value $\bar{D}_j$ and variable $\hat{\sigma}_j^2$.

g_j: Target profit of jth retailer

(For contract and preference between farmers and retailers)

z_{ij} : 0-1 decision variable between ith farmer and jth retailer for the agricultural product. In the case of contract, $z_{ij} = 1$. Otherwise, $z_{ij} = 0$.

C_{ij}: Transportation cost by a truck from ith farmer to jth retailer regardless of production volume. C_{ij} is initially set as a constant value dependent on distance between ith farmer and jth retailer. To simplify the following discussion, we assume that production volume from ith farmer to jth retailer can be all packed into the only one truck.

A: Set of possible all matching patterns between farmers and retailers, i.e., $(i,j) \in A$, $(i = 1,2,\ldots,m; j = 1,2,\ldots,n)$.

A_p: Set of preference matching patterns between farmers and retailers. This means that a retailer selects some farmers who want to buy the agricultural product and the farmer also wants to contract. For instance, retailer 3 selects farmers 1, 2, 3 and 4, and farmers 1, 3 and 4 want to contract. In this case, $(1,3), (3,3), (4,3) \in A_p$ and $(2,3) \notin A_p$

Consequently, we decide the optimal decision of S_{ij} and z_{ij} derived from contracts between farmers and retailers under several uncertainties considering transportation cost and their preferences.

2.2 Mathematical Modelling of Our Proposed Model

We formulate an FIS-based agricultural supply chain model. The best cases of our proposed model are to achieve that all matchings between farmers and retailers are included in A_p, and to maximize each total profit of all retailers.

To check the first case, we formulate the following mathematical programming problem:

$$\begin{array}{ll} \textit{Maximize} & \sum_{(i,j)\in A_p} z_{ij} \\ \textit{subject to} & R_j(\boldsymbol{S}) \geq g_j, (j = 1,2,\ldots,n) \\ & S_i^{min} z_{ij} \leq S_{ij} \leq S_i^{max} z_{ij}, (i = 1,2,\ldots,m; j = 1,2,\ldots,n) \\ & \sum_{j=1}^{n} S_{ij} \leq S_i^{max}, (i = 1,2,\ldots,m) \\ & S_{ij} \geq 0, z_{ij} \in \{0,1\}, (i = 1,2,\ldots,m; j = 1,2,\ldots,n) \end{array} \quad (1)$$

where $R_j(\boldsymbol{S})$ is the profit function of jth retailer formulated as follows:

$$R_j(\boldsymbol{S}) = p_j\left(\sum_{i=1}^{m} Q_iS_{ij} - \left[\sum_{i=1}^{m} Q_iS_{ij} - D_j\right]^+\right) - \sum_{i=1}^{m} \hat{C}S_{ij} - \sum_{i=1}^{m} C_{ij}z_{ij} \\ -s_j\left[D_j - \sum_{i=1}^{m} Q_iS_{ij}\right]^+ - \beta_j\left[\sum_{i=1}^{m} Q_iS_{ij} - D_j\right]^+ \tag{2}$$

where $[x]^+ = \max\{x, 0\}$. In problem (1), the first constraint is for each retailer, and the second and third constraints are for each farmer. This problem is a 0-1 nonlinear and stochastic programming problem, because it includes some max functions $[x]^+$ and random demands and production volume, and hence, it is impossible to solve problem (1) directly.

In the real-world situations to apply our proposed FIS, it is important to deal with our proposed model efficiently as well as to obtain the optimal solution. Actually, numerical datasets of demands and production volume can be collected by FIS. Therefore, we introduce a data-driven approach called a scenario-based approach to our proposed model. We consider the following S scenarios derived from FIS:

$$\boldsymbol{D} \to \boldsymbol{d}_s = \{d_{1s}, d_{2s}, \ldots, d_{nS}\}, \boldsymbol{Q} \to \boldsymbol{q}_s = \{q_{1s}, q_{2s}, \ldots, q_{ms}\} \\ \Pr\{\boldsymbol{D} = \boldsymbol{d}_s \textstyle\bigcap \boldsymbol{Q} = \boldsymbol{q}_s\} = \frac{1}{S}, (s = 1, 2, \ldots, S) \tag{3}$$

Using these scenario data and considering expected value of $R_j(\boldsymbol{S})$, we equivalently transform expected value $E\left[R_j(\boldsymbol{S})\right]$ as follows:

$$E\left[R_j(\boldsymbol{S})\right] \\ = \frac{1}{S}\left(p_j\left(\sum_{i=1}^{m} q_{is}S_{ij} - \xi_{ijs}\right) - \sum_{i=1}^{m}\left(\hat{C}_iS_{ij} + C_{ij}z_{ij}\right) - s_j\eta_{ijs} - \beta_j\xi_{ijs}\right), \\ \xi_{ijs} \geq \sum_{i=1}^{m} q_{is}S_{ij} - d_{js}, \xi_{ijs} \geq 0, \ \eta_{ijs} \geq d_{js} - \sum_{i=1}^{m} q_{is}S_{ij}, \eta_{ijs} \geq 0 \tag{4}$$

From transformation (4), problem (1) can be also transformed into a standard 0-1 linear programming problem, and hence, it is not difficult to solve 0-1 linear programming problems even if the number of decision variables is much increasing.

Furthermore, in the optimal solution, if all contracts between farmers and retailers are included in A_p, it may be possible to improve the profit of each retailer. Therefore, we consider the following auxiliary problem:

$$\begin{aligned} &\textit{Maximize}\ \lambda \\ &\textit{subject to}\ E\left[R_j(\boldsymbol{S})\right] - g_j \geq \lambda, (j = 1, 2, \ldots, n) \\ &\qquad \textstyle\sum_{(i,j)\in A_p} z_{ij} = z^* \\ &\qquad S_i^{min} z_{ij} \leq S_{ij} \leq S_i^{max} z_{ij}, (i = 1, 2, \ldots, m; j = 1, 2, \ldots, n) \\ &\qquad \textstyle\sum_{j=1}^{n} S_{ij} \leq S_i^{max}, (i = 1, 2, \ldots, m) \\ &\qquad S_{ij} \geq 0, z_{ij} \in \{0, 1\}, (i = 1, 2, \ldots, m; j = 1, 2, \ldots, n) \end{aligned} \tag{5}$$

where z^* is the optimal value of problem (1). This problem is also transformed into a 0-1 linear programming problem. Consequently, our proposed model with FIS will be useful in terms of real-world application, because all mathematical programming problems can be efficiently solved using optimization solvers.

3 Numerical Example

We provide the following simple dataset with 4 farmers and 3 retailers. To simplify the mathematical programming problem, shortage cost s_j and discarding cost β_j at all retailers are the same as $s_j = 10, \beta_j = 5$, respectively. Furthermore, A_p is initially set as {(1,1), (3, 1), (4, 1), (1, 2), (3, 2), (3, 3), (4, 3)} based on questionnaires among all farmers and retailers.

From this optimal cultivated areas S_{ij} as shown in Table 1, preferences between farmers and retailers defined by A_p are held satisfying the target profits of all retailers.

Table 1. Dataset and optimal solution of farmers and retailers.

Farmer	$\bar{Q}_i$	σ_i^2	S_i^{min}	S_i^{max}	C_i
1	10	4	30	200	15
2	8	2	20	100	10
3	15	5	50	150	10
4	12	4	30	150	15

Retailer	$\bar{D}_j$	$\hat{\sigma}_j^2$	p_j	g_j
1	500	30	25	4000
2	400	20	25	3500
3	600	80	30	5000

C_{ij}	Retailer 1	Retailer 2	Retailer 3
Farmer 1	200	250	400
Farmer 2	150	150	150
Farmer 3	400	300	600
Farmer 4	500	400	500

Optimal S_{ij}	Retailer 1	Retailer 2	Retailer 3
Farmer 1	30	63	0
Farmer 2	0	0	0
Farmer 3	50	50	50
Farmer 4	60.07	0	89.93

4 Conclusion

This paper proposed mathematical modelling for agricultural supply chain management under several uncertainty in terms of sustainability and preferences. Using the data-driven approach based on FIS, the proposed problem is transformed into a 0-1 linear programing problem. Therefore, it is possible to solve the large-scale problems using our modelling and solution approach in the real-world agricultural system.

References

1. Hasuike, T., Kashima, T., Matsumoto, S.: Contribution of mathematical model for food supply chain considering environmental load. In: The 28th Annual Conference of the Japanese Society for Artificial Intelligence, 1B3-OS-02b-3 (2014). (in Japanese)
2. Holzworth, D.P., et al.: Agricultural production systems modelling and software: current status and future prospects. Environ. Model. Softw. **72**, 276–286 (2015)

3. Janssen, S.J.C., et al.: Towards a new generation of agricultural system data, models and knowledge products: information and communication technology. Agric. Syst. **155**, 200–212 (2017)
4. Kashima, T., Matsumoto, S., Matsutomi, T.: Effects of sharing farmers' information using content management system. In: Ozok, A.A., Zaphiris, P. (eds.) OCSC 2013. LNCS, vol. 8029, pp. 296–303. Springer, Heidelberg (2013). https://doi.org/10.1007/978-3-642-39371-6_34
5. Wright, H.J., et al.: Using ICT to strengthen agricultural extension systems for plant health. J. Agric. Food Inf. **17**(1), 23–36 (2016)

Formalising Specific-Energy Consumption Under a Production-Management Form Where Rush Orders Are Added in Time Slots

Shungo Arai[1], Hironori Hibino[1(✉)], Takamasa Horikawa[1], and Makoto Yamaguchi[2]

[1] Tokyo University of Science, 2641 Yamazaki, Noda, Chiba, Japan
hibino@rs.tus.ac.jp
[2] Akita University, 1-1, Tegatacho, Akita, Akita, Japan

Abstract. Factory-production activity is conducted based on production plans, which will unavoidably have to be revised due to changes in the production context. These changes should be considered when drafting production plans because of the frequent occurrence of rush orders with short deadlines. Since rush orders interrupt regular orders, we may consider that increased setup times, lower production quantities, and increased specific-energy consumption will accompany their addition.

We have previously supposed a management form that immediately adds rush orders to the production line, and proposed expressions for calculating the specific-energy consumption. Actual companies, looking to restrict increases in setup times, may implement management where rush orders are accumulated and added in time slots. However, in studies on formulae for calculating specific-energy consumption that consider rush orders, we see no consideration of management where the rush orders are added in time slots. Accordingly, this study presents a pre-emptive evaluation method using specific-energy consumption by formalising it for management where rush orders are added in time slots.

Keywords: Rush order · Specific energy consumption
Production management

1 Introduction

Efficient energy use is becoming a vital issue in all fields. One concern in industry is the reduction of energy consumed in production activities. Revisions to Japan's Energy Conservation Act stipulate the annual reduction of specific-energy consumption by at least 1% [1]. In addition, following COP21 (United Nations Climate Change Conference) in December 2015, greenhouse-gas reduction targets have been released, and it is now obligatory to establish measures for attaining these targets [2]. Accordingly, to achieve a more energy-efficient industry, energy-management techniques are needed to understand and analyse in detail how energy is consumed in production processes, and to use energy efficiently [3, 4]. Thus, going forward, the industrial world is simultaneously considering productivity and energy-consumption amounts, and is seeking

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 50–57, 2018.
https://doi.org/10.1007/978-3-319-99704-9_7

both production planning using specific-energy consumption and pre-emptive evaluation methods [5–13].

Factory-production activity is based on production plans. These plans will be unavoidably revised because of the changes in production context that accompany uneven operation times, the arrival of rush orders, etc. When drafting production plans, changes in the production context should be considered. Rush orders with short deadlines should especially be considered because of their frequent occurrence [14, 15].

In particular, rush orders interrupt regular orders. When a rush order is added to the production line, setup preparations are needed to set aside the regular order to attend to the rush-order production, and again to return to the regular order. This leads to increased setup times and delayed deliveries.

Trzyna et al. analysed production times for regular orders accompanied by added rush orders [16]. Zhu et al. proposed a mixed-integer linear programming method for minimising the total running time [17]. Other studies have proposed methods for restricting delayed-delivery and setup time increases using production-scheduling methods [18–22]. However, these studies focus on productivity when rush orders are added, and do not assess the energy-consumption amounts.

Meanwhile, the present authors have proposed pre-emptive evaluation methods that consider the energy-consumption amounts in addition to productivity [10–13]. In these pre-emptive evaluation studies, expressions for calculating the specific-energy consumption have been proposed. In particular, in one of our studies on calculating specific-energy consumption while considering rush orders, we supposed and formalised a management form that immediately adds rush orders to the production line [13].

We see that actual companies, looking to restrict increases in setup times, may implement management forms where rush orders are added in certain time slots; namely, rather than adding rush orders to the production line immediately, this management form will enter rush-order production after a certain period of time, once the lot size is larger [23]. However, studies on formulae for calculating specific-energy consumption that consider rush orders do not consider management where rush orders are added in time slots.

Accordingly, this study presents a pre-emptive evaluation method that formalises specific-energy consumption for management where rush orders are added in time slots. Specifically, we suppose a management form where rush orders are not added immediately to the production line; instead, time slots are set aside for building larger lot sizes. Under this supposition, we derive the total time for each production facility state, derive the total energy-consumption amount, and propose a formula for calculating the specific-energy consumption.

2 Formalising the Specific-Energy Consumption

2.1 Specific-Energy Consumption

In industry, 'specific-energy consumption' has become an indicator for assessing the production quantity versus the energy consumed during production [24]. In this study, we define specific-energy consumption *SEC* as follows.

$$SEC = \frac{E}{P}, \tag{1}$$

where:

SEC is the specific energy consumption [kWs/product],
P is the total production quantity in the production line, and
E is the total energy consumption [kWs].

2.2 Preconditions

This study presumes the following conditions.

- The state of a production facility (herein, 'facility') will either be running, setup, or idle.
- The facilities are linked in series.
- Rush orders appear according to a 'generation interval' *GIRO* [seconds/unit]; the generation interval is fixed, irrespective of time.
- The total operation time *T* [seconds] is sufficient in duration.
- There are buffers prior to each facility, and the buffer capacity is unlimited.

2.3 Production Form in This Study

In this study, we suppose a management form where rush orders are added in time slots [23]. Specifically, this is where rush orders are added into rush-order-addition time slots, and their production interrupts the regular orders. Meanwhile, time slots not allocated to rush-order additions ('no-addition slots') are slots during which rush orders will be buffered (i.e. and not acted upon). Any rush orders that arrive during the no-addition slots will be collectively entered into production at the start of the next rush-order-addition time slot.

2.4 In-process Inventory Coefficient q^k

We define the in-process inventory coefficient as the value of facility *k*'s production quantity P^k over the total production quantity *P*. Here, we can express the production quantity for each facility, using the total production quantity.

$$q^k = \frac{P^k}{P}, \tag{2}$$

where:

Superscript k is the ordinal number of the k-th facility in the production line,
q^k is the coefficient of facility k's in-process inventory, and
P^k is the production quantity of facility k.

2.5 Total Run-Time T_r^k for Facility k

Facility k's production quantity P^k is the product of the facility's throughput p_r^k and running time T_r^k; it can therefore be expressed as follows.

$$T_r^k = \frac{P^k}{p_r^k} = \frac{q^k P}{p_r^k}, \tag{3}$$

where:

Subscript r indicates that the facility is in its running state,
T_r^k is the total running-state time of facility k [seconds], and
p_r^k is the throughput in facility k [products/second].

2.6 Total Setup Time T_s^k for Facility k

The setup time T_s^k is the product of facility k's per-work setup time $SetUp^k$ and its production quantity P^k; it can therefore be expressed as follows. $SetUp^k$ is detailed later in Sect. 2.8.

$$T_s^k = P^k \times SetUp^k = q^k P \times SetUp^k, \tag{4}$$

where:

Subscript s indicates that the facility is in its setup state,
T_s^k is the total setup-state time of facility k [seconds], and
$SetUp^k$ is the per-work setup time of facility k [seconds/product].

2.7 Total Idle Time T_i^k for Facility K

The idle time is the total operating time T minus the running time and setup time; accordingly, it may be expressed as follows.

$$T_i^k = \mathrm{T} - T_r^k - T_s^k, \tag{5}$$

where:

Subscript i indicates that the facility is in its idle state, and

T_i^k is the total idle-state time of facility k [seconds].

2.8 Specific-Energy Consumption SEC^k for Facility k

If we take the electricity consumption for each of the states of facility k to be e_r^k, e_s^k, and e_i^k, respectively, the energy consumption E^k in facility k is as follows.

$$E^k = e_r^k T_r^k + e_s^k T_s^k + e_i^k T_i^k, \tag{6}$$

where:

e_r^k is the electricity consumption per unit time in the running state of facility k,
e_s^k is the electricity consumption per unit time in the setup state of facility k, and
e_i^k is the electricity consumption per unit time in the idle state of facility k.

The specific-energy consumption for facility k, SEC^k, is as follows.

$$\begin{aligned} SEC^k &= E^k / P \\ &= \left(\left(e_r^k T_r^k + e_s^k T_s^k + e_i^k T_i^k\right)\right)/P \\ &= q^k \left(\frac{e_r^k}{p_r^k} + e_s^k SetUp^k\right) \\ &+ e_i^k \left(\frac{1}{p} - q^k \left(\frac{1}{p_r^k} + SetUp^k\right)\right), \end{aligned} \tag{7}$$

where:
p is the throughput for the entire production line [products/second].

Since throughput p is the minimum throughput value if facility k were to operate independently, i.e. for p_0^k, it may be expressed as follows.

$$p = min\{p_0^1, p_0^2, , , , p_0^k, , , , p_0^n\} \tag{8}$$

Here, p_0^k, the throughput from facility k, if it were to operate independently, is the reciprocal value of the sum of the per-work setup time and the cycle time in facility k, as shown in Formula (9).

$$p_0^k = \left(\frac{1}{p_r^k} + SetUp^k\right)^{-1} \tag{9}$$

The total setup time for facility k, T_s^k, is the sum total of the setup time for the sections producing only rush orders, the setup time for sections producing both rush orders and regular orders, and the setup time for sections producing only regular orders. Accordingly, the per-work setup time $SetUp^k$ can be expressed as below in Formula (10).

$$
\begin{aligned}
SetUp^k &= \frac{T_s^k}{q^k P} \\
&= \frac{\lambda^k}{LS} + \frac{Rt \times (\mu^k + \nu^k)}{q^k p \times t_{no\text{-}addition}} \\
&+ \frac{1 - Rt}{q^k p \times GIRO} \times \left(\mu^k + \nu^k - \frac{LS_{RO}}{LS}\lambda^k\right) \\
&- \frac{Rt}{q^k p \times GIRO} \times \left(\frac{\mu^k + \nu^k}{t_{no\text{-}addition}} + \frac{LS_{RO} \times A^k}{p_r^k \times GIRO}\right) \times \left(\mu^k + \nu^k - \frac{LS_{RO}}{LS}\lambda^k\right) \\
&- \frac{Rt \times LS_{RO}}{q^k p \times GIRO} \times A^k \times \frac{\lambda^k}{LS}
\end{aligned}
\tag{10}
$$

where:

λ^k is the setup time between regular orders [seconds],
μ^k is the setup time from a regular order to a rush order [seconds],
ν^k is the setup time from a rush order to a regular order [seconds],
LS is the lot size of the regular order,
LS_{RO} is the lot size of the rush order,

d is the number of times that rush orders are collated (i.e. number of time slots), and $t_{no\text{-}addition}$ is the length of time during which rush orders are not added [seconds/day].

In this study, we assume *d* is same value as the number of days in the schedule.

$$R_t = \frac{dt_{no\text{-}addition}}{T} \tag{11}$$

Here, when there are only rush-order-addition slots, i.e. when $dt_{no\text{-}addition} = 0$, then $R_t = 0$. This indicates that the company's management form is to add rush orders to the production line immediately.

We also define common term A^k as follows.

$$A^k = 1 + \frac{\mu^k}{t_{no\text{-}addition}} + \frac{LS_{RO}}{p_r^k \times GIRO} \tag{12}$$

Above, we proposed Formula (7) for calculating the specific-energy consumption, as well as Formulae (10), (11), and (12) for calculating Formula (7)'s setup time per-work $SetUp^k$. We have therefore proposed a formula for calculating the specific-energy consumption under a management form where rush orders are added in time slots.

3 Conclusion

In this study, we presented a pre-emptive evaluation method for simultaneously assessing both the energy-consumption amount and productivity of a production facility by proposing a formula for specific-energy consumption that considers rush orders. In particular, we proposed a formula for calculating the specific-energy consumption that supposes a management form where rush orders are added in time slots.

In the future, we will verify the validity of our proposed formula by undertaking case studies.

References

1. International Energy Agency (IEA), Japan. https://www.iea.org/policiesandmeasures/pams/japan/name-30692-en.php. Accessed 5 Apr 2018
2. United Nations Framework Convention on Climate Change, Adoption of the Paris Agreement. http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf. Accessed 30 Mar 2018
3. Ministry of Economy, Trade and Industry. Long-Term Energy Supply and Demand Outlook. http://www.meti.go.jp/english/press/2015/pdf/0716_01a.pdf. Accessed 18 May 2018
4. Ministry of Economy, Trade and Industry, Energy Innovation Strategy. (in Japanese). http://www.meti.go.jp/press/2016/04/20160419002/20160419002-2.pdf. Accessed 18 May 2018
5. He, Y., Liu, B., Zhang, H., Gao, H., Liu, X.: A modeling method of task-oriented energy consumption for machining manufacturing system. J. Clean. Prod. **23**(1), 167–174 (2012)
6. Wilson, J., Arokiam, A., Belaidi, H., Ladbrook, J.: A simple energy usage toolkit from manufacturing simulation data. J. Clean. Prod. **122**, 266–276 (2016)
7. Ainha, R., Chaturvedi, N.: A graphical dual objective approach for minimizing energy consumption and carbon emission in production planning. J. Clean. Prod. **171**, 312–321 (2018)
8. Heilala, J., et al.: Simulation-based sustainable manufacturing system design. In: Mason, S., Hill, R., Mönch, L., Rose, D., (eds.) 2008 Winter Simulation Conference, Miami, FL, USA, pp. 1922–1930 (2008)
9. Sakuma, T., Hibino, H., Yamaguchi, M.: Manufacturing system simulation for evaluation of productivity and energy consumption. J. Adv. Mech. Des. Syst. Manuf. **8**(2), 178–189 (2013)
10. Yamaguchi, M., Kobayashi, T., Hibino, H.: Manufacturing system simulation to evaluate energy productivity (Formulation of relationship between productivity and energy consumption). Trans. JSME **82**(835), 15-00495 (2016). (in Japanese)
11. Kobayashi, T., Yamaguchi, M., Hibino, H.: Manufacturing system simulation to evaluate energy productivity (A study on lot size dependence for energy consumption per unit of production throughput considering breakdown states). Trans. JSME **82**(835), 15-00502 (2016). (in Japanese)
12. Hibino, H., Yamamoto, M., Yamaguchi, M., Kobayashi, T.: A Study on Lot-Size Dependence of Energy Consumption per Unit of Production Throughput Considering Buffer Capacity. International Journal of Automation Technology **11**(1), 46–55 (2017)
13. Kobayashi, T., Yamaguchi, M., Hibino, H.: Lot size dependence for energy consumption per unit of production throughput considering rush orders in manufacturing line. IFAC-StudysOnLine **50**(1), 5000–5005 (2017). https://doi.org/10.1016/j.ifacol.2017.08.904
14. Tanimizu, Y., Komatsu, Y., Ozawa, C., Iwamura, K., Sugimura, N.: Extension of reactive scheduling method using co-evolutionary genetic algorithms (Application to open shop scheduling problems and experimental evaluation). Trans. JSME Ser. C **79**(802), 2207–2220 (2013). (in Japanese)

15. Hendry, L., Land, M., Stevenson, M.: Investigating implementation issues for workload control (WLC): a comparative case study analysis. Int. J. Prod. Econ. **112**(1), 452–469 (2008)
16. Trzyna, D., Kuyumcu, A., Lödding, H.: Throughput time characteristic of rush orders and their impact on standard order. Procedia CIRP **3**, 311–316 (2012)
17. Zhu, J., Gu, X., Jiao, B.: Efficient Short-term scheduling of multiproduct batch plants under demand uncertainty. Progress Nat. Sci. **18**(4), 487–493 (2008)
18. Sakaguchi, T., Tanimizu, Y., Sugimura, N.: Genetic algorithm based reactive scheduling (2nd report, modification of production schedule for additional jobs). Trans. JSME Ser. C **71** (711), 3299–3305 (2005). (in Japanese)
19. Tanimizu, Y., Komatsu, Y., Ozawa, C., Iwamura, K., Sugimura, N.: Co-evolutionary genetic algorithms for reactive scheduling. J. Adv. Mech. Des. Syst. Manuf. **4**(3), 569–577 (2010)
20. Kaihara, T., Yao, Y.: A new approach on CPS-based scheduling and WIP control in process industries. In: Proceedings of the 2012 Winter Simulation Conference, Berlin, Germany (2012)
21. Yao, Y., Kaihara, T., Sashio, K.: A study on action type scheduling method for machining job shop –auction method for managing priority jobs. In: 49th Japan Automatic Joint Control Conference, J-STAGE (2006). (in Japanese). https://doi.org/10.11511/jacc.49.0.525.0
22. Yao, Y., Kaihara, T., Fujii, N., Hori, E.: A study on method of automated scheduling for dynamically changing manufacturing environment. Trans. JSME Ser. C **77**(784), 4718–4729 (2011). (in Japanese)
23. Daitokkyuu! printkiban.com, Considering delivery times. http://daitokkyu-kiban.com/time/. Accessed 2 Apr 2018. (in Japanese)
24. Ministry of Economy, Trade and Industry, Strategic Energy Plan. http://www.enecho.meti.go.jp/en/category/others/basic_plan/pdf/4th_strategic_energy_plan.pdf. Accessed 19 May 2018

Implementation Challenges Affecting the Environmental Improvement Performance in Pharmaceutical Production:

Results of a Green Kaizen Pilot

Seyoum Eshetu Birkie[1(✉)], Martin Kurdve[2], Monica Bellgran[1], and Jouni Korhonen[1]

[1] KTH Royal Institute of Technology, 100 44 Stockholm, Sweden
seyoume@kth.se
[2] Chalmers University of Technology, 412 96 Gothenberg, Sweden

Abstract. This paper reports on working findings in an action research-based project, implementing a green kaizen pilot in a European pharmaceutical manufacturing company. The aim of the study is to investigate how continuous improvement initiatives with focus on environment originally developed for the automotive manufacturing industry could apply to the pharmaceutical industry. It also aspires to understand the enabling and hindering issues are for such implementation. There are considerable similarities of implementing lean in general in the two sectors, however, some key differences and challenges were apparent when implementing this specific green kaizen method called Green Performance Map. An implication for pharma practitioners implementing the green kaizen method concerns how to improve working procedures and production equipment to become more environmentally friendly amid high regulatory demands on process quality. Implementation challenges are discussed in terms of fidelity, locus and extensiveness of lean practices implementation.

Keywords: Sustainable production · Continuous improvement
Green performance map

1 Introduction

Proponents of lean production posit that the principles and underlying practices of lean should be applicable to any industry and any business process [1, 2]. However, implementation in different industries could be at varying level of maturity. Some researchers debate that European pharmaceutical manufacturers might not have the readiness to implement lean practices [3]. It is argued that in these companies, lean implementation is often employed as an isolated project-based solution rather than as a holistic approach. However, this situation seems to be changing with tightening requirements on the production performance in different industries; the pharmaceutical business is no exception. This condition creates the necessary incentives at corporate level to emphasize the implementation of a more integrated lean management system,

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 58–66, 2018.
https://doi.org/10.1007/978-3-319-99704-9_8

rather than ad hoc lean initiatives. Besides, some pharmaceutical manufacturers are embarking on initiatives that also respond to green or environmental issues.

Researchers recognise that green is a natural progression to lean and that continuous improvements holistically applied in the organization could enable the achievement of reduced waste in both operational and environmental fronts [4, 5]. However the lean-green agenda is yet far from being promoted despite the potential opportunities for long term sustainable productivity. There is limited empirical base on how such integrative approach can be implemented and whether a common platform of such approach can be devised across different industries [4].

The green kaizen pilot presented in this paper was performed at a European pharmaceutical manufacturing company, supported in operations by a global lean management system developed during more than 15 years. The purpose of the pilot was to investigate how a green kaizen method developed for discrete manufacturing, (mainly in automotive sector), could be implemented in pharmaceutical industry as a means to facilitate environmental improvements at all levels. The pilot comprised of testing a green kaizen method called Green Performance Map (GPM) in practice within two separate production lines. The implementation aspects are the focus of this study and the two research questions set forth to answer in this paper are:

- RQ1: What are the implementation aspects of using a green kaizen method for environmental improvements in pharmaceutical production?
- RQ2: How could the implementation of methods for environmental improvements be facilitated in a pharmaceutical lean environment?

2 Frame of Reference

2.1 Lean – Implementation and Innovation

Lean production is by some regarded as an integrated socio-technical system with main objective of eliminating waste [6] while others consider lean production as a concept [7]. On the corporate level, the term lean is often used to signal the involvement of the whole company and not only production. Regardless of the labelling, elimination of waste is considered a fundamental component of the whole lean concept. This waste elimination is achieved by reducing variabilities in internal processes as well as those connecting with supplier, customer and other stakeholders. Lean is based on guiding principles described as e.g. focus on people, a value driven process view, problem solving, and long term thinking [1, 2]. These principles are translated into observable operational practices, which can be bundled into consistent and interrelated practices. Some bundles like total quality management, and total productive maintenance (TPM), focus on internal processes while others address external connections [6]. The journey towards a system aligned with the principles is driven by strategies like continuous improvement (or kaizen) and teamwork.

Lean implementation is often path dependent and unique for an organization [8]. Therefore, undergoing a lean transformation process can be considered as a way of diffusing innovative practices in the enterprise. In this view, lean practices implemented in an organization can be characterized in terms of fidelity and extensiveness [9]. *Fidelity* refers to the in-kind resemblance of the adopted practices to the features of previous version of practices; that is, if the practices are implemented according to the state-of-the-art, while *extensiveness* refers to the degree or extent of implementation of the practice, compared to that of a previous version. As an additional dimension, *locus* refers to the multitude of units or divisions in the organization that are part of the implementation. This is important because silo-type lean implementation not only undermines performance benefits, but also restricts diffusion of innovative practices. For pharma, this is a relevant implementation aspect to consider due to regulatory process standardization and approval.

2.2 Green Lean, and Green Performance Map

The global environmental and climate reality is pushing manufacturing companies to take responsibility, driving towards sustainable and CO_2-neutral operations. With the recognized benefits of eliminating waste and pursuing continuous improvement, lean is sometimes adopted to incorporate the environmental (green) actions. The potential synergy between lean and sustainability has been a topic of recent research engagement [10] and lean and green could e.g. be viewed in integration as strategies or management systems [10, 11]. In some of the studies, performance indicators were also introduced to capture environmental and social dimensions of sustainability [11, 12].

Corporate environmental management involves several similar elements as in lean production [13]. Green production could be integrated with lean [13] but both suffer from the similar implementation challenges such as how to engage personnel and to manage team based improvement work. One approach mentioned is the adaptation of different lean analysis tools such as environmental value stream map to support green lean implementation. However, only a few tools are designed to support environmentally focused continuous improvement practice. With this as a background, the GPM [14] is a tool that was developed by a research team including two of the authors, with the purpose of facilitating environmental improvement work in industry.

Most of the lean practices appear to support and improve environmental performance of firms in different sectors. Starting with Toyota's achievement of considerable emissions reduction with green lean, similar improvement examples are reported for food and drinks as well as retail sectors [5]. However, there are some challenges for implementation. This argument seems to suggest that lean practices need not be strictly implemented to enhance environmental performance. However, one may argue that the benefits of a single practice should not undermine gains at an overall system level lean implementation [8].

3 Methodology

A qualitative and action oriented systems approach was applied when performing the pilot study with implementation of the GPM tool at the pharma case company. The empirical data was collected over a period of 6 months through different techniques; assessment survey conducted at the two lines (the respondents were the production team member, 12 in total), observations at the production lines (both as included in the GPM structured 5-step procedure and as follow-up), individual interviews with selected respondents and group interviews and discussions with the production operator teams and the supportive team (lean manager, lean change agent, production engineers, environmental expert and coordinators, energy experts and production leaders).

Data was also collected during a number of working and project meetings. The pilots selected were two semi-automated production lines for pharma-products operating in two-shifts. The production processes were both quite similar to the character of discrete manufacturing. The meetings, observations and interviews were documented and stored in a common project directory. In addition, eleven student thesis projects performed at the case study company during the past ten years were reviewed to get a historical perspective of the company's lean transformation progress. The review served as a comparison to the pilot in identifying and comparing challenges when working with continuous improvements and where green kaizen is emphasized.

4 Empirical Findings

With the need for accelerating operational excellence the case study company initiated their lean transformation process during the early 2000. Preconditions like design of production equipment and production engineering competence were emphasized and operational tools like visual management, 5S and lean leadership were introduced. During the first phase, management worked extensively with lean related questions before it was transferred to the operator level. One production unit took the lead and showed quite soon annual productivity improvements results. This progress of the "lean front-runner" inspired other units at the site. Some, however, chose a reverse implementation procedure emphasizing the operators and first line managers. With a bottom-up approach, the implementation challenge was to maintain top managers' interest. Despite the challenges faced, the lean journey continued and six years later, the lean engagement on operator level was noticed also outside the company. Education and lean training was key element for creating the operator engagement.

The case company visualized their production system as a house with a base of "standardized work flow oriented leadership and teamwork", the two pillars "right-from-me" and "just-in-time" combined with goal principles related to "customer focus" and "elimination of losses". The classical PDCA cycle was used to follow continuous improvements, and a set of performance priorities was determined as overall goal. At the selected business unit, lean improvements are currently driven at team level by working with daily visual management and weekly PDCA improvement meetings. Besides, improvements are driven by implementing lean tools such as 5S combined with good manufacturing practice (GMP) and TPM. The implementation of tools and practices are often run as pilots before rolled-out on a broader scale. Environmental aspects have been integrated in the kaizen initiative; however, no extensive attempts have been made to highlight the environmental improvements specifically.

A green kaizen pilot was initiated in the case company to emphasize environmental improvements, with the GPM tool implemented at operator team level (see Fig. 1). The predefined 5 + 1 step procedure was followed and the input-output model was used for identification of a large number of environmental aspects. Measurement possibility, "low hanging fruit" potential, and improvement performance vs effort on operator level were the main motives for selecting five environmental aspects considered as waste and prioritized for further improvement activities, see A–E:

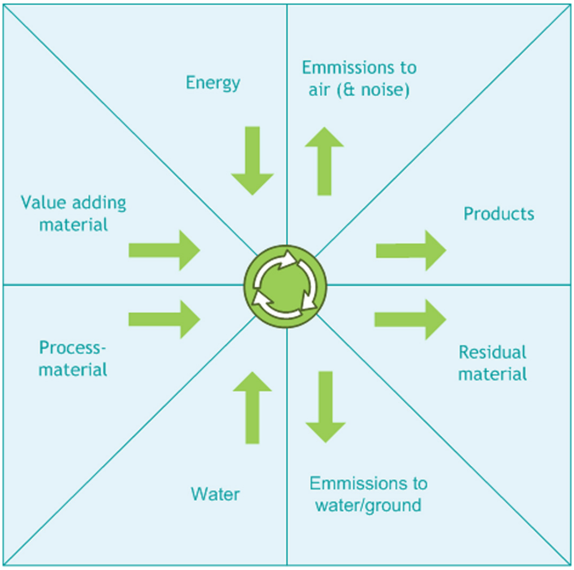


Fig. 1. The green performance map implemented [14] (Color figure online)

(A) Use of Standardized Rubber Gloves: Gloves of a cleanliness level above the requirements were used, implying individual extensive packaging. No material recycling was collected, i.e. both packaging and gloves were thrown in mixed trash. Two proposals came out of the green kaizen pilot: (1) to use a plastic recycling bin and (2) to order gloves in multiple packaging. Implementation challenge: The teams were reluctant to change packaging due to uncertainties regarding pharma standard.

(B) Amount of Cotton Gloves Used/Day Per Person: The standard, based on GMP, demanded higher cleanliness gloves at the specific station compared to other stations. The consumption of gloves was, however, almost three times as high as expected by the standard. Implementation challenge: from a behavior perspective, consumption of gloves was directly reduced to almost theoretical level as a result of the attention of the pilot. The issues concerned how to identify the best way to measure the glove consumption, and how to reduce the consumption while at the same time fulfilling the pharma requirements of the specific station.

(C) Reuse of "Scrap": A component often fell on the conveyer belt in one station becoming scrap, although it was not contaminated. The severe waste this caused could easily be eliminated by a small technical redesign. Implementation challenge: The pharma standard was an obstacle for making the redesign since the proposal had to go through an extensive change procedure due to the tough pharma regulations.

Two additional environmental aspects were prioritized; **(D) measuring the energy consumption** at one production station (by energy experts), and **(E) reduction of packaging material waste** from one cell (on operator level at the production line). Here, the implementation challenges had to do with resources and behavior rather than pharma standards and regulations.

Environmental aspect A (solution 1) and B could be improved locally by the operator team, while the rest required participation from support functions, and A2 additional involvement of suppliers reducing the tempo of the implementation. Solutions to B, C and E had large duplication improvement potential since they were generic and possible to implement within a number of production lines at the company. The potential for making a broader successful implementation depended on lean maturity, resources, and organizational support including management commitment.

In order to relate the environmental improvement maturity to the traditional kaizen, an analysis of 11 lean kaizen projects conducted at the production site for a period of 10 years was made. Implementation challenges and enablers were identified, most lean improvements not specifically considering green improvements.

The analysis indicated that the case company had a rather mature operational improvement system. Team driven visual management and improvement work was apparent and support functions worked in standardised ways with improvements. The analysis indicated that the maturity has grown, showing fewer implementation issues after ten years. This can be seen, e.g., by the contradicting observations (marked as C in Table 1) in the pilot of issues which previously considered challenges of implementation. The major remaining challenges included perception of lack of time/resources for improvement work, rigid documentation demands making it difficult to change standard operating procedures (SOP), and insufficient inter-team cooperation.

Table 1. Implementation challenges and enablers found in empirical studies

Implementation aspects	Pilot	Papers (published 2007–2017)										
(i) Implementation challenges		1	2	3	4	5	6	7	8	9	10	11
Batch production	A	X										
Lean leadership not fully implemented	N	X	X			X		X				
Standardised work not team driven	S	X	X	X					X			C
Regulation control of operation practice & changes	A	X							X		C	
Lack of engagement, reluctance to participate	C			X					X	X		X
Lack of resources to implement improvements	A			X			X		C		X	S
Lack of time/resources to follow up improvements	A				X		X					
Standardised work not followed/fully implemented	N				X			X	X			

(*continued*)

Table 1. (*continued*)

Implementation aspects	Pilot	Papers (published 2007–2017)										
(i) Implementation challenges		1	2	3	4	5	6	7	8	9	10	11
Deviation reporting and improvement proposal not handled properly	S				X	X			X		C	
Lack of support (OP-Maint/Tech) competence	C					X			X		S	
Documentation requirements complicated	S					X		X			S	
Insufficient co-operation between teams/functions	S					X			X			S
(ii) Implementation enablers									X		S	
Focus on value creation/operations	A	X					X		X		X	
Quality focus	A	X	X	X					X			
Flow focus	S	X	X	X	X						X	X
OEE, reporting system for deviations	S	X	X			X		X	X	X	X	
Visual management	A		X	X	X		X	X	X	X	X	
Weekly Safety-Health-Environment meetings	A				X		X		X	X		
Engagement/teamwork	A	X	P	P			X		X		X	X
Use of lean analysis tools (VSM, SPC, 5Y etc.)	A	P	P						X	X	X	X
Use of Lean implementation tools (5S, OP-M, PDCA, SMED, etc.)	A	P			X				X	X	X	X
(Team driven) standardized work SOP	C			P		P				X	X	X
Team driven improvement meetings & projects	S			X	X		X		X	X		X
Available time for improvement implementation	S						X				X	X

Note: (1) A = Apparent/evident, X = mentioned, C = contradicted, P = pilot implementation, S = some occurrences/evidence, N = not observed; (2) green kaizen pilot performed in 2018

5 Discussion and Conclusion

The empirical findings indicated that the participants in the pilot had primary focus to strictly follow business and corporate standards specific to the pharmaceutical industry. Lack of willingness to question the standards was an obstacle for green kaizen actions. Following standards and regulations is fundamental to pharmaceutical and value of changes must be ensured. Investing time and resources to drive the change process to assess and change the standard, was a general obstacle. This indirect calculation of the reasonable "business case" is probably made intuitively by employees.

The regulatory requirements in pharmaceutical industry are extensive including how the production processes should be operated at all steps dealing with the product (value adding activities) and must be accurately communicated to the authorities; similar regulatory patterns exist in other safety critical industries such as the airlines. The requirements are detailed including also what type of equipment that will be used. The regulatory process restrictions could become barrier for some lean and green kaizen within pharma, as in food industry, for example. One conclusion is that it becomes important to make really good business cases for each proposed change, i.e.

the costs should be worth the economic benefits of a change. Measuring and follow-up of improvements might also push towards further challenging standards.

The empirical findings also indicate that lean implementation in the pharmaceutical industry context is not that different from the manufacturing industry in terms of daily lean practice routines. However, pharma is more focused on process and quality. “Hunting waste” and optimizing the production flow is not as important as the delivery of (extremely) high quality in pharmaceutical processes and products. The study confirmed that the production part is often very small compared to product and process development costs in the pharma business. These differences, along with path dependent idiosyncrasies affect incentives for implementing lean in the two sectors.

When it comes to green initiatives, the lean practice bundles connecting with external actors in the value chain could provide superior environmental improvement. In terms of extensiveness, the lean implementation varies in the organization; some practices and tools are exercised in general while others are implemented to a lesser extent, possibly also due to individual differences of team leaders.

The innovativeness of lean implementation journey can be viewed in terms of fidelity, locus and extensiveness [7]. In terms of fidelity, the lean practices implemented in the case company appear to resemble those common in the automotive sector, which has been forerunner in lean implementation. This is also valid at higher aggregation levels as in practice bundles; this may not necessarily be a good thing considering that lean (and green) journey is path dependent and tailoring to specific context is often imperative. Even so, the case company has challenges to address and exploit some lean principles. A strong extensiveness in implementation could be signalled by questioning existing routines that neither add to fulfilment of regulatory requirements, nor contribute to economic or other forms of value. The implementation of lean tools and practices seemed to vary among different operation units (locus) in the case company. Extant literature suggests that more benefits are likely to be gained from lean transformation (with or without green issues) when such efforts cover processes on shop floor and beyond. The challenges observed in the pilot and reported in earlier studies suggest that further environmental improvement potential might have been masked away-hinting the urgency to systematically address those challenges.

Acknowledgement. The research team acknowledges the contribution of the case study company, and the funding agency, VINNOVA (Produktion2030 program).

References

1. Liker, J.K.: The Toyota way: 14 principles from the world’s greatest manufacturer. McGraw-Hill, New York (2004)
2. Womack, J.P., Jones, D.T.: Lean Thinking: Banish Waste and Create Wealth in Your Corporation. Free Press, New York (2003)
3. Garza-Reyes, J.A., Betsis, I.E., Kumar, V., Radwan Al-Shboul, M.A.: Lean readiness – the case of the European pharmaceutical manufacturing industry. Int. J. Prod. Perform. Manag. **67**(1), 20–44 (2018)

4. Chaplin, L., O'Rourke, S.T.J.: Could lean and green be the driver to integrate business improvement throughout the organisation? Int. J. Prod. Perform. Manag. **67**(1), 207–219 (2018)
5. Zokaei, K., Lovins, H., Wood, A., Hines, P.: Techniques for Improving Profits and Sustainability. CRC Press, London (2013)
6. Shah, R., Ward, P.T.: Defining and developing measures of lean production. J. Oper. Manag. **25**(4), 785–805 (2007)
7. Bhamu, J., Sangwan, K.S.: Lean manufacturing: literature review and research issues. Int. J. Oper. Prod. Manag. **34**(7), 876–940 (2014)
8. Netland, T.H., Aspelund, A.: Company-specific production systems and competitive advantage: a resource-based view on the Volvo production system. Int. J. Oper. Prod. Manag. **33**(11/12), 1511–1531 (2013)
9. Ansari, S.M., Fiss, P.C., Zajac, Z.J.: Made to fit: how practices vary as they diffuse. Acad. Manag. Rev. **35**(1), 67–92 (2010)
10. León, H.C.M., Calvo-Amodio, J.: Towards lean for sustainability: understanding the interrelationships between lean and sustainability from a systems thinking perspective. J. Clean. Prod. **142**, 4384–4402 (2017)
11. Carvalho, H., Cruz-Machado, V.: Integrating lean, agile, resilience and green paradigms in supply chain management (LARG_SCM). In: Li, P. (ed.) Supply Chain Management, pp. 27–48. InTech, New Delhi (2011)
12. Chugani, N., Kumar, V., Garza-Reyes, J.A., Rocha-Lona, L., Upadhyay, A.: Investigating the green impact of lean, six sigma, and lean six sigma: a systematic literature review. Int. J. Lean Six Sigma. **8**(1), 7–32 (2017)
13. Kurdve, M., Zackrisson, M., Wiktorsson, M., Harlin, U.: Lean and green integration into production system models - experiences from Swedish industry. J. Clean. Prod. **85**, 180–190 (2014)
14. Bellgran, M., Kurdve, M., Wiktorsson, M.: Green Performance Map: Handbook. Mälardalen University, Mälardalen (2012)

A Stochastic Programming Model for Multi-commodity Redistribution Planning in Disaster Response

Xuehong Gao and Gyu M. Lee(✉)

Department of Industrial Engineering, Pusan National University, Busan, Republic of Korea
glee@pnu.edu

Abstract. When a large-scale disaster occurs, a set of relief centers should be determined to accommodate evacuees and a variety of multi-commodity should be distributed to these relief centers to provide basic life support. Because the multi-commodity distribution at peacetime may be imperfect and unbalanced, the surplus commodities in some relief centers can be redistributed to other relief centers with shortages, to make the effective and efficient use of these commodities. This multi-commodity redistribution problem is also an important issue in the emergency management. Various uncertain elements include transportation network, supply and demand, making this problem a big challenge. To handle this problem, a two-stage mixed-integer stochastic programming model was proposed to facilitate this multi-commodity redistribution process. In our model, we define the dissatisfaction cost based on the relief center size, unmet demand and oversupply of commodity in the relief center. Then, our objectives are to minimize the total dissatisfaction cost in the first stage and minimize the total transportation time in the second stage, sequentially. Finally, a randomly generated numerical instance is tested and computational results show that the proposed model can provide effective and efficient decisions in the multi-commodity redistribution process.

Keywords: Humanitarian logistics
Two-stage mixed-integer stochastic programming · Multi-commodity
Redistribution

1 Introduction

In recent days, natural or man-made disasters of large scale have occurred more frequently than ever. A large number of people are impacted significantly and a lot of assets are damaged severely. Upon these disasters, rapid and effective responses to these emergency events should be conducted. A set of relief centers should be determined to accommodate evacuees and a variety of multi-commodity should be distributed to these relief centers to provide basic life support there. However, relief centers may have surplus commodities or shortages because of the imperfect multi-commodity distribution at the peacetime. Hence, these surplus commodities should be redistributed to others to make the effective and efficient use of these commodities.

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 67–78, 2018.
https://doi.org/10.1007/978-3-319-99704-9_9

Generally, disaster response activities are divided into the four phases that come from the "disaster cycle": (a) mitigation, (b) preparedness, (c) response, (d) recovery (or rehabilitation) [1]. In this study, our work mainly focuses on the multi-commodity redistribution process, which belongs to the latter part of response phase.

At the beginning of the multi-commodity redistribution process, the quantities for each kind of commodities are estimated and considered uncertain at relief centers. For each kind of commodities, some relief centers may be considered as demand relief centers while others are considered as supply relief centers. In addition to demand and supply uncertainties, another uncertain element is the availability of transportation network [2]. Tasks to redistribute surplus commodities to demand relief centers and to deliver these commodities over the transportation network are very difficult to complete under those uncertainties. Against the backdrop of uncertainties, the aim of this paper is to present this multi-commodity redistribution problem with stochastic elements and understand it using the mathematical programming.

Clark and Culkin [3] summarized three principles that were used to define humanitarianism: humanity, impartiality and neutrality based on some earlier research [4, 5]. In this study, the fairness in the multi-commodity redistribution process is taken into account. In addition to the fairness, we introduce another principle, the timeliness, because these commodities should be delivered as quickly as possible.

The rest of this paper is organized as follows. Section 2 reviews the previous research that are related to stochastic programming models for both commodity distribution and redistribution. Section 3 provides a problem description of concern in this study. A two-stage mixed-integer stochastic programming model is presented in Sect. 4. The solution method is provided in Sect. 5. Then, a numerical analysis and computational results are presented and discussed in Sect. 6. Finally, Sect. 7 concludes this study with contributions and further directions.

2 Literature Review

Humanitarian logistics research has attracted growing attention as the human suffering caused by disaster events continues to increase. We reviewed the prior studies about disaster management that focus on the commodity distribution problem and paid careful attention on how to handle uncertainty in the humanitarian logistics using scenario-based approaches.

Many studies mainly surveyed on the treatment of uncertainty in humanitarian logistics for disaster management [2, 6]. Several studies [1, 7–9] emphasized that a suitable model for post-disaster humanitarian logistics should address human suffering, at least through a proxy measure, instead of only focusing on the monetary objective of commercial logistics. Various mathematical programming methods have been proposed for analyzing the humanitarian logistics problems considering fairness and equity.

Stochastic programming models are widely used and have been successfully applied to handle uncertain elements in humanitarian logistics. We reviewed some stochastic programming models with a single commodity. Jia et al. [10] proposed several models with solution approaches to determine facility locations of medical suppliers in response to a large-scale emergency disaster, which addressed the demand uncertainty and medical supply insufficiency.

Humanitarian logistics usually involves multiple kinds of commodities and multiple stages of relief operations. Under these considerations, a number of multi-stage and multi-commodity stochastic programming models has been developed to handle humanitarian logistics problems. Rawls and Turnquist [11] presented a two-stage stochastic mixed-integer programming model that provided a pre-positioning strategy for hurricanes or other disaster threats considering uncertain demand. Noyan et al. [12] developed a two-stage stochastic programming model that incorporated the hybrid allocation policy to achieve high levels of accessibility and equity simultaneously, while demand and network-related uncertainties were considered through a finite set of scenarios. Zhou et al. [13] designed a multi-objective optimization model for a multi-period dynamic emergency resource scheduling problem. The objectives were to minimize unsatisfied demand of affected points with the purpose of satisfying the demand of people in disaster areas, and to minimize the risk of choosing the damaged road to guide the rescue team to select appropriate and efficient roads. Caunhye et al. [14] proposed a two-stage location-routing model with recourse for integrated preparedness and response planning under uncertainty, where the locations of warehouses and their inventory levels were determined in the first stage, and transshipment quantities, delivery quantities, and vehicle routes were determined for every scenario of uncertain realization in the second stage.

These previous studies depict that multi-stage stochastics programming models can handle uncertain elements efficiently in humanitarian logistics. And little research concerning multi-commodity redistribution process has been conducted in the past. Lubashevski et al. [15, 16] implemented the required redistribution of vital resources between the affected and neighboring cities in the disaster area, which did not consider uncertainty. In comparison with the previous models, we study the multi-commodity redistribution process, considering three uncertain elements, which are transportation network, supply and demand. This study proposes a two-stage mixed-integer stochastic programming model for this multi-commodity redistribution problem. In the first stage, the goal is to minimize the total dissatisfaction cost for all relief centers. In the second stage, we try to minimize the total transportation time. The decisions at the second stage are subject to the decisions in the first stage [17–20].

3 Problem Description

A transportation network which consists of a number of roads and relief centers is considered in this study. A set of commodities has been delivered to these relief centers before the disaster. Upon the disaster, surplus commodity at some relief centers needs to be shipped to other relief centers to satisfy unmet demand. Due to the uncertainty in disastrous situations, we do not know who will need how much of which commodities. It makes the surplus and the demand at relief centers uncertain. In addition, the availability of transportation network may be uncertain because the roads may be damaged or destructed in the disaster area. A vehicle depot is the place to store multiple types of vehicles, which are used to deliver these commodities between relief centers.

To take these uncertainties into account, we propose a two-stage mixed-integer stochastic programming model based on a scenario-based approach. In the first stage, we capture the uncertainties in demand and supply by representing each of them in terms of a number of discrete realizations of stochastic quantities that constitute distinct scenarios. Here, a specific realization of an uncertain element is called a scenario. For each kind of commodities in a demand or supply relief center, we have a set of scenarios Ξ. For a particular scenario $\xi \in \Xi$, there is a probability of occurrence $\pi(\xi)$, such that $\pi(\xi) > 0$ and $\sum_{\xi \in \Xi} \pi(\xi) = 1$. In the second stage, similarly, three transportation network availabilities (scenarios) with different probabilities are considered. According to the previous descriptions, some main assumptions are made.

(1) Both the levels of supply and demand for each kind of commodities are uncertain. The supply and demand commodity quantities are consecutive integer numbers (scenarios) with equivalent probabilities in each of relief centers.
(2) Roads can be damaged in different degrees, which leads to uncertain availability of the transportation network.
(3) Types of vehicles have different capacities and speeds, which are allowed to deliver mixed commodities. Each vehicle cannot be used more than once.

4 Stochastic Programming Model

The notations used in this model are as follows:

Sets

$\mathcal{TF}$	Set of stages, indexed by $\mathcal{F} \in \mathcal{TF}$
$\mathcal{R}$	Set of relief centers
$\mathcal{S}$	Set of supply relief centers, indexed by $s \in \mathcal{S}$
$\mathcal{D}$	Set of demand relief centers, indexed by $d \in \mathcal{D}, (\mathcal{S}, \mathcal{D} \in \mathcal{R}\ \&\ \mathcal{S} \cap \mathcal{D} \geq 0)$
$\mathcal{E}$	Set of commodities, indexed by $e \in \mathcal{E}$
$\mathcal{T}$	Set of vehicle types, indexed by $l \in \mathcal{T}$
Ξ	Set of scenarios, indexed by $\xi \in \Xi$

Deterministic parameters

AS_{es}^{min}	The minimal quantity of commodity e should be transported out from relief center s
AS_{es}^{max}	The maximal quantity of commodity e can be transported out from relief center s
AD_{ed}^{min}	The minimal quantity of commodity e should be transported to relief center d
AD_{ed}^{max}	The maximal quantity of commodity e can be transported to relief center d
M	A big positive number
AN^l	Available number of vehicle type l
W^e, V^e	Weight and volume of commodity e
C^{lw}, C^{lv}	Weight and volume capacities of vehicle type l
Z^s, Z^d	The size of relief center s and d
D_{sd}	Distance between relief centers s and d

VS^l	Travel speed of vehicle type l
LU^l	Loading and unloading time of vehicle type l

Stochastic parameters

$r_{sd}(\xi)$	Availability of road between relief centers s and d in scenario ξ
$p_{sd}(\xi)$	Probability of occurrence for $r_{sd}(\xi)$
$oc_s^e(\xi)$	Outgoing quantity of commodity e at relief center s in scenario ξ
$ic_d^e(\xi)$	Incoming quantity of commodity e at relief center d in scenario ξ
$p_d^e(\xi)$	Probability of occurrence for $ic_d^e(\xi)$
$p_s^e(\xi)$	Probability of occurrence for $oc_s^e(\xi)$

Decision variables in the first stage

ad_s^e	The expected amount of commodity e delivered in relief center s
ar_d^e	The expected amount of commodity e received in relief center d

Decision variables in the second stage

$w_{sd}^e(\xi)$	Amount of commodity e delivered from s to d in scenario ξ
$n_{sd}^{le}(\xi)$	Number of vehicle type l used to deliver commodity e from s to d in scenario ξ
$n_{sd}^l(\xi)$	Number of vehicle type l from s to d in scenario ξ

In the proposed model, the objective is to minimize the total dissatisfaction cost (Ψ_1) plus the expected value of the second stage objective function (total transportation time).

$$\text{Min } \Psi_1 + E_\xi[Q(ar_d^e, ad_s^e, \xi)] \tag{1}$$

The completed formulation is given as the following two-stage mixed-integer stochastic programming model. In the first stage ($\mathcal{F}1$), for the set of scenarios, we model the stochastic programming as a deterministic optimization problem, by expressing the expected value Ψ_1 as follows:

$$\begin{aligned} \mathcal{F}1\text{: Min } \Psi_1 = & \sum_{e\in\mathcal{E}}\sum_{d\in\mathcal{D}}\sum_{\xi\in\Xi} p_d^e(\xi)\cdot Z^d \cdot [ic_d^e(\xi) - ar_d^e]\cdot \wp_d^e(\xi) \\ & + \sum_{e\in\mathcal{E}}\sum_{s\in\mathcal{S}}\sum_{\xi\in\Xi} p_s^e(\xi)\cdot Z^s \cdot [ad_s^e - oc_s^e(\xi)]\cdot q_s^e(\xi) \end{aligned} \tag{2}$$

Subject to:

$$\sum_{s\in\mathcal{S}} ad_s^e = \sum_{d\in\mathcal{D}} ar_d^e \qquad \forall\, e\in\mathcal{E}. \tag{3}$$

$$\frac{ic_d^e(\xi) - ar_d^e}{M} + 1 \geq p_d^e(\xi) \quad \forall\, d \in \mathcal{D}, e \in \mathcal{E}, \xi \in \Xi. \tag{4}$$

$$\frac{ad_s^e - oc_s^e(\xi)}{M} + 1 \geq q_s^e(\xi) \quad \forall\, s \in \mathcal{S}, e \in \mathcal{E}, \xi \in \Xi. \tag{5}$$

$$ic_d^e(\xi) - ar_d^e \leq M \cdot p_d^e(\xi) \quad \forall\, d \in \mathcal{D}, e \in \mathcal{E}, \xi \in \Xi. \tag{6}$$

$$ad_s^e - oc_s^e(\xi) \leq M \cdot q_s^e(\xi) \quad \forall\, s \in \mathcal{S}, e \in \mathcal{E}, \xi \in \Xi. \tag{7}$$

$$AS_{es}^{min} \leq ad_{sd}^e \leq AS_{es}^{max} \quad \forall\, s \in \mathcal{S}, e \in \mathcal{E}. \tag{8}$$

$$AD_{ed}^{min} \leq ar_{sd}^e \leq AD_{ed}^{max} \quad \forall d \in \mathcal{D}, e \in \mathcal{E}. \tag{9}$$

$$p_d^e(\xi) = \begin{cases} 1 & \text{if } ar_d^e \text{ is smaller than } ic_d^e(\xi) \\ 0 & \text{otherwise} \end{cases} \quad \forall\, d \in \mathcal{D}, e \in \mathcal{E}, \xi \in \Xi. \tag{10}$$

$$q_s^e(\xi) = \begin{cases} 1 & \text{if } ad_s^e \text{ is greater than } oc_s^e(\xi) \\ 0 & \text{otherwise} \end{cases} \quad \forall\, s \in \mathcal{S}, e \in \mathcal{E}, \xi \in \Xi. \tag{11}$$

The objective function (2) aims to minimize the total dissatisfaction cost considering the relief center size, unmet demand and oversupply of commodity in the relief center. Constraint (3) guarantees the balance of outgoing and incoming for each kind of commodities for all the relief centers. Constraint sets (4)–(7) guarantee that the dissatisfaction costs of relief center s and d are positive numbers. Constraints (8) and (9) define the constraints of variables. Constraints (10) and (11) are auxiliary binary variables. After that, we can solve the second stage problem after we obtain the decision variables from the first stage [19]. So, the second stage problem ($\Psi_2 = E_\xi[Q(ar_d^e, ad_s^e, \xi)]$) can be written as:

$$\mathcal{F}2\text{: Min } \Psi_2 = \sum_{s \in \mathcal{S}} \sum_{d \in \mathcal{D}} \sum_{l \in \mathcal{T}} \sum_{\xi \in \Xi} p_{sd}(\xi) \cdot n_{sd}^l(\xi) \cdot [LU^l + \frac{D_{sd} \cdot r_{sd}(\xi)}{VS^l}] \tag{12}$$

Subject to:

$$\sum_{s \in \mathcal{S}} w_{sd}^e(\xi) \geq ar_d^e \quad \forall\, d \in \mathcal{D}, e \in \mathcal{E}, \xi \in \Xi. \tag{13}$$

$$\sum_{d \in \mathcal{D}} w_{sd}^{e}(\xi) \leq ad_{s}^{e} \qquad \forall\, s \in \mathcal{S}, e \in \mathcal{E}, \xi \in \Xi. \tag{14}$$

$$\sum_{s \in \mathcal{S}} ad_{s}^{e} = \sum_{d \in \mathcal{D}} ar_{d}^{e} \qquad \forall\, e \in \mathcal{E}. \tag{15}$$

$$\sum_{e \in \mathcal{E}} w_{sd}^{e}(\xi) \cdot W^{e} \leq \sum_{l \in \mathcal{T}} n_{sd}^{l}(\xi) \cdot C^{lw} \qquad \forall\, s \in \mathcal{S}, d \in \mathcal{D}, \xi \in \Xi. \tag{16}$$

$$\sum_{e \in \mathcal{E}} w_{sd}^{e}(\xi) \cdot V^{e} \leq \sum_{l \in \mathcal{T}} n_{sd}^{l}(\xi) \cdot C^{lv} \qquad \forall s \in \mathcal{S}, d \in \mathcal{D}, \xi \in \Xi. \tag{17}$$

$$\sum_{s \in \mathcal{S}} \sum_{d \in \mathcal{D}} n_{sd}^{l}(\xi) \leq AN^{l} \qquad \forall\, l \in \mathcal{T}, \xi \in \Xi. \tag{18}$$

$$n_{sd}^{l}(\xi) \geq 0 \qquad \forall\, s \in \mathcal{S}, d \in \mathcal{D}, l \in \mathcal{T}, \xi \in \Xi. \tag{19}$$

$$w_{sd}^{e}(\xi) \geq 0 \qquad \forall\, s \in \mathcal{S}, d \in \mathcal{D}, e \in \mathcal{E}, \xi \in \Xi. \tag{20}$$

The objective function (12) is to minimize the total transportation time. Constraint (13) ensures that the total incoming shipment from relief center s should be bigger than or equal to the demand in relief center d. Constraint (14) ensures the total outgoing shipment from relief center d cannot exceed the quantity of commodity in relief center s. Constraint (15) guarantees the transportation balance between relief centers s and d. Constraints (16) and (17) restrict that assigned vehicles should be able to deliver the mixed commodities. Constraint (18) ensures that the total number of vehicles cannot exceed the total available quantity. Constraints (19) and (20) are nonnegative constraints of variables.

5 Solution Method

Before we get the optimal solution of the second stage problem, we can calculate the best upper bound Ψ_2^*. The upper bound Ψ_2^* can be found by generating a feasible solution using the model U_P, where a vehicle carry only one kind commodity. The upper bound model U_P is written as:

$$U_P: \Psi_2^* = \text{Min} \sum_{e \in \mathcal{E}} \sum_{s \in \mathcal{S}} \sum_{d \in \mathcal{D}} \sum_{l \in \mathcal{T}} \sum_{\xi \in \Xi} p_{sd}(\xi) \cdot n_{sd}^{le}(\xi) \cdot [LU^l + \frac{D_{sd} \cdot r_{sd}(\xi)}{VS^l}] \tag{21}$$

Subject to:

$$(13)\text{–}(15), (20). \tag{22}$$

$$w_{sd}^{e}(\xi) \cdot W^e \leq \sum_{l \in \mathcal{T}} n_{sd}^{le}(\xi) \cdot C^{lw} \quad \forall\, s \in \mathcal{S}, d \in \mathcal{D}, e \in \mathcal{E}, \xi \in \Xi. \tag{23}$$

$$w_{sd}^{e}(\xi) \cdot V^e \leq \sum_{l \in \mathcal{T}} n_{sd}^{le}(\xi) \cdot C^{lv} \quad \forall s \in \mathcal{S}, d \in \mathcal{D}, e \in \mathcal{E}, \xi \in \Xi. \tag{24}$$

$$\sum_{e \in \mathcal{E}} \sum_{s \in \mathcal{S}} \sum_{d \in \mathcal{D}} n_{sd}^{le}(\xi) \leq AN^l \quad \forall\, l \in \mathcal{T}, \xi \in \Xi. \tag{25}$$

$$n_{sd}^{le}(\xi) \geq 0 \quad \forall\, s \in \mathcal{S}, d \in \mathcal{D}, l \in \mathcal{T}, e \in \mathcal{E}, \xi \in \Xi. \tag{26}$$

where objective function (21) aims to minimize the total transportation time. Constraints (23) and (24) guarantee that the assigned vehicles are able to deliver commodity e. Constraint (25) restricts the available number of vehicles. Constraint (26) is nonnegative constraint. However, decision variable $n_{sd}^{l}(\xi)$ can be reduced by allowing the vehicle to deliver mixed commodities. Then, the second stage problem can be rewritten as:

$$\text{Min } \Psi_2 = \sum_{s \in \mathcal{S}} \sum_{d \in \mathcal{D}} \sum_{l \in \mathcal{T}} \sum_{\xi \in \Xi} p_{sd}(\xi) \cdot n_{sd}^{l}(\xi) \cdot [LU^l + \frac{D_{sd} \cdot r_{sd}(\xi)}{VS^l}] \tag{27}$$

Subject to:

$$(18) \text{ and } (19). \tag{28}$$

$$\Psi_2 < \Psi_2^*. \tag{29}$$

$$\sum_{l \in \mathcal{T}} n_{sd}^{l}(\xi) \cdot C^{lw} \leq \sum_{e \in \mathcal{E}} \sum_{l \in \mathcal{T}} n_{sd}^{le*}(\xi) \cdot C^{lw} \quad \forall\, s \in \mathcal{S}, d \in \mathcal{D}, e \in \mathcal{E}, \xi \in \Xi. \tag{30}$$

$$\sum_{l \in \mathcal{T}} n_{sd}^{l}(\xi) \cdot C^{lv} \leq \sum_{e \in \mathcal{E}} \sum_{l \in \mathcal{T}} n_{sd}^{le*}(\xi) \cdot C^{lv} \quad \forall s \in \mathcal{S}, d \in \mathcal{D}, e \in \mathcal{E}, \xi \in \Xi. \tag{31}$$

$$\sum_{e \in \mathcal{E}} w_{sd}^{e*}(\xi) \cdot W^{e} \leq \sum_{l \in \mathcal{T}} n_{sd}^{l}(\xi) \cdot C^{lw} \quad \forall s \in \mathcal{S}, d \in \mathcal{D}, e \in \mathcal{E}, \xi \in \Xi. \tag{32}$$

$$\sum_{e \in \mathcal{E}} w_{sd}^{e*}(\xi) \cdot V^{e} \leq \sum_{l \in \mathcal{T}} n_{sd}^{l}(\xi) \cdot C^{lv} \quad \forall s \in \mathcal{S}, d \in \mathcal{D}, e \in \mathcal{E}, \xi \in \Xi. \tag{33}$$

$$n_{sd}^{l}(\xi) \geq 0 \quad \forall s \in \mathcal{S}, d \in \mathcal{D}, l \in \mathcal{T}, \xi \in \Xi. \tag{34}$$

where objective function (27) aims to minimize the total transportation time under the upper bound Ψ_2^* (29). Constraints (30) and (31) ensure the capability of vehicles cannot exceed the upper bound of solution in model U_P. Constraints (32) and (33) restrict that assigned vehicles are able to deliver the mixed commodities. Constraint (34) is non-negative constraint.

6 Numerical Analysis

To illustrate the effectiveness of the proposed solution approach, a numerical analysis is carried out and related results are reported in this section. 10 relief centers, 4 kinds of commodities (water, food, tents and medicine) and 2 vehicle types (small and big vehicles) are considered. Relief center size is an integer number randomly generated in the interval [20, 50]. The minimal and maximal values that denote the quantities of demand and supply commodity are integer numbers multiplied by 10 and drawn from the intervals [0, 5] and [8, 12], respectively. Each kind of commodities has two characteristics which are weight and volume for per unit of commodity. Then, we have the weights 1.5, 1.0, 1.5 and 1.0, and the volumes 1.0, 2.0, 2.0 and 2.0 for each kind of commodities, respectively. Two vehicle types with different weight and volume capacities are considered, which are 20 and 30, and 26 and 40 for small and big vehicles, respectively. Besides, different loading and unloading time 3 and 5 are considered for the small and big vehicles respectively. And travel time is related to the vehicle speeds, which are 0.2 and 0.125 for small and big vehicles, respectively. In this instance, three different road availabilities in the transportation network are considered with probabilities 0.5, 0.3 and 0.2, respectively. The distance pairs between relief centers in each of availabilities ($D_{sd} \cdot r_{sd}(\xi)$) are random integer numbers generated from the intervals [5, 20], [20, 30] and [30, 50], respectively. In the first stage, the possible supply commodity quantities are consecutive integer numbers from AS_{es}^{min} to AS_{es}^{max} with probability $1/(AS_{es}^{max} - AS_{es}^{min} + 1)$, and the demand commodity quantities are also consecutive integer numbers from AD_{ed}^{min} to AD_{ed}^{max} with probability $1/(AD_{ed}^{max} - AD_{ed}^{min} + 1)$, respectively.

The main results for the first stage problem are provided in Fig. 1, which shows the minimal and maximal quantities of commodities can be delivered, and minimal and maximal quantities of commodities hope to be received. Besides, decision variables of anticipated amount of delivered and received commodity for each relief centers are also provided. Besides, for each kind of commodities, we can observe that the anticipated amount of delivered commodity is closely related to parameters AS_{es}^{min}, AS_{es}^{max} and Z^s. Similarly, the anticipated amount of received commodity is closely related to parameters AD_{ed}^{min}, AD_{ed}^{max} and Z^d.

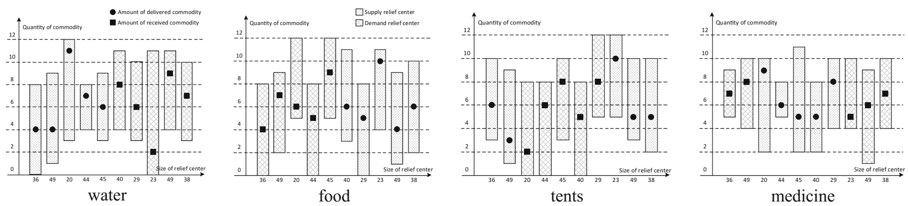


Fig. 1. Optimal redistribution strategies in the first stage

After the decision variables are obtained in the first stage, we can make the optimal set of the second stage decisions. The solution is summarized in Table 1 for the upper bound model U_P and the optimal model $\mathcal{F}_2$. Besides, the results also reveal that a higher objective function value Ψ_2^* is obtained in the upper bound model U_P because of each type of vehicles carrying only one kind commodity during the transportation process. On the other hand, we can obtain a smaller objective function value Ψ_2 and a better solution $\sum_{s\in\mathcal{S}}\sum_{d\in\mathcal{D}} n_{sd}^l(\xi)$ because we improve the vehicle utilization by allowing vehicles to carry mixed commodities.

Table 1. Solution strategies of upper bound model U_P and second stage model $\mathcal{F}_2$

AN^l	ξ	Upper bound U_P			Optimal $\mathcal{F}_2$		
		Ψ_2^*	Small vehicle	Big vehicle	Ψ_2	Small vehicle	Big vehicle
50	Scenario 1	10752.4	49	32	10499.7	50	30
	Scenario 2		49	32		50	30
	Scenario 3		46	34		50	30

7 Conclusions

This study presents a two-stage mixed-integer stochastic programming model for the multi-commodity redistribution problem. Three uncertain elements including supply, demand and transportation network are introduced into the proposed model. Besides, a numerical analysis is applied to demonstrate the applicability of the solution method for the proposed model. At the end, we can explore the problem of interests from the following aspects in future studies. It is interesting to generate multi-commodity redistribution planning considering multi-period process. Another future consideration is to extend this work to the budget-based uncertain cases. These questions will be considered in further research.

Acknowledgements. This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2015R1A2A1A10054253 and No. 2018R1A2B3008890).

References

1. Altay, N., Green, W.G.: OR/MS research in disaster operations management. Eur. J. Oper. Res. **175**(1), 475–493 (2006)
2. Rath, S., Gendreau, M., Gutjahr, W.J.: Bi-objective stochastic programming models for determining depot locations in disaster relief operations. Int. Trans. Oper. Res. **23**(6), 997–1023 (2016)
3. Clark, A., Culkin, B.: A network transshipment model for planning humanitarian relief operations after a natural disaster. In: Vitoriano, B., Montero, J., Ruan, D. (eds.) Decision Aid Models for Disaster Management and Emergencies. Atlantis Computational Intelligence Systems, vol. 7, pp. 233–257. Atlantis Press, Paris (2013). https://doi.org/10.2991/978-94-91216-74-9_11
4. Tomasini, R.M., Van Wassenhove, L.N.: A framework to unravel, prioritize and coordinate vulnerability and complexity factors affecting a humanitarian response operation. Faculty and Research, INSEAD, pp. 1–15 (2004)
5. Van Wassenhove, L.N.: Humanitarian aid logistics: supply chain management in high gear. J. Oper. Res. Soc. **57**(5), 475–489 (2006)
6. Liberatore, F., Pizarro, C., de Blas, C.S., Ortuño, M.T., Vitoriano, B.: uncertainty in humanitarian logistics for disaster management. A review. In: Vitoriano, B., Montero, J., Ruan, D. (eds.) Decision Aid Models for Disaster Management and Emergencies. Atlantis Computational Intelligence Systems, vol. 7, pp. 45–74. Atlantis Press, Paris (2013). https://doi.org/10.2991/978-94-91216-74-9_3
7. Haddow, G., Bullock, J., Coppola, D.P.: Introduction to Emergency Management. Butterworth-Heinemann, Oxford (2017)
8. Holguín-Veras, J., et al.: On the appropriate objective function for post-disaster humanitarian logistics models. J. Oper. Manag. **31**(5), 262–280 (2013)
9. Sahay, B.S., Gupta, S., Menon, V.C. (eds.): Managing Humanitarian Logistics. SPBE. Springer, New Delhi (2016). https://doi.org/10.1007/978-81-322-2416-7
10. Jia, H., Ordóñez, F., Dessouky, M.M.: Solution approaches for facility location of medical supplies for large-scale emergencies. Comput. Ind. Eng. **52**(2), 257–276 (2007)
11. Rawls, C.G., Turnquist, M.A.: Pre-positioning of emergency supplies for disaster response. Transp. Res. Part B: Methodol. **44**(4), 521–534 (2010)
12. Noyan, N., Balcik, B., Atakan, S.: A stochastic optimization model for designing last mile relief networks. Transp. Sci. **50**(3), 1092–1113 (2015)
13. Zhou, Y., et al.: A multi-objective evolutionary algorithm for multi-period dynamic emergency resource scheduling problems. Transp. Res. Part E: Logist. Transp. Rev. **99**, 77–95 (2017)

14. Caunhye, A.M., et al.: A location-routing model for prepositioning and distributing emergency supplies. Transp. Res. Part E: Logist. Transp. Rev. **90**, 161–176 (2016)
15. Lubashevskiy, V., Kanno, T., Furuta, K.: Resource redistribution under lack of information: short-term recovery after large scale disasters. J. Adv. Simul. Sci. Eng. **3**(1), 1–16 (2016)
16. Lubashevskiy, V., Kanno, T., Furuta, K.: Resource redistribution method for short-term recovery of society after large-scale disasters. Adv. Complex Syst. **17**(05), 1450026 (2014)
17. Popela, P., et al.: Two-stage stochastic programming for engineering problems. Eng. Mech. **21**(5), 335–353 (2014)
18. Birge, J.R., Louveaux, F.: Introduction to Stochastic Programming. Springer, New York (2011)
19. Shapiro, A., Philpott, A.: A tutorial on stochastic programming. www2.isye.gatech.edu/~ashapiro/publications.html (2007)
20. Higle, J.L., Stochastic programming: optimization when uncertainty matters. In: Emerging Theory, Methods, and Applications. INFORMS, pp. 30–53 (2005)

Operations Management in Engineer-to-Order Manufacturing

Dual Resource Constrained (DRC) Shops: Literature Review and Analysis

Matthias Thürer(✉)

Institute of Physical Internet, Jinan University,
Zhuhai, People's Republic of China
matthiasthurer@workloadcontrol.com

Abstract. The majority of manufacturing systems in practice are constrained by machine capacity and labour capacity. Consequently a broad literature on Dual Resource Constrained (DRC) shops exists. However, to best of our knowledge, no systematic review of the literature has been presented. Rather, existing reviews follow an ad-hoc procedure for article selection. In response, this study presents a systematic review of the literature concerned with DRC operating issues, such as worker assignment and production planning and control methods. Results highlight that, while early literature on dual resource constraint job shops was mainly simulation based, recent literature tends towards advanced scheduling mechanisms. This arguably introduces a bias towards deterministic contexts. Moreover, most DRC literature focuses on shop floor control decisions as labour assignment and dispatching. This neglects higher-level planning and control methods, such as order release control.

Keywords: Dual resource constrained shop · Systematic literature review
Operations management

1 Introduction

A major aim of job shop research is to align workload and capacity. Most research thereby assumes that capacity is a single variable. However, in practice most manufacturing systems are not only constrained by machine capacity, but also by labour capacity [4]; machines need a worker and workers have to be assigned to the machines. In addition, workers may possess different skills and be able to operate certain machines at different speeds. This type of highly complex shop that is constraint by machines and human resources is known as Dual Resource Constrained (DRC) job shop in the literature.

A broad body of literature on DRC shops exists and, consequently, several reviews have been presented [12, 25, 27]. However, existing reviews do not follow a systematic procedure for article retrieval. Rather, a set of papers considered relevant by the authors is discussed. In response, this study presents a systematic review of the literature on DRC shops. The objective is twofold: first, to provide a comprehensive view of the field; second, to update the latest review by [27].

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 81–86, 2018.
https://doi.org/10.1007/978-3-319-99704-9_10

2 Method – Review of the Literature

This paper starts by asking: What is the current state-of-the-art of the literature on Dual Resource Constrained (DRC) job shops? To answer this question a systematic review of the literature was conducted. The bibliographic database used for sourcing the articles was Scopus – due to its large coverage, e.g. compared to Web of Science, and its accuracy in terms of citation counts, e.g. compared to Google Scholar. In order to keep the number of articles reasonable and to ensure the quality of the sources, the search was restricted to peer-reviewed articles. Scopus was queried in December 2017 using the term: 'Dual Resource Constrained'. To keep results to a manageable number, the search was restricted to the title, abstract, and keywords of papers. There was no restriction on the year of publication or the journals considered (beyond being peer-reviewed). For the search term 82 articles were retrieved. The original sample of 82 articles was further reduced by excluding apparently unrelated articles. Using several channels for retrieving the full articles a total of 43 articles were obtained. Each of these articles was carefully read and analyzed.

3 Results

[25] subdivided the literature into design issues, such as skill level of workers and associated training, and operating issues, such as worker assignment and production planning and control methods. There is only little research that focuses on the former, mostly focussed on layout decisions. As most previous research, in this study we focus on the operating level. The operating level seeks to align three elements: (i) the workload (or demand), (ii) the machine capacity/capability and (iii) the worker capacity/capability. Most research assumes that the machine capacity/capability is fixed and focuses on the remaining two elements: the workload, which is controlled by dispatching and order release rules, and worker assignment, which is driven by the questions When? Where? and Who?. Another research stream combines the control of the workload and worker assignment by advanced scheduling techniques. However, this presupposes that demand and capacity availability is known in advance and thus deterministic. The following three sections discuss these three aspects.

3.1 Control of the Workload

[3] assess the impact of four different job release rules (Immediate Release, Backward Infinite Loading, Forward Finite Loading and Maximum Shop Load) and two dispatching rules (Modified Operation Due Date and Critical Ratio) on a DRC job shop. The authors show that backward Infinite Loading and Forward Finite Loading can improve performance compared to Immediate Release. Both release methods, three levels of labour flexibility (modelled by labour efficiency matrices) and two labour assignment rules were also considered by [23]. Results show no statistically significant performance difference between both release methods. [22] later showed that the relative performance of five dispatching rules was not affected by labour flexibility (again modelled by labour efficiency matrices). Finally, the general impact of demand

variance was assessed by [9]. The authors show that any reduction of variance through higher planning levels has the potential to dominate performance improvements achievable at order release, dispatching and worker assignment.

3.2 Worker Assignment

[8] assess the impact of labour flexibility (this is the number of machines a worker can operate) and compare its impact to staffing decisions, this is a general increase of labour capacity. They highlight that both decisions, staffing and labour flexibility, should play complementary roles. Later [7] assess different levels of flexibility across workers, i.e. some workers being able to work on all machines and some workers only being able to work on one machine. They show that having a small number of highly flexible workers may be a better option than having all workers with average flexibility. However these findings are in the context of perfectly interchangeable workers. A first study to question the assumption of perfectly interchangeable workers was [2] who introduced a labour efficiency matrix that determines the efficiency of a certain worker at a certain machine. [2] investigated five "when" and seven "where" rules demonstrating that a simple "where" rule that moves a worker to the station where the worker is most efficient dominates all other where and when rules. So in addition to deciding when a worker should be transferred and where the worker should be transferred to, managers have to decide whom to transfer. This need to decide *who* to assign was later emphasized by [5].

There are mainly two types of 'when' rules used in the literature, a 'centralised' rule that transfers a worker each time a job is completed, and a 'decentralised' rule that transfers a worker after completing all jobs (in process and queuing) at the current station. The incorporation of future workload information into the 'when' rules did not improve performance enough to impact manager's decisions [10] On the other hand, there exists a broad set of different 'where' rules. However, the literature typically argues that the 'where' rule has less impact than the 'when' rule [27]. Meanwhile, 'who' rules are dominated by efficiency considerations.

Another important stream in the context of worker assignment, specifically in the context of cross-trained workforces which may possess different skill levels, is learning. [21] assesses the impact of worker learning (in the form of throughput losses that occur during the learning period), worker flexibility (number of stations a worker can operate), and labour attrition (assuming an equal attrition rate across workers). [11] investigate the interplay of learning and attrition (assuming an equal attrition rate across workers), assessing the impact of loosing trained work force and having to train the replacement. This research is extended by [14], which assessed the combined impact of flexibility, staffing and learning (being learning modelled as a decrease in processing with operator task repetition), and [15, 16] who also include forgetting assessing the interplay of worker flexibility, forgetting rates, attrition rates and flexibility acquisition policies. Using the same learning model [26] later assessed the impact of different part life cycles (i.e. the frequency of changes in produced part types). Meanwhile, [28] used a dual-phase learning and forgetting model (DPLFM) to assess the impact of task type on the effectiveness of training and transfer policy.

Finally, a transfer delay was considered by [20] and [24], who assess the interaction of staffing level, distance between stations, buffer size between stations, coefficient of variation and different assignment rules using agent based modelling.

3.3 Advanced Scheduling Techniques

The majority of studies discussed in the above two sections assume a stochastic environment. This prohibits the use of scheduling. Rather some greedy heuristics need to be applied. If, on the contrary, the DRC job shop is assumed to be deterministic advanced scheduling techniques can be applied. Different techniques can be identified in the literature. For example: [6] use genetic algorithms to solve the production scheduling problem in DRC job shops; [1] dynamically select worker assignment and dispatching rule employing artificial neural networks (as meta-models to reduce computational complexity) and a fuzzy inference system (to cope with multiple performance criteria); [18] use variable neighbourhood search; [17] use dynamic neighbourhood search in a DRC job shop with interval processing times; [19] use a branch population genetic algorithm; [30] use e knowledge-guided fruit fly optimization algorithm; and, [29] use a hybrid discrete particle swarm optimization. Finally, [13] present a mixed-integer linear programming model to solve the problem of allocating one worker to *n* tasks (flexibility level) in *m* cycles within a constrained time period taking into account fatigue and recovery.

4 Conclusion

The majority of manufacturing systems in practice are constrained by machine capacity and labour capacity. Consequently a broad literature on Dual Resource Constrained (DRC) shops exists. However, to best of our knowledge, no systematic review of the literature has been presented. In response this paper started by asking: What is the current state-of-the-art of the literature on Dual Resource Constrained (DRC) job shops? The systematic review of the literature highlights that there is a tendency towards advanced scheduling mechanisms in recent years. While early literature on dual resource constraint job shops was mainly simulation based, recent literature tends towards mathematical modelling. However, advanced scheduling mechanisms presuppose a deterministic context. This study therefore calls for more research on DRC shops in a stochastic context as typically for many small and medium sized make-to-order companies that often produce a high variety of order at short notice. Another important observation is the apparent lack of literature on higher-level planning and control methods, such as order release control. Most literature focuses on shop floor control decisions as labour assignment and dispatching. More research is therefore needed that explores the impact of higher level planning and control decisions on DRC performance.

References

1. Araz, Ö.U., Salum, L.: A multi-criteria adaptive control scheme based on neural networks and fuzzy inference for DRC manufacturing systems. Int. J. Prod. Res. **48**(1), 251–270 (2010)
2. Bobrowski, P.M., Park, P.S.: An evaluation of labor assignment rules when workers are not perfectly interchangeable. J. Oper. Manag. **11**, 257–268 (1993)
3. Bobrowski, P.M., Park, P.S.: Work release strategies in a dual resource constrained job shop. Omega **17**(2), 177–188 (1989)
4. Bokhorst, J.A.C., Gaalman, G.J.C.: Cross-training workers in dual resource constrained systems with heterogeneous processing times. Int. J. Prod. Res. **47**(22), 6333–6356 (2009)
5. Bokhorst, J.C.A., Slomp, J., Gaalman, G.J.C.: On the who-rule in dual resource constrained (DRC) manufacturing systems. Int. J. Prod. Res. **42**(23), 5049–5074 (2004)
6. ElMaraghy, H., Patel, V., Abdallah, I.B.: Scheduling of manufacturing systems under dual-resource constraints using genetic algorithms. J. Manuf. Syst. **19**(3), 186–201 (2000)
7. Felan, J.T., Fry, T.D.: Multi-level heterogeneous worker flexibility in a Dual Resource Constrained (DRC) job-shop. Int. J. Prod. Res. **39**(14), 3041–3059 (2001)
8. Felan, J.T., Fry, T.D., Philipoom, P.R.: Labour flexibility and staffing levels in a dual-resource constrained job shop. Int. J. Prod. Res. **31**(10), 2487–2506 (1993)
9. Fredendall, L.D., Melnyk, S.A.: Assessing the impact of reducing demand variance through improved planning on the performance of a dual resource constrained job shop. Int. J. Prod. Res. **33**(6), 1521–1534 (1995)
10. Fredendall, L.D., Melnyk, S.A., Ragatz, G.: Information and scheduling in a dual resource constrained job shop. Int. J. Prod. Res. **34**(10), 2783–2802 (1996)
11. Fry, T.D., Kher, H.V., Malhotra, M.K.: Managing worker flexibility and attrition in dual resource constrained job shops. Int. J. Prod. Res. **33**(8), 2163–2179 (1995)
12. Hottenstein, M.P., Bowman, S.A.: Cross-training and worker flexibility: a review of DRC system research. J. High Technol. Manag. Res. **9**(2), 157–174 (1998)
13. Jaber, M.Y., Neumann, W.P.: Modelling worker fatigue and recovery in dual-resource constrained systems. Comput. Ind. Eng. **59**, 75–84 (2010)
14. Kannan, V.R., Jensen, J.B.: Learning and labour assignment in a dual resource constrained cellular shop. Int. J. Prod. Res. **42**(7), 1455–1470 (2004)
15. Kher, H.V.: Examination of flexibility acquisition policies in dual resource constrained job shops with simultaneous worker learning and forgetting effects. J. Oper. Res. Soc. **51**, 592–601 (2000)
16. Kher, H.V., Malhotra, M.K., Philipoom, P.R., Fry, T.D.: Modeling simultaneous worker learning and forgetting in dual resource constrained systems. Eur. J. Oper. Res. **115**, 158–172 (1999)
17. Lei, D., Guo, X.: An effective neighbourhood search for scheduling in dual-resource constrained interval job shop with environmental objective. Int. J. Prod. Econ. **159**, 296–303 (2015)
18. Lei, D., Guo, X.: Variable neighbourhood search for dual-resource constrained flexible job shop scheduling. Int. J. Prod. Res. **52**(9), 2519–2529 (2014)
19. Li, J., Huang, Y., Niu, X.: A branch population genetic algorithm for dual-resource constrained job shop scheduling problem. Comput. Ind. Eng. **102**, 113–131 (2016)
20. Malhotra, M.K., Kher, H.V.: An evaluation of worker assignment policies in dual resource-constrained job shops with heterogeneous resources and worker transfer delays. Int. J. Prod. Res. **32**(5), 1087–1103 (1994)

21. Malhotra, M.K., Fry, T.D., Kher, H.V., Donohue, J.M.: The impact of learning and labor attrition on worker flexibility in dual resource constrained job shops. Decis. Sci. **24**(3), 641–664 (1993)
22. Park, S.P.: The examination of worker cross-training in a dual resource constrained job shop. Eur. J. Oper. Res. **51**, 291–299 (1991)
23. Park, S.P., Bobrowski, P.M.: Job Release and labor flexibility in a dual resource constrained job shop. J. Oper. Manag. **8**(3), 230–249 (1989)
24. Sammarco, M., Fruggiero, F., Neumann, W.P., Lambiase, A.: Agent-based modelling of movement rules in DRC systems for volume flexibility: human factors and technical performance. Int. J. Prod. Res. **52**(3), 633–650 (2014)
25. Treleven, M.D.: A review of the dual resource constrained system research. IIE Trans. **21**(3), 279–287 (1989)
26. Yue, H., Slomp, J., Molleman, E., Van Der Zee, D.J.: Worker flexibility in a parallel dual resource constrained job shop. Int. J. of Prod. Res. **46**(2), 451–467 (2008)
27. Xu, J., Xu, X., Xie, S.Q.: Recent developments in dual resource constrained (DRC) system research. Eur. J. Oper. Res. **215**, 309–318 (2011)
28. Zamiska, J.R., Jaber, M.Y., Kher, H.V.: Worker deployment in dual resource constrained systems with a task-type factor. Eur. J. Oper. Res. **177**, 1507–1519 (2007)
29. Zhang, J., Wang, W., Xu, X.: A hybrid discrete particle swarm optimization for dual-resource constrained job shop scheduling with resource flexibility. J. Intell. Manuf. **28**, 1961–1972 (2017)
30. Zheng, X.L., Wang, L.: A knowledge-guided fruit fly optimization algorithm for dual resource constrained flexible job-shop scheduling problem. Int. J. Prod. Res. **54**(18), 5554–5566 (2016)

Controlling Customer Orders in the ETO/VUCA Contexts

Stanisław Strzelczak[1](✉) and Viswavikram Viswanathan[2]

[1] Faculty of Production Engineering, Warsaw University of Technology, Warsaw, Poland
s.strzelczak@wip.pw.edu.pl
[2] Essel Propack, Międzyrzecz, Poland
viswavikrammct@gmail.com

Abstract. Under hyper-competition customers expect to accept last-minute changes in their orders. In such circumstances ETO manufacturing exhibits the VUCA specificity and suffers from many issues like delays, excessive costs, low quality etc. This paper examines operative controlling as a mean to facilitate discovery and response to the changes and disturbances. The approach derives from the phenomenological research and the reflection on theory and practice. The solution uses an integrated model that represents all workflows subject to changeable contexts and is based on three pillars: (i) run-time data extraction; (ii) integrated representation of workflows; (iii) providing current information to shareholders. The concept was validated by prototyping and a use-case.

Keywords: ETO manufacturing · VUCA · Operational control Changeability

1 Introduction

Manufacturing industry is increasingly facing the requirement to deliver high variety of customized products in very low volumes. Under hyper-competition customers are reluctant to compromise product long delivery and specifications, but rather expect to accept even at last minute changes in their orders. Thus, the context of engineering-to-order (ETO) tends towards the VUCA (volatility-uncertainty-complexity-ambiguity) specificity [1]. It can be summarized as follows [2]:

1. Customer-order specifics penetrates backward the activities of value stream; this happens in a variable way: from parent to child orders and within singular orders;
2. Parallel engineering, purchasing, subcontracting and manufacturing is a must; purchasing or even manufacturing must be started before products and processes are fully engineered; cross-functional and cross-processual dependencies are multiple, complex and elusive; despite this orders, products, processes, costs and quotations have to be parametrized right at the first time;
3. Frequent changes in customer order specifications occur; they are often missed or misinterpreted and hard to track; together with the processual complexity of production support, this causes frequent errors that are difficult to discover; altogether

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 87–94, 2018.
https://doi.org/10.1007/978-3-319-99704-9_11

the state of affairs becomes vague; sharing current engineering and operational data, both internally and with subcontractors, becomes very difficult.

In such conditions, engineering, production planning and control (PPC), purchasing and quality assurance, require more effort and time and are less robust. The causes are the need to multiple re-work and reliance on incomplete or Small Data. Thus, the outputs of these activities (process plans, material and time standards, schedules, quality specifications, etc.) are less accurate, often fault and late. The failures, starting from customer order specification until delivery and installment of products, are hard to discover because the legacy systems (CRM, CAD, PLC, CAE, ERP, MES) provide a limited visibility across functions and processes. Analyzing effects and responses to the changes and distortions, like announcing them, is difficult. Ultimately the compliance with specifications, punctuality, quality, productivity and costs are deteriorated. The perpetual change in customer orders significantly enhances the VUCA features.

The aim of this paper is to explore the potential of operative controlling as a means to deal with the change along execution of customer orders and the side-negative effects. The targeted management functions are quick exposure of change and early warning of threats. Another important function is facilitating the development of responses to the emerging issues. The approach derives from phenomenological research and existing knowledge, including theories of: ETO manufacturing [3–7], PPC [8–10] and operations research [11]. The solution aims at overall visibility and applies integrated model of customer orders fulfillment which enables the control of all workflows affected by the emerging change and disruptions. The framework is built on three pillars: (i) run-time data extraction, whether from legacy systems or dedicated means; (ii) augmenting reality subjected to decision making through cross-functional and cross-processual representation of all workflows related; (iii) continuous dissemination of information about changes and their likely consequences.

Basically the tool based on this model is intended as an overlay to legacy systems, using their data. It can be also developed into an independent solution using dedicated data sources. The model should be used by relevant organizational routines. The solution was validated by a use case supported by a developed prototype software tool.

2 Literature

The key concept of ETO is customer order decoupling point (CODP), which was originally defined as the earliest point in a process where a product is designed for a specific customer [12]. This way the material flow along supply chain could be divided into two sub-processes: pre- and post-CODP. The latter requires individualized control of orders and pegging abilities, while the former may be based on replenishment. An extensive review of literature, which considers the supply chain context of ETO [3], suggests a spectrum of generic strategies including: integration [13], information management [8], re-engineering, time-compression and flexibility. Although all these strategies can to a certain extent support the ETO/VUCA context, a direct aid is given only by the information management strategy [8]. Some authors differentiate the engineering changes in ETO environment [14] and analyze their impact on material flows throughout the entire order fulfilment process [6]. Also the need for early warning of risks is suggested, like the approaches to identify their symptoms [15].

The need to differ perspectives in ETO by decoupling engineering and manufacturing was suggested in [4]. This approach has been extended by recognizing decision domains and degrees of CODP penetration [16, 17], dynamics of CODP location [5], and distinction of resource and process related decoupling [16].

The literature assesses the use of existing PPC methods and systems for ETO manufacturing [8, 9]. In general, poor match is pointed out between the specificity of ETO (dynamics, uncertainty, complexity) and its needs for the decision support, with the abilities of MRP/ERP [5]. Some authors even suggest uselessness of MRP/ERP for the ETO manufacturing [8, 17]. They indicate such shortcomings as [8]: (i) inability to cope with incomplete or uncertain information at the early stage of order execution; (ii) non-suitability of capacity planning for ETO; (iii) inability to operate non-physical processes. Actually some ERP systems are equipped with functions that reduce these shortcomings. The critic does not consider the often needed traceability of parent or child orders. For this purpose many systems offer the indented tracking and pegging.

Heterogenous approaches to production planning are also hybridized (e.g. the project approach and the overall framework of PPC [9]). What MRP/ERP systems are not able to effectively operate is the horizontal integration through linking of planned workflows and items. Thus, the support to cross-functional and cross-process coordination of customer orders is not possible. Also the correspondence of cycle times (lead times) and workloads (rough processing times) is an Achilles heel of MRP/ERP.

The interest in the applicability of MES systems to ETO context is limited. MES systems generally focus on the field. They are not directly affected by the CODP-related type of manufacturing, but rather by the approach to shop-floor control, the complexity of material flows, the degree of automation and the layout of resources. Arbitrating about suitability of MES systems for ETO manufacturing is risky because of the diversity of conditioning. Hybridization is normally an imperative therein.

Some authors propose the frameworks for PPC in the ETO context. One of the approaches is based on distinction of four decision categories: driving (why and when flows are initiated), differentiation (uniqueness of flows), delimitation (triggering flows) and maintaining transparency of workflows using basic BOMs [17]. Process and resource decoupling is applied and various lead-time contexts, i.e. types (internal vs. external, adapt, delivery and supply) and their relating. Another framework learns from the particular VUCA aspects of ETO, the rules of PPC, and the structuring of ETO manufacturing (identifying the generic items of material flow control, and the production phases) [8]. Following that four generic 'production units' are proposed: conceptual design, product engineering, component manufacturing and assembly.

The need to hybridize production situations in information systems was also examined, considering various factors such as [5, 9]: demand variability, disruptions, and specific complexity factors. The framework proposed in [5] considers the following 'hybridizations': (i) different types of manufacturing (ETO, etc.) in master production schedule; (ii) merging 'order requirements planning', 'project requirements planning' and 'project capacity planning' with standard MRP functions; (iii) differently aggregated product data; (iv) various generic data (routings, pricing structures and budgets). Network planning is assumed as basis to scheduling, planning materials and capacity, monitoring progress and accounting costs. Another hybrid approach assumes integration of aggregate demand management with preliminary engineering by using the standard MRP functions and project planning [9]. The customer changes are controlled along the project planning and scheduling by using the pegging function. This way re-costing, re-budgeting and re-quotation are enabled.

Despite the abundance of ETO literature, only few papers address the issues related to the VUCA context and the use of controlling customer orders as a countermeasure against the negative effects. Such aspects as customer change management, links of activities in different functions or domain ambiguity, are considered to a limited extent, if at all. Existing knowledge and solutions provide only limited support for the ETO/VUCA context, especially in regard to the customer changes. Nevertheless, literature recognizes the need to apply multi-perspective viewing of the domain and hybridize different production situations within the integrated functionalities of PPC.

3 Phenomenology of Change in Customer Orders

This section examines the phenomenology of changes in customer orders along their execution. The aim is to develop a base for a suitable domain representation that could be used by the controlling framework. The following functions of a firm may be affected by the customer changes: sales, engineering, PPC, purchasing, manufacturing, internal logistics and accounting. If the decoupling zone [4] goes beyond the boundaries of a focal organization, suppliers (subcontractors or partners) are external stakeholders of the changes. The items subject to cascading changes are: (i) engineering orders, items, workloads, cycles; related tasks or schedules; (ii) manufacturing items, workloads, capacity loads, orders and schedules; (iii) purchasing items, orders and schedules; (iv) costs, budgets; (v) quotations and due dates in customer orders.

The sequential view of customer order execution which shows the cascading of changes is presented in Fig. 1. Lifelines represent organizational functions and provide multi-perspective view of the domain. Sequential and causal dependencies can be both considered. Another wave of changes is driven by faults and disruptions. Faults may stay undiscovered for a long time. If not discovered they result in disruptions and losses. The typical causes for them are miscommunications or mistaken actions and items. Both disruptions and faults, like the cascading of customer change, require early warning. The symptoms subjected to tracking are: (i) actual and likely delays or speedups; (ii) missing or obsolete items (materials, work); (iii) under- or over-utilization of capacity; (iv) excessive costs or exceeded budgets; (v) impossibilities (e.g. assembly cannot be completed as input items are incorrect). The above conceptualization should be regarded as an adaptable reference, not as a rigid pattern. It provides the basic setup to tailor digital tools to support the controlling of customer orders. It also sets a reference to design organizational routines for the controlling.

Another factor of VUCA, which interacts with the cascading changes in customer order specifications is the successive disaggregation (explosion) of items subject to planning or execution, including: (i) product design; (ii) process plan; (iii) workloads and capacity loads; (iv) material requirements; (v) schedules; (vi) costs and budgets.

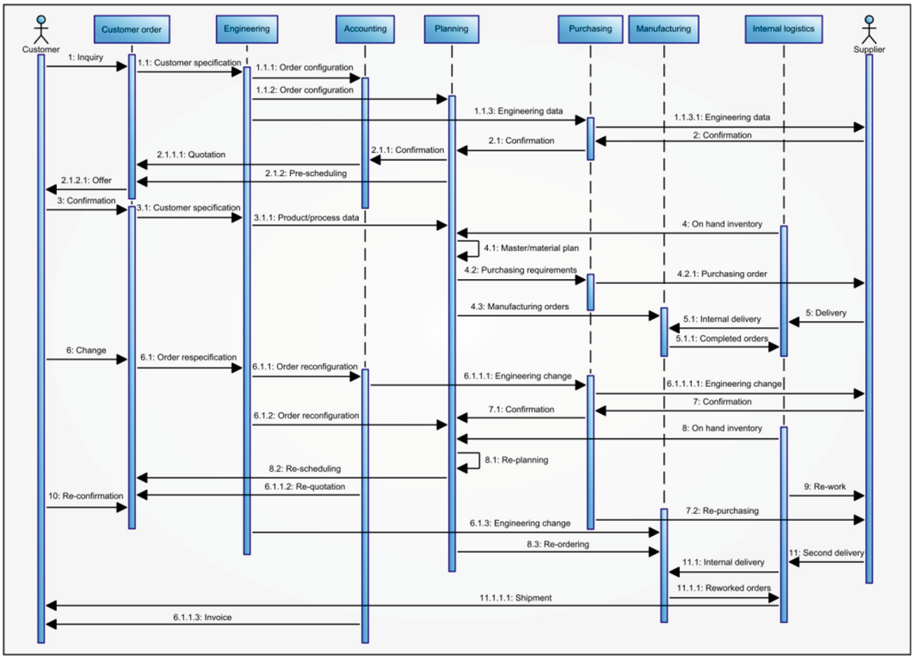


Fig. 1. Cascading of changes in customer orders

The third factor of VUCA in ETO is the dynamics of decoupling zones [17]. The range of customer order penetration may vary over time: along product life-cycle, from customer order to customer order, and from product to product. The fourth factor of VUCA in ETO relates to the common use of resources (materials, capacities) by different orders. Finally, industrial practices expose the role of holistic visibility, which is weakly supported by the legacy systems that mostly focus on the material flows and the capacity utilization. Consequently the ambiguity and uncertainty arise.

4 Integrated Model of Customer Order Fulfillment in ETO

This section outlines an integrated model of customer orders in ETO. The IT tool based on this model should facilitate timely and adequate responses to the arising changes in customer orders. The approach learns from the existing knowledge and recognizes the VUCA factors identified in Sect. 3. It attempts to compromise three alternative ways to the possible IT support: (i) overlaying legacy systems; (ii) hybridizing existing models, systems or functionalities; (iii) applying entirely new approach. The first two approaches apply BOM-like structures or layered networks to represent: products, requirements, bills of capacities, engineering and manufacturing processes, bills of costs and budgets. The model applies ontological domain representation and follows the transformational paradigm by recognizing: outputs (tasks), activities (transformations) and resources [10]. The basic constituents are activities (Fig. 2).

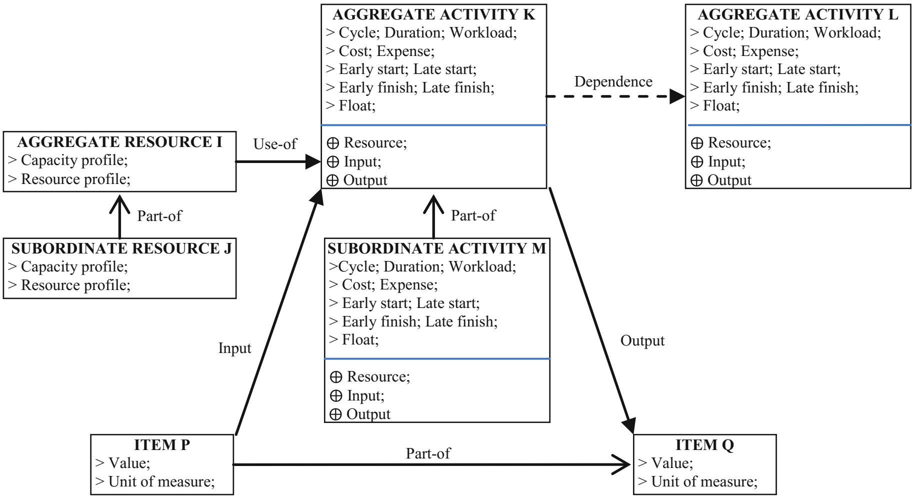


Fig. 2. Generic constituents for domain representation

Basically, but not obligatorily, activities have inputs and outputs, and engage resources. They are attributed with the parameters of workload, time, costs and expense. Resources are attributed with the capacity and load profiles. Both can be rolled up to aggregate resources or overall capacity factors. The basic mereology of resources and activities presumes distributive parthood relationships, which enables aggregation or decomposition, when needed and successively (in run-time mode). For this purpose the models of aggregation and decomposition presented in [10] (see: Figs. 34, 33) can be adapted, accordingly. Costs can be subjected to additive accumulation, while expenses can be time-phased and rolled-up (additive forward accumulation). Time-phasing may follow various rules, like offsetting (backward) and forward timing. The early and late dates can be estimated, like the floats. The third category of nodes is items. Items are linked by the mereological relationships. The parthood relation is basically used to represent BOMs. It parallelizes the linked input and output relations, i.e. in reference to activities executing the parthood relation. Items are attributed with the values, which can be rolled up. Activities are also linked by the dependence relations, e.g. time dependencies (finish-to-start (FS), etc.). Backward and forward rollups of dates enable calculations of the early and late dates, as well as floats.

The proposed way of abstracting generalizes both, the distributive structures of bills (BOMs etc.) and the networks used for scheduling. It can represent all items subject to change in customer order specifications, which were identified in Sect. 3. It recognizes the dynamics of decoupling zones and commonality of resources. It also enables to follow the symptoms of threats that are subject to early warning, and to identify the items affected by revealing events through tracking of dependencies. The proposed model can be equally used by various functions of ETO manufacturing. Through layering - by organizational functions - it supports cross-functional visibility. Layers represent the state of affairs in functions, while cross-layer dependencies secure the holistic view of operations. The viewing of layers is as follows. Manufacturing, logistics and planning views the related activities, resources and material items. Engineering views the related activities, resources, and engineering or material data items. Purchasing views the related activities, resources and material items. Accounting views the costs and expense. Sales view their activities and the contract items.

To benefit from the model organizational routines are needed: (i) supervision of data sourcing; (ii) monitoring symptoms subject to early warning; (iii) cascading changes or disruptions; tracking of subsequent effects; (iv) re-engineering, re-work, re-planning, re-purchasing, re-costing, re-budgeting, etc. Altogether the digital tools and organizational routines can facilitate early warning of threats, as well as development of appropriate responses to the changes in specifications of customer orders.

5 Case Study

A limited validation was performed based on a case study in KraussMaffei plant in Sučany (Slovakia). The factory engineers and manufactures customized injection moulding machines. The final assembly is takted (14 steps, each along one shift). Electrical control cabinets are made through fixed-station assembling. Components are fabricated, supplied or subcontracted. Such arrangement results in very simple structuring of the decoupling zones. The factory exploits SAP ERP as well as Camos CPQ (to customize, price and quote products). Both systems are integrated via Camos Connect SAP interface. The case fully reflects the specificity of ETO manufacturing.

After analysis, a software tool was prototyped by adapting the proposed model. It is an overlay to SAP and Camos. It implements timing calculations described in Sect. 4 [2]. The data extraction from legacy systems is applied accordingly. Although the developed functions are basic, they can effectively facilitate early warning and enables timely responses to the arising changes and deviations. Multi-perspective viewing of the domain is provided. With this regard relevant organizational routines were also shaped. Further details of the validation are presented in [2].

6 Summary and Further Work

Integrated controlling of customer orders based on multi-perspective conceptualization of the decoupling zone was outlined in this paper. The layers of model represent key functions of production affected by the ETO environment, including engineering, planning, manufacturing, purchasing and logistics, and costing. The model entangles processual interdependencies, including the vertical precedencies and horizontal dependencies, as well as the influence relationships of effects that emerge due to changes imposed by customers or errors. The approach enables cross-functional transparency, which is crucial under the VUCA ETO conditioning. Operation of the model is based on the run-time data extraction, as well as sharing of the latest information and developed responses with all shareholders. The further work should focus on adaptation of various PPC methods, further detailing and diversification, considering inter-organizational aspects. The development issues provide another challenge.

References

1. Benett, N., Lemoine, G.J.: What VUCA really means for you. Harvard Business Review 2014/January-February (2014)
2. Viswanathan, V.: Controlling of engineering management in ETO manufacturing in KraussMaffei technologies. Master Thesis (supervisor: S. Strzelczak), Warsaw University of Technology, Faculty of Production Engineering, Warsaw (2017)
3. Gosling, J., Naim, M.M.: Engineer-to-order supply chain management: a literature review and research agenda. I.J. Prod. Econ. **122**(2), 741–754 (2009)
4. Wikner, J., Rudberg, M.: Integrating production and engineering perspectives on the customer order decoupling point. I.J. Oper. Prod. Manag. **25**(7), 623–641 (2005)
5. Giesberts, P.M.J., van der Tang, L.: Dynamics of the customer order decoupling point: impact on information systems for production control. Prod. Plan. Control **3**(3), 300–313 (1992)
6. Willner, O., Powell, D., Gerschberger, M., Schönsleben, P.: Exploring the archetypes of engineer-to-order: an empirical analysis. I.J. Oper. Prod. Manag. **36**(3), 242–264 (2016)
7. Sriram, P.K., Dreyer, H.C., Alfnes, E.: Understanding key engineering changes for materials management in ETO environment. In: Umeda, S., Nakano, M., Mizuyama, H., Hibino, H., Kiritsis, D., von Cieminski, G. (eds.) APMS 2015. IAICT, vol. 460, pp. 256–262. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-22759-7_30
8. Bertrand, J.W.M., Muntslag, D.R.: Production control in engineer-to-order firms. Int. J. Prod. Econ. **30–31**, 3–22 (1993)
9. Sriram, P.K., Alfnes, E., Arica, E.: A concept for project manufacturing planning and control for engineer-to-order companies. In: Emmanouilidis, C., Taisch, M., Kiritsis, D. (eds.) APMS 2012. IAICT, vol. 398, pp. 699–706. Springer, Heidelberg (2013). https://doi.org/10.1007/978-3-642-40361-3_89
10. Strzelczak, S.: Implementing ontologies in manufacturing and logistics – from theoretical fundamentals to prospects. In: Strzelczak, S., Balda, P., Garetti, M., Lobov, A. (eds.) Open Knowledge Driven Manufacturing and Logistics - the eScop Approach, OWPW, pp. 111–213 (2015)
11. Nagurney, A., Dong, J.: Supernetworks: Decision-Making for the Information Age. Edward Elgar Publishing, Cheltenham (2002)
12. Sharman, G.: The rediscovery of logistics. Harv. Bus. Rev. **62**(5), 71–79 (1984)
13. Hicks, C., McGovern, T., Earl, C.F.: A typology of UK engineer-to-order companies. Int. J. Logist.: Res. Appl. **4**(1), 43–55 (2001)
14. Jarrett, T.A.W., Eckert, C.M., Caldwell, N.H.M., Clarkson, P.J.: Engineering change: an overview and perspective on the literature. Res. Eng. Des. **22**(2), 103–124 (2011)
15. Haji-kazemi, S., Arica, E., Semini, M., Alfnes, E., Andersen, B.: Detecting early warning signs of delays in shipbuilding projects. In: Umeda, S., Nakano, M., Mizuyama, H., Hibino, H., Kiritsis, D., von Cieminski, G. (eds.) APMS 2015. IAICT, vol. 460, pp. 215–222. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-22759-7_25
16. Gosling, J., Hewlett, B., Naim, M.M.: Extending customer order penetration concepts to engineering designs. I.J. Oper. Prod. Manag. **37**(4), 402–422 (2017)
17. Wikner, J.: On decoupling points and decoupling zones. Prod. Manuf. Res. **2**(1), 167–215 (2014)

Defining Solution Spaces for Customizations

Nikolas Käkelä(✉) and Joakim Wikner

Jönköping University, 551 11 Jönköping, Sweden
nikolas.kakela@ju.se

Abstract. Customization in different flavors have been identified as an important differentiator if low-cost competitiveness is not viable. To provide a customer unique solution is however not the same as providing a solution that is designed and individualized for a particular delivery to a customer. These two cases are illustrations of how customer requirements may be fulfilled differently depending on the match between stated requirements and the solution offered. The range of solutions that can be offered is represented by a solution space consisting of either predefined or postdefined solutions. Predefined refers to solutions that are defined before commitment to a customer and postdefined refers to solutions that are defined after commitment to a customer. Both cases are constrained by a boundary of possible solutions but the postdefined solutions provide opportunities for bounded innovation beyond what the predefined solutions can provide. Combining the properties of the different solution spaces provides not only an operational definition of customization but also supports in identifying strategic opportunities for extending the solutions and types of customizations a business provides.

Keywords: Customization · Solution space · Decoupling point

1 Introduction

Increased proliferation of demand has led to suppliers' adoption of a variety of customer driven production practices. Several research contributions have been made to provide further understanding of these practices. Hoekstra and Romme [1] suggested logistics structures based on decoupling points to illustrate how customer driven production approaches can be classified. In this context the Configure-to-order (CTO) and Engineer-to-order (ETO) systems diverge from other production approaches by being comprised of customization activities that are driven by commitment to a customer rather than driven by speculation.

Within the CTO-approach, the possible range of customized solutions is designed or engineered before commitment to a specific customer, but then configured in accordance to each customer's needs once the customer order is received. Notably, the customized solution is generated within the boundaries of the predefined configuration possibilities. In this sense it differs from the ETO-approach. For ETO the engineering activities are performed in line with each customer's needs and there are in most cases no predefined solutions or alternatives to select from when customizing. This should however not be interpreted as that the customers freedom of choice is without

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 95–100, 2018.
https://doi.org/10.1007/978-3-319-99704-9_12

constraints. ETO-companies have boundaries as to what orders they embark on too, but the boundaries are operationalized differently.

In this research, the set of possible solutions when customizing is referred to as the solution space that represent what can be offered by the supplier. The solution space is decisive for the range of solutions that can be offered to the customer. Some suppliers establish clear boundaries in advance as to what solutions they offer, allowing production processes to be stable by decreasing product variety. Others benefit from not having the solution space constrained and instead provide products fully tailored to customers' needs. Regardless of the position of the supplier on this matter, the solution space is both an operational and strategic concern for suppliers offering customized products. The purpose of this research is therefore to define solution spaces that embrace different types of customization.

2 Methodology

The conceptual approach that this research is based on is derived from the researchers' experiences from research projects focusing on customization related topics. The research is conducted with an analytical conceptual approach, using logical relationship-building rather than empirical data for theory development [2].

3 Categories of Flow Drivers

Customization is by definition based on customer requirements but the preconditions for customization are established before commitment to a customer. This differentiation is in line with the decoupling of speculation driven activities and commitment driven activities provided by the customer order decoupling point (CODP) [1]. The CODP is a time-based concept that is defined based on the relation between the time the customer must wait for delivery to be performed and the total lead-time required to perform all activities related to the delivery. Activities performed when the customer is waiting is here referred to as commitment driven (CD) activities and activities that must be performed in advance of committing to a customer is here referred to as speculation driven (SD) activities. SD activities are based on expectations about future requirements that may not be perfectly in line with future customer requirements related to CD activities. To cover for this difference the interface between SD and CD is usually associated with a stock point that decouples the two types of flow: SD and CD. In relation to customization it is obviously not suitable to combine customization with SD since the actual customer requirements are not known at that instant in time. CD activities are however well suited for customization but at the same time it does not exclude the delivery of standardized products to customer order, i.e. CD. Even if customization and CD are intimately connected there are several different types of customizations that may be performed and this is related to the solution space of the customized solutions.

4 Categories of Solution Spaces

While a mass producer must identify the universal needs shared by its target customers, a mass customizer instead identifies the idiosyncratic needs of their customers. By doing this, the mass customizer can predefine alternative solutions that customers can demand, and engineering activities (note that "engineering" here basically represents all types of activities not related to the physical delivery, i.e. provisioning, of the product) can in this way be SD. However, for customizers, where these engineering activities are CD, the activity of identifying the needs of a customer is repeated for each individual commitment. It becomes clear that there is a fundamental difference in defining solutions where engineering activities are SD rather than being CD.

4.1 Predefined and Postdefined Solutions

To further distinguish SD solutions from CD solutions, the solutions relation to the CODP can be considered. A solution that is SD is in this research referred to as a *predefined* solution meaning that the customized solution is defined upstream from (before) the CODP. It is a customization system where the possible solutions have been clearly defined before the customer order is received. In contrast, a CD solution is here referred to as a *postdefined* solution. Consequently, only downstream of (after) the CODP does the solution become clearly defined and the constraints actuated.

For predefined solutions, customers need to keep their adaptations within the confines of a set of established solutions or list of options. It limits the customer's freedom of choice but allows the supplier to establish stable processes for providing the customization, enabling low-cost adjustments to the production process [3].

For postdefined solutions, the customer is less constrained. Here, the customer can get response for truly individualized requirements as there are no predefined solutions that the customer chooses from. However, while customers are free to make inquires without any constraints, the suppliers always have some sort of boundary as to what commitments they take on. The suppliers might for example turn down customer orders that go far beyond their area of expertise.

4.2 Solution Spaces

Predefined and postdefined solutions can be further defined in terms of solution spaces. The concept of "solution space" is used in for example optimization theory where it refers to the set of all possible points that satisfy a problem's constraints. The concept has also been applied for innovation toolkits and mass customization, referring to the set of possible solutions that a customer can choose from when a supplier provides customizations. This application of the concept does however not portray a comprehensive understanding of the role of solution spaces for customization. To address this, three types of solution spaces can be identified in relation to some key product delivery strategies as illustrated in Fig. 1.

For standardized products or services, the solution space can be considered as "collapsed" into one predefined solution (the grey dot in the small circle). No efforts are made to offer customizations that corresponds to idiosyncratic needs of customers.

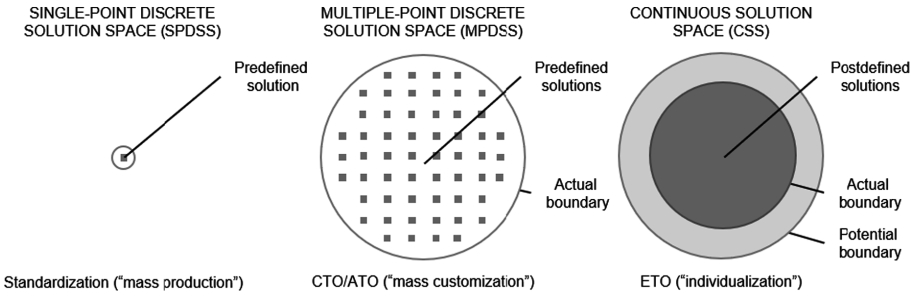


Fig. 1. Categories of solution spaces

Thus, the boundary as to what solutions that are offered coincides with the single selectable alternative. This type of solution space is here referred to as a single-point discrete solution space (SPDSS). Each individual product would then be represented as a separate SPDSS. The actual delivery of the product can be based on inventory (make-to-stock, MTS) or made to customer order (make-to-order, MTO) but, in any case only one specific predefined solution is offered. Mass customization approaches have, on the other hand, a solution space constituted by a set of predefined solutions that have been established based on speculation of customers' needs (the larger circle with several discrete dots). It thus differs from SPDSS by predefining multiple solutions and that the specific solution is configured based on customer requirements. Therefore, this type of solution space is referred to as a multiple-point discrete solution space (MPDSS). This case is in line with the assumptions of the product delivery strategy assemble-to-order (ATO) or more specifically CTO. The complete set of predefined solutions thus result in a de facto actual boundary of the solutions that can be offered. Postdefined solutions can be associated with customizations that are individualized. The definition of the solution is here driven by commitment, giving customers more freedom when customizing at the expense of longer delivery lead time compared to predefined solutions. The boundary of the customer's freedom is less distinct than for mass customization and standardization (i.e. where standardization basically represent mass production). It can drive the supplier to occasionally go outside their comfort zone, take on challenging commitments and in that way expand their solution space, which is represented by a potential boundary. This type of solution space is referred to as a continuous solution space (CSS) and is usually associated with ETO.

As a SPDSS does not offer any customization possibilities, it is not included below. Focus is directed towards MPDSS and CSS and how they require different measures to be developed. The intention of developing the solution space for a case of MPDSS is to further delineate what customizations the supplier can offer. To attain a refined MPDSS, the supplier must have a good understanding of the product attributes of which customers' needs diverge [4]. Suppliers with a CSS are on the other hand devoted to developing competence to understand customers' needs and competence to engineer products fulfilling those needs [5].

5 Solution Spaces and Customization

The different solution spaces, MPDSS and CSS, can be further delineated based on being driven by speculation or by commitment as in Table 1. A MPDSS requires rules that are established on speculation but used after the CODP. A CSS on the other hand requires the competences of an engineer, designer or alike. These competences are established based on speculation (SD) but are in fact used based on commitment (CD).

Table 1. Solution spaces and flow drivers

	MPDSS	CSS
Speculation driven (SD)	Establish rules	Establish competences
Commitment driven (CD)	Use rules	Use competences

The full potential of MPDSS can only be reached if customized solutions can be provided while maintaining stability in the production process. This would enable customizations to be provided repeatedly while maintaining a cost-efficient system allowing the customization to be provided at relatively low cost. Postdefined solutions (CSS) are generally intended for less cost sensitive customer segments that require a greater freedom of choice. It is a common assumption in the literature that postdefined solutions (CSS) are delivered only once. However, in practice postdefined solutions can be delivered more than once and this is usually not covered in the literature. In addition to CD/SD for solution spaces, it is therefore also important to consider if there is one delivery or multiple separated deliveries for each solution. Combining single delivery and multiple deliveries with the three categories of solution spaces as in Table 2, it is possible to identify five solution/delivery scenarios.

Table 2. Solution spaces and delivery scenarios

	SPDSS	MPDSS	CSS
Single delivery (S)	N/A	CTO/S	ETO/S
Multiple deliveries (M)	MTS (MTO)	CTO/M	ETO/M

A predefined solution from SPDSS (mass production) of which there is only one delivery is not applicable, as the risk would be too high to establish customization rules on speculation for only one future delivery. Instead, the actual solution must be delivered repeatedly, making it a standardized mass production MTS scenario (possibly MTO if the volumes are low). A solution generated from a MPDSS implies a CTO-production approach (sometimes also referred to as ATO). Such a solution sometimes has the potential to be delivered for multiple commitments and accordingly, the production approach can be divided into a single (CTO/S) or multiple delivery scenario (CTO/M). The same goes for CSS, where postdefined solutions can be delivered for both single (ETO/S) and multiple (ETO/M) deliveries.

6 Conclusions

To conclude, this research has identified different customization scenarios and accounted for flow drivers, solution spaces, delivery scenarios and product delivery strategies. Furthermore, it has introduced the notion of postdefined solutions which corresponds to individualizations and stand in contrast to predefined solutions and mass customization. The research has also identified three categories of solution spaces that refer to the set of possible solutions for customization.

Three managerial implications have been identified. First, the notion of postdefined solutions can give insights into the role of engineers in customization settings. Second, the categories of solution spaces can contribute to the understanding of both operational and strategic implications that customizations have on supplying suppliers. Third and finally, the research addresses the importance of considering delivery scenarios for both types of solution spaces. This has to a noticeable extent been overlooked in previous customization research.

The research provides a foundation for various directions of further research. The categories of solution spaces could be further refined to also cater for hybrid solutions where a combination of predefined and postdefined solutions are offered. A second avenue is to actually extend the delivery scenario aspect to not only cover multiple deliveries for a single proposal but also involve the potential of multiple proposals supporting a higher level of repetitiveness and its implications for improvement and learning.

Acknowledgements. This research was performed in collaboration with industry in the project The Whispering Game (KKS-20160210), funded by the research environment SPARK at Jönköping University and the Knowledge foundation.

References

1. Hoekstra, S., Romme, J.: Integrated Logistical Structures. McGraw-Hill, London (1992)
2. Wacker, J.G.: A definition of theory: research guidelines for different theory-building research methods in operations management. J. Oper. Manag. **16**(4), 361–385 (1998)
3. Piller, F.T.: Mass customization: reflections on the state of the concept. Int. J. Flex. Manuf. Syst. **16**(4), 313–334 (2004)
4. Salvador, F., De Holan, P.M., Piller, F.T.: Cracking the code of mass customization. MIT Sloan Manag. Rev. **50**(3), 71 (2009)
5. Engström, A., Wikner, J.: Identifying scenarios for ambidextrous learning in a decoupling thinking context. In: Lödding, H., Riedel, R., Thoben, K.-D., von Cieminski, G., Kiritsis, D. (eds.) APMS 2017. IAICT, vol. 514, pp. 320–327. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-66926-7_37

A Conceptual Framework for Stage Configuration

Bjørn Christensen(✉), Thomas D. Brunoe, and Kjeld Nielsen

Department of Materials and Production, Aalborg University,
9220 Aalborg, Denmark
BJCES@mp.aau.dk

Abstract. Increased competition for creating best business cases in the ETO and capital goods industry forces companies to provide increased variety of product configurations to match diverse operating conditions, while simultaneously reducing the cost of supply. The ETO and capital goods industry is further characterized by rapid new technology introductions, constantly setting new standards in product performance and by an external environment with frequently shifting local regulations. To remain competitive in this volatile and unpredictable situation, this paper suggests a conceptual framework enabling companies to align new product development with sales order processes in a step-wise approach using product configuration. This alignment supports a five-stage approach in committing order specifications, thereby postponing configuration decisions according to the maturity of the sales order. Moreover, the stage-wise postponement enables the management of product specifications on different aggregation levels. The committed level of specifications, targets the relevant decision-making processes in product configuration without needless over-specification of the product. The stages are (1) qualifying a sales opportunity, (2) recommending an optimal solution, (3) signing the sales offer and performing supply chain planning, (4) releasing the order for production and completing customer specific design, (5) executing production, transportation and service operations.

Keywords: Staged configuration · Conceptual framework · ETO
Capital goods

1 Introduction

Tendering and transparent bidding schemas increase competition in the Engineer-To-Order (ETO) and capital good industry. This is the result of decreased sales prices, greater expectations to product performance, as well as the demanded flexibility to adapt product offerings to customer unique and diverse requirements. This forces companies to quickly offer an increased number of variants early during new product development, and provide engineered solutions outside the standard solution space to match specific operating conditions and improve the customers' business case [1]. Providing more product variants while reducing cost has been researched by numerous scholars in the domain of mass customization. Mass customization is a business

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 101–109, 2018.
https://doi.org/10.1007/978-3-319-99704-9_13

strategy enabling manufacturers to customize product offerings to individual customer requirements at a cost near mass production [2]. In this context, business processes must be robust towards product variety and directly linked to the information generated through product selection, usually implemented using product configurators, as all information used in the subsequent processes are derived from the configuration process. In addition, the integration between configurators and the subsequent processes can have great influence on the efficiency of these processes [3].

Although mass customization was originally intended for the consumer market, the enablers of mass customization have gradually been applied in other markets as well, including capital goods and ETO oriented markets [4]. However, since most traditional configuration approaches are aimed at mass customization, they do not necessarily fit the needs of ETO and capital goods companies [5]. For instance, in ETO companies, product requirements may be gradually determined over time, implying that not all variables can be decided in an early configuration process [6]. Furthermore, in ETO supply chains, availability, sourcing, local regulations etc. may influence the configuration processes, which is also not supported in traditional product configurators [7].

To solve these challenges, Brunoe [8] developed the concept of multi-level configuration to address the management of stage-wise postponing decisions in product configuration for complex ETO business and manufacturing processes. Zeng [9] introduced the concept of staged postponement of committing order specifications. The concept supports a gradual commitment of product features and order attributes during the order delivery process. This enables gradual decision making in the value chain without creating excess and uncertain product information. Through a sales configurator prototype, Kristianto et al. [6] suggest a concept for a system-level product configurator for ETO supply chains, thereby stage-wise automating the connection between the design of a global product structure, value chain processes, and ETO design activities. Czarnecki et al. [10] propose the concept of stage configuration through cardinality-based feature modelling. In this concept, feature models have dedicated configuration choices, which specified, results in new feature models prepared for further configuration until a finished variant is achieved.

The above-mentioned research deal with specific domains within complex ETO product configuration and are thereby limited in terms of a consolidated concept, that can be applied to manage and adapt product configuration in the ETO and capital goods industry. Thus, the purpose of this paper is to address the research question; How can product configuration decisions be divided into stages to increase the support of ETO and capital goods business processes, thereby enabling stage configuration?

2 Method

To address the research question and thereby define the concept of stage configuration, empirical requirements must be captured and organized to frame an abstract approach for performing stage-wise product configuration in the ETO and capital goods industry. To collect such requirements, this paper applies a requirement engineering methodology proposed by Pandey [11], in a Danish case company, see adapted methodology in Fig. 1. The company produce capital goods for the energy sector with great diversity in market reach and the capability to configure a wide range of products to accommodate local regulations, diverse operating conditions, market fluctuation etc. The company must further be flexible to react to individual customer requirements outside the standard solution space.

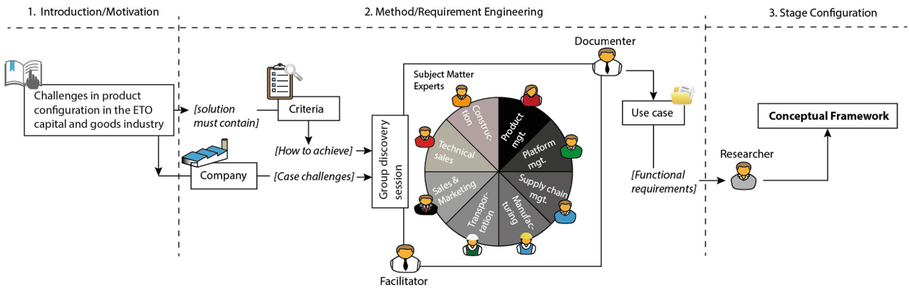


Fig. 1. Requirement engineering using group discovery sessions

To do so, the company wants to adapt a stage-wise approach to product configuration, enabling the supply chain to operate on different specification levels according to – the maturity of the sales order. Further, the company pursues this implementation through the employment of the following main criteria; (1) step-wise committing product specifications, (2) flexibility for adapting and changing product specifications, (3) autonomous interlinkage between product configuration and supply chain processes, (4) management of complex engineering knowledge, and (5) configuration of non-standard solutions. Requirement engineering is a facilitated and systematic approach, where subject matter experts join in face-to-face discussions with the purpose of consolidating requirements towards a business initiative [11]. The business initiative originates from the mentioned criteria. Subject matter experts are stakeholders, which are either impacted by or will influence the new business initiative. In this research, the discussions were divided into group discovery sessions with themes defined by senior configuration specialists, senior supply chain specialists, and chief specialists in product management, joined by different key stakeholders from the entire organization.

3 Conceptual Framework for Stage Configuration

In Fig. 2, the framework for staged configuration proposed in this paper is illustrated. The framework facilitates a stage-wise commitment of product specifications throughout the sales order process, aligning it with stages in solution space modelling for new product development. The left-hand side of the framework denotes the relevant business processes and the x-axis denotes the time. At the top of Fig. 2, the stages of solution space modelling, i.e. the development of product family models and implementation in a configuration system, are presented with corresponding gates for the stage-gate approach to new product development [12]. At the bottom, the stages in the sales order process are presented with timings for committing product specifications. Both the stages in solution space modeling and the sales order process loop between business processes until a "go" decision can be made. In each stage, information is transferred to the configurator and distributed to be applied in later stages. The timing of the sales order stages indicates when they can happen at the earliest.

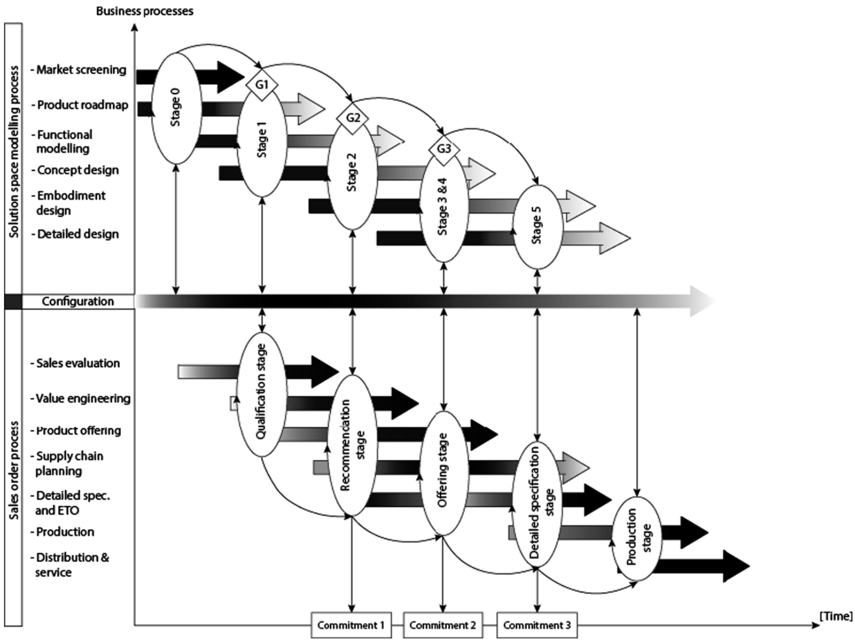


Fig. 2. Stage configuration conceptual framework.

3.1 Qualification Stage

The purpose of the qualification stage is to enable the user of the sales configurator to explore and communicate with customers on opportunities to co-create a profitable business case without having detailed knowledge of product specifications. Requirements to the product do not need to be translated to product functionalities by the customer. Instead, the customer focus on defining the boundaries for the opportunity and operating variables. Due to the high-level modelling of the solution space, the qualification stage provides an agile and fast response to key stakeholders and customers when competitiveness in tender rounds must be assessed and prioritized. Further, an engagement from both the customer and the company can be accepted without making any commitments, thereby using the configurator solely as a co-creation platform. The business processes involved are (1) Sales evaluation: Sales engineers use the configurator to access information provided from stage 0 and 1 in solution space modelling. Through the configurator, sales opportunities can be evaluated and communicated with key accounts to further investigate the fit with market and account strategies, and to clarify main risk through a risk assessment. (2) Value engineering: When the objectives and requirements are defined for an opportunity, a preliminary recommendation can be presented using the configurator. The recommendation is based on main characteristics from the solution space, performance of the configuration, cost and operating assumptions. Because the sales order process is in a very early stage, this information is somewhat uncertain. There is uncertainty in the performance of the product, the cost, and the variables defining the operating environment. (3) Product offering: Based on the recommended configuration, sales engineers seek to optimize scope and increase the value of the opportunity by offering a non-binding business case or indicative offer, with a minimum acceptable contribution margin. By assessing the offer, it should be considered if a solution outside the standard solution space provides a better business case.

3.2 Recommendation Stage

From an initial business case assessment, the customer and the company can decide to engage in further exploration of the optimal configuration, either by joining forces in tendering rounds, suppling an end-customer, or through further negotiation in a traditional B2B sales process. At this stage, value engineers can calculate the optimal configuration in detail by applying a more mature solution space, consisting of main characteristics and constraints. In order to only include relevant configurations in the calculations, the customer can further constrain the solution space by defining requirements for acceptable performance measures, investments cost, local product regulation etc. The cost of the recommended configuration is gathered from the manufacturing footprint established in Sales and Operation Planning (S&OP) and managed by supply chain planning. Not all product characteristics need to be committed in this stage. If a characteristic does not have a significant effect on product performance, cost, or is crucial in securing capacity at vendors or production sites, it can be postponed for later specification and thereby mitigate uncertainties.

The involved business processes are (1) Value engineering: In the recommendation stage, the level of detail increases as the sales order process matures. At this stage, the solution space is elaborated with additional standard and customer unique product characteristics and functionalities. This enables value engineers to reduce uncertainty and through the configurator perform simulations to optimize how multiple configurations interact and operate, resulting in one final recommendation. (2) Product offering: Due to volatile and fluctuating market conditions, the customer is often conservative in committing a complete configuration and will have to postpone some specification decisions in order to preserve the possibility to adjust the configuration according to both future technical development and changing local regulations. However, because the optimal configuration was elicited in the value engineering process, the customer can commit characteristics with high impact on performance and cost, and postpone the specification of options and auxiliary systems to be decided in the next stage, thereby mitigating future unforeseen restrictions and possibilities. (3) Supply chain planning: The sales offer and the partly specified configuration will be included in the sales forecast. From the forecast assessment, the sales forecast enters S&OP. The output is a batch-based allocation of production on a regional level, with corresponding production slots, lead-times and committed product characteristics. The indicative/binding configuration created in value engineering is part of the batch allocation and subject to further processing and specification as the sales offer mature. (4) Detailed specification and ETO: The recommendation proposed in the value engineering process can deviate from the standard product program and recommend a non-standard solution. If a non-standard solution is recommended, the company must perform feasibility studies on alternative designs and create a compatible solution, which fulfill general specifications. Based on the design, cost estimations must be added to the non-binding offer.

3.3 Offering Stage

With an accepted configuration from the recommendation stage, consisting of committed main product characteristics, the purpose of the offering stage is to move the sales offer towards an unconditional signed order through negotiations with the customer. To do so, the customer must further configure the configuration to include more characteristics and options. This must be performed to secure exact cost calculation, detailed capacity allocations and lead time commitments. Although the configuration must be specified in further details, characteristics and options with less influence on product cost and performance can be step-wisely postponed throughout the supply chain planning process. This postponement provides the customer with the flexibility to commit options in a step-wise manner according to supply chain constraints on lead times, inventory, and capacity.

The involved business processes are (1) Product offering: The configurable solution space now includes options and technical system attributes. The technical attributes define the product design to a level where it is possible to commit a final offer and a signed contract. The final offer does not have to include all product characteristics, but options requiring long lead-times must be committed together with main characteristics to comply with delivery constraints. (2) Supply chain planning: Before the company can sign an offer, decisions must be made regarding from where the product should be sourced. This is performed as the first step in the Master Production Scheduling process, where capacity slots occupied by the sales forecast is converted into sales orders with actual configurations. Production is allocated to factories based on minimizing the cost across the company´s delivery portfolio, while obeying lead time and inventory constraints. (3) Detailed specification and ETO: Beside allocating production and preparing capacity for the sales order, the design must be further matured in order to commit the exact cost of the configuration into the offer. The information needed contain 3D documentation of the main product structure, product and production drawings, design documentations, and material creation.

3.4 Detailed Specification Stage

The purpose of the detailed specification stage is to enable the customer to postpone the last product specification just in time before approval for production. By doing so, the company can limit themselves to only maintain and create variants which are going to be produced, including BoMs, design, and information enabling manufacturing.

Timing is crucial in this stage, as a too late commitment will delay the delivery date. The customer gains benefits in postponing product options just in time, and the company gains benefits in avoiding managing frequent change to the configuration.

The involved business processes are (1) Supply chain planning: Following a signed order, the detailed master planning activities have resulted in a preferred factory to source from, with corresponding and adjusted lead-times. The lead-times trigger a forced decision on whether the sales order should be approved for producing and purchasing materials or it should be postponed e.g. due to non-fulfilled contractional obligations. If the order is approved for production, a purchase requisition is generated to the factory for purchasing the materials. The product must be completely specified and configured before approving it for production. (2) Detailed specification and ETO: Before approving the sales order for production, the final design including 3D documentations and design drawings must be finalized. To achieve this, the final product variant is configured in the PLM system, generating the final related design and production BoMs. The BoMs are added to the product modules, developed in stage 3 and 4, and transferred to the factories where the BoMs are selected for production. (3) Production: When the sales order is approved for production, planned orders are converted into production and purchasing orders, depending on the make/buy setup. From these orders, the factory makes production scheduling and prepares the necessary adjustment to routings for non-standard solutions, updating relevant information in the Manufacturing Execution System.

3.5 Production Stage

(1) Production: It is not possible for the customer to make further specifications of the product in the production stage. The production processes focus on executing production and purchasing orders created in the detailed design stage. After completing production, the product in stored as finished goods inventory and from there transported to the delivery destination. Documenting the specification as-produced enables the possibility to create configuration transparency throughout the value chain. (2) Distribution and service: The vendor selected for delivering the needed materials also defines which spare parts should be managed in the service business. For capital goods, which typically include service agreements, it is not favorable to divide the purchase of the same material number on multiple vendors, because that may require more inventory, different tooling, different interfaces to other components and extensive complexity in planning regular maintenance. The vendor selection is also crucial for configuring the transport solution and determining which transport equipment is needed.

4 Conclusion and Future Work

In this paper, we present a conceptual framework for stage configuration. The framework is created based on data from a case study performed at a large capital goods company and is therefore specific to the setup of that company. The framework aligns solution space modelling in stage-gate new product development, with sales order processes by using a product configurator to facilitate the information flow between the two domains. Compared to previous research, this framework integrates the development of ETO and standard product design with value chain processes using product configuration, thereby enabling a stage-wise postponement of configuration decisions. This is further managed under the conditions of long order horizons, with frequent changes in product specifications, and extensive complexity in product architecture. By applying this conceptual framework, companies will gain benefits from specification flexibility, transparency in order uncertainties, and the capability to manage product configurations without creating excess amounts of unnecessary information impacting and demanding resources throughout the entire organization.

The framework is still conceptual and requires further research to investigate how to operationalize each stage in different contexts and industries. We suggest that the main topics of future research in stage configuration should focus on the following questions: (1) How does decisions in both the sales order process and the solution space modelling process impact each other? (2) How can partly and aggregated product specifications be applied in detailed values chain processes? (3) How can a configurator be applied to optimize the match between the operating environment and the recommended solution? (4) How can solutions outside the standard solution space be an integrated part of standard stage configuration?

References

1. Veldman, J., Alblas, A.: Managing design variety, process variety and engineering change: a case study of two capital good firms. Res. Eng. Des. **23**(4), 269–290 (2012)
2. Pine, B.J.: Mass Customization: The New Frontier in Business Competition. Harvard Business School Press, Boston (1993)
3. Salvador, F., Forza, C.: Configuring products to address the customization-responsiveness squeeze: a survey of management issues and opportunities. Int. J. Prod. Econ. **91**, 273–291 (2004)
4. Duchi, A., Pourabdollahian, G., Sili, D., Cioffi, M., Taisch, M., Schönsleben, P.: Motivations and challenges for engineer-to-order companies moving toward mass customization. In: Grabot, B., Vallespir, B., Gomes, S., Bouras, A., Kiritsis, D. (eds.) APMS 2014. IAICT, vol. 440, pp. 320–327. Springer, Heidelberg (2014). https://doi.org/10.1007/978-3-662-44733-8_40
5. Christensen, B., Brunoe, T.D.: Product configuration in the ETO and capital goods industry: a literature review and challenges (2018, in press)
6. Kristianto, Y., Helo, P., Jiao, R.J.: A system level product configurator for engineer-to-order supply chains. Comput. Ind. **72**, 82–91 (2015)
7. Lu, R.F., Petersen, T.D., Storch, R.L.: Modeling customized product configuration in large assembly manufacturing with supply-chain considerations. Int. J. Flex. Manuf. Syst. **19**(4), 685–712 (2007)
8. Brunoe, T.D.: Product family modelling for multi level configuration (2007)
9. Zeng, Q.: Staged Postponement of Committing Order Specifications. Hong Kong University of Science and Technology, Hong Kong (2007)

10. Czarnecki, K., Helsen, S., Eisenecker, U.: Staged configuration using feature models. In: Nord, R.L. (ed.) SPLC 2004. LNCS, vol. 3154, pp. 266–283. Springer, Heidelberg (2004). https://doi.org/10.1007/978-3-540-28630-1_17
11. Pandey, D., Suman, U., Ramani, A.: An effective requirement engineering process model for software development and requirements management, pp. 287–291 (2010)
12. Cooper, R.G.: Stage-gate systems: a new tool for managing new products. Bus. Horiz. **33**(3), 44–54 (1990)

Dynamic Weight Configuration of Dispatching Rule Using Machine Learning

Jong-Ho Shin[1], Chaekyo Lee[1], Sangrae Kim[2], and Jun-Gyu Kang[2](✉)

[1] Chosun University, Gwangju 61452, Republic of Korea
[2] Sungkyul University, Anyang 14097, Republic of Korea
jun-gyu.kang@sungkyul.ac.kr

Abstract. The manufacturing execution systems (MES) is one of the key elements consisting smart factory. It is responsible for shop floor control by performing managing resources, dispatching production orders, executing production orders, collecting production data, analyzing production performances, and so on. Through these functionalities, the MES aims high productivity. The dispatching in the MES helps these aims. The selection of job in manufacturing execution systems (MES) is performed by dispatching rule. The dispatching rule is composed of several factors affecting scheduling objective and constraint. In most cases, the dispatching rule is expressed as the weighted sum of factors and the weight moderates the relative importance among factors. To find optimal weight configuration requires heavy calculation burden so that it cannot adapt dynamic order changes. To solve this problem, one of machine learning algorithms is used in this study. The multi-layer perceptron learns the best weight configuration according to orders and predict the best weight configuration for new orders. The proposed method is tested by field data and proved its usefulness.

Keywords: Dispatching rule · Weight configuration · Multi-layer perceptron

1 Introduction

The manufacturing execution systems (MES) is one of the key elements consisting smart factory. As a part of the smart factory on shop floor level, the MES performs various roles such as managing resources, dispatching production orders, executing production orders, collecting production data, analyzing production performances, and so on. Through these functionalities, the MES aims to achieve high productivity and reduced cycle-time. Especially, the dispatching and executing are closely related with these aims. Therefore, lots of methodologies to improve the dispatching and execution are developed and implemented into the MES.

The most common method to improve the dispatching is to use dispatching rules in the selection of job for execution. The dispatching rule is a kind of construction heuristic algorithm to achieve optimal scheduling. The dispatching rule priorities all the possible jobs awaiting for processing in front of machine. Whenever a machine becomes available, the dispatching rule calculates priorities of all the waiting jobs and selects the highest priory job in order to process it. According to objectives and

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 110–115, 2018.
https://doi.org/10.1007/978-3-319-99704-9_14

constraints of scheduling, the dispatching rule is composed of various factors and, mostly, it is expressed as a weighted sum of these factors. The relative importance among factors are coordinated by the weights which are multiplied to the factors. In case that several factors are involved in the dispatching rule, it is difficult to find appropriate weights since the relative importance among factors is vague. To find an optimal weight configuration needs heavy calculation time. Moreover, the dynamically changing orders make job selection for optimal scheduling complicate. The weight configuration also should be modified according to the dynamic order changes. Hence, it is necessary to develop a methodology to define proper weight configuration with respect to orders.

To cover these problems, this study proposes a dynamic weight configuration methodology according to orders using machine learning technology. In the proposed methodology, the most appropriate weight configuration which can give the lowest tardiness and the highest throughput can be decided whenever order information is given. To do this, the simulation test to find the best weight configuration is performed and the found best weight configuration depending on orders through simulation is learned by the machine learning algorithm. Then, the machine learning algorithm predicts and provides the best weight configuration for the given new orders without simulation test. The proposed methodology is tested by the real manufacturing process and proves its effectiveness.

2 State-of-the-Art

Regarding scheduling problems, many research works have proposed multi-attribute dispatching rules. Korytkowski *et al.* (2013) proposed an ant colony optimization to determine dynamic multi-attribute dispatching rules to maximize job shop system performance. Yang et al. (2007) uses genetic algorithm to solve a multi-attribute combinatorial dispatching (MACD) decision problem in a flow shop with multiple processors (FSMP) environment. Rokni and Fayek (2010) applied fuzzy set theory in a multi-criteria optimization framework for industrial shop scheduling.

The scheduling performance of multi-attribute dispatching rule depends on its scaling factor values (Pfund et al. 2008). Jeong and Randhawa (2001) proposes multi-attribute dispatching rules for automatic guided vehicle. In this work, three attributes are included in the dispatching rule and additive waiting model is used to compute weights. A neural network is also used to adjust weights reflecting changes in system.

The dispatching rule using multi attribute is widely used in the field. However, the balance of relative importance remains difficult problem. Especially, the dynamic weight configuration requires heavy calculation time so that it is required to relieve this problem.

3 Multi-Layer Perceptron (MLP) for Weight Configuration

3.1 Dispatching Rule of Targeted Stage

The studied shop floor in this research produces the spark plug of automobile. The manufacturing process of the spark plug is composed of several stages. During this process, this study focuses on dispatching improvement at the assembly stage. The assembly stage has parallel machines and the waited jobs in front of machines is selected by the dispatching rule. The information required in the calculation of the dispatching rule is collected by MES and transferred from ERP system. Then, the MES calculates dispatching values of each waiting job, selects the best one, and guides operators to work with the most appropriate job.

The dispatching rule used in this stage has six factors, which is expressed as follows.

$$D = w_1 f_1 + w_2 f_2 + w_3 f_3 + w_4 f_4 + w_5 f_5 + w_6 f_6 \quad (1)$$

Each factor from f_1 to f_6 is included in order to keep due date, make group with same kind of jobs, give special priority to OEM job, avoid machine idle, follow specific machine allocation, and better throughput. For each waiting job, the dispatching rule value 'D' is calculated using Eq. (1) and the lowest value of job is selected to be processed. The value of factors are extracted from order information and the monitored data from MES. The weights from w_1 to w_2 plays important role to moderate the relative importance among factors. Depending on the characteristics of orders, these weights should be modified so as to assure the lower tardiness and high throughput.

3.2 Experimental Environment

For the development and test in this study, the simulation environment is developed and used. The following figure shows developing environment (Fig. 1).

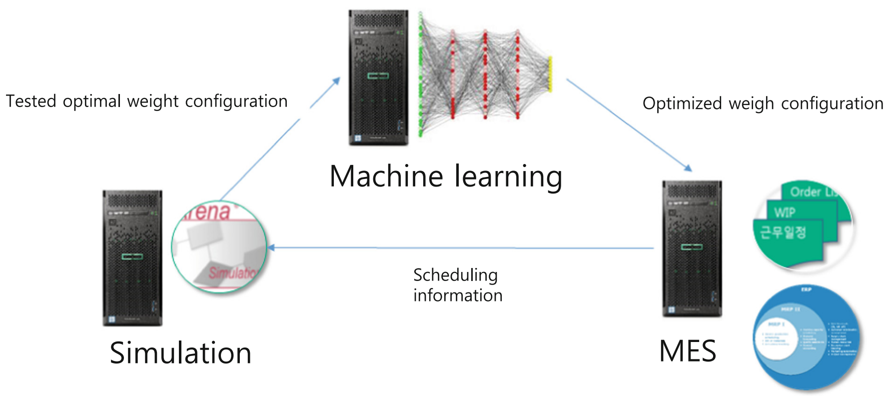


Fig. 1. Experimental architecture and data.

The information of orders required for scheduling such as orders, work-in-process (WIP), working schedule, and so on is collected and provided to simulation model. The simulation model is made by Arena simulation software and simulates the whole manufacturing process. The dispatching rule is implemented in the simulation model and used whenever each machine becomes available in order to select job. The simulation module tests all the possible combinations of weight configuration with given orders and, then, finds the best weight configuration. The best weight configuration with respect to orders is learned by machine learning algorithm. The learned machine learning algorithm is implemented to moderate weight configuration according to orders in the field.

3.3 Experiment and Result

To train machine learning algorithm, the input and output should be defined. The input of scheduling is defined by orders. The orders have various information such as product ID, processing route, order date, due date, and so on. This information is converted as a vector which has more than 270 elements. Depending the orders for scheduling, a new vector is defined and each orders can be specified. The output is extracted from simulation module. Among, the tested possible weight configurations, the best weight configuration giving lower tardiness and higher throughput is used as the output of machine learning. For training, several pairs of input and output are prepared.

The used machine learning algorithm in this study is multi-layer perceptron (MLP). The multi-layer perceptron is a class of feedforward artificial neural network and used to distinguish non-linear data and is used for classification and regression. The MLP is composed of several layers consisting of perceptrons. In this study, the MLP has 20 layers and the same number of perceptrons as input vector per each layer.

To conduct the experiment, we generate 2000 input and output sets. Among 2000 test data sets, 70% of data is used for training, 15% of them is used for validation, and the rest is used for testing. The performance of the MLP model is expressed as root mean square error (RMSE) between actual the best weight configuration by simulation and the predicted weight configuration by MLP. The MLP in this study is coded and tested using MATLAB 2017b.

The following table shows the experimental results.

Table 1. Performance comparison experiment depending on training function.

Model	Training function	RMSE	Error max	Error min
1	Levenberg-Marquardt backpropagation	0.192	1.163	0.046
2	Bayesian regularization backpropagation	0.133	1.961	0.071
3	Scaled conjugate gradient backpropagation	0.265	0.877	0.079
4	Resilient backpropagation	0.264	1.0054	0.065

As shown in Table 1, four kinds or training function are tested with the fixed MLP structure. Bayesian regularization backpropagation as Model 2 shows the lowest RMSE. However, this function generates the predicted weight configuration with large errors. The RMSE of Levenberg-Marquardt backpropagation as Model 1 has large error than Model 2 but the number of prediction values with a large error value is less.

Figure 2 shows the error histogram change with respect to MLP structure. As errors between real value and predicted value, the histogram which has more instances near zero means better MLP structure. According to Fig. 2, MLP structures having layer 10 and 30 give worse prediction result than MLP with 20 layers. In addition, when the layer is 30, the red circle shows that the RMSE of the training data becomes low. This means that, as the layers of the Model get deeper, the over-fitting phenomenon occurs so that the MLP is optimized for training data and does not predict test data well.

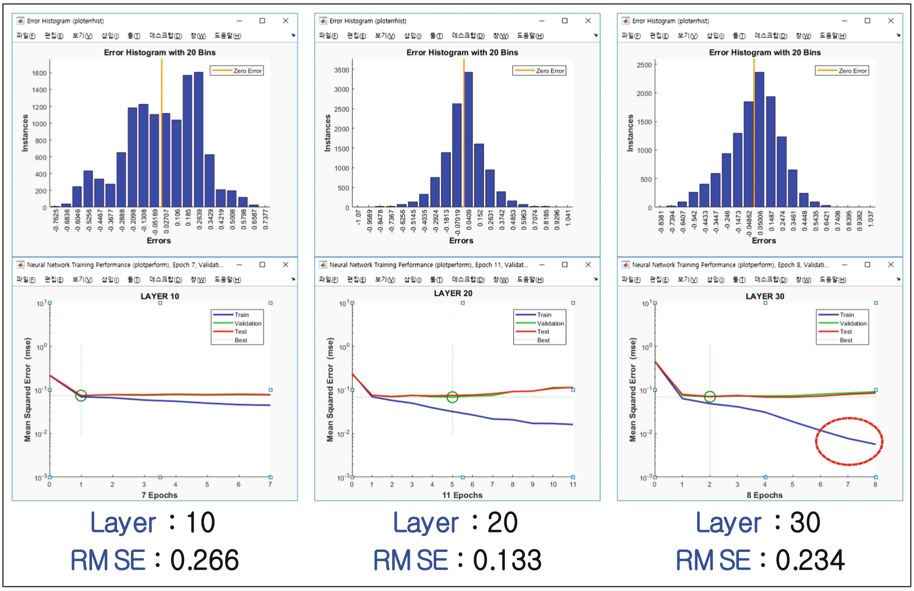


Fig. 2. Model performance comparison by layer (Color figure online)

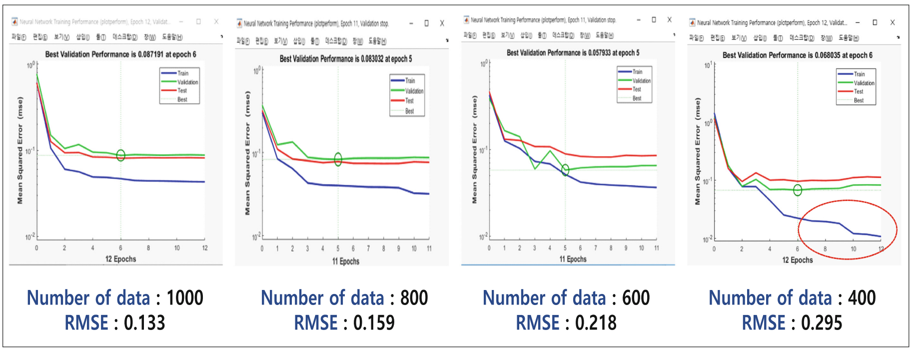


Fig. 3. Comparison of model performance by number of data

Figure 3 shows the effect of data used in machine learning. When the data is less, the over-fitting occurs and the RMSE becomes worse. Hence, to get usable result, an appropriate amount of data is needed.

4 Conclusion and Discussion

In many shop floor, the MES plays an important role to manage jobs. The dispatching rule is one of key method to priority jobs and execute job in the MES. The dispatching rule is composed of multiple factors and they are balanced by weights. In dynamic order environment, the relative importance of factor should be adapted according orders. In this study, we have proposed an intelligent methodology to configure weight of dispatching rule. The proposed methodology uses multi-layer perceptron to learn the best weight configuration. The training data for learning is generated by simulation module. The experiments based on real field problem is performed and the effectiveness of MLP is validated through experiments.

References

Jeong, B.H., Randhawa, S.U.: A multi-attribute dispatching rule for automated guide vehicle systems. Int. J. Prod. Res. **39**(13), 2817–2832 (2001)

Korytkowski, P., Rymaszewski, S., Wiśniewski, T.: Ant colony optimization for job shop scheduling using multi-attribute dispatching rules. Int. J. Adv. Manuf. Technol. **67**, 231–241 (2013)

Yang, T., Kuo, Y., Cho, C.: A genetic algorithms simulation approach for the multi-attribute combinatorial dispatching decision problem. Eur. J. Oper. Res. **176**(3), 1859–1873 (2007)

Pfund, M., Fowler, J.W., Gadkari, A., Chen, Y.: Scheduling jobs on parallel machines with setup times and ready times. Comput. Ind. Eng. **54**(4), 764–782 (2008)

Rokni, S., Fayek, A.R.: A multi-criteria optimization framework for industrial shop scheduling using fuzzy set theory. Integr. Comput.-Aided Eng. **17**(3), 175–196 (2010)

Customizations vs. Platforms – A Conceptual Approach to COSI

Jenny Bäckstrand(✉) and Martin Lennartsson

School of Engineering, Jönköping University,
Gjuterigatan 5, 55111 Jönköping, Sweden
{Jenny.Backstrand,Martin.Lennartsson}@ju.se

Abstract. In recent years, many manufacturers have experienced an increased demand for customized products and services, which requires the manufacturer to simultaneously offer both standardized and customized products. Consequently, several manufacturing strategies must be efficiently employed. These companies do not express the same prerequisites as 'pure' ETO companies since they need to be able to differentiate customized orders from standard orders, but also be able to differentiate between the manufacturing dimension and the engineering dimension of customization. Whereas standard orders can be processed with a platform approach, the customized orders contain specific requirements and information represented by 'customer-order specific information' (COSI). This paper defines and presents competitive scenarios where platform constraints are combined with COSI for efficient customizations. Implications for the approach and a path forward is discussed.

Keywords: Customizations · ETO · Customer order specific information
Product platforms

1 Background

One of the main challenges of today's manufacturing is to be able to be efficient and contributing to high effectiveness, i.e. customer satisfaction [1] while being responsive in order to comply with changing customer demand. Customer satisfaction is defined as "the extent to which a product's perceived performance matches a buyer's expectations" [2]. All companies wish they could produce exactly *what* customers want *when* they want it, since it would not only satisfy customers but also reduce cost [3] and create competitive advantage [4]. The essential problem of customization is how to produce a customized product within the company's capabilities while maximizing customer satisfaction [5] since going too far in customization would ruin efficiency but on the other hand, being too rigid in customization would risk customer satisfaction [1]. The answer to this balance between customer satisfaction and supply chain efficiency is often mass-customization or 'assemble-to-order' (ATO) strategy where standard modules are assembled according to customer requirement.

Mass-customization is generally delivered through standardized products or custom-assembly of modularized components or by product platforms [6] where the view of customized products are that they "[…] are slight variations of standard

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 116–123, 2018.
https://doi.org/10.1007/978-3-319-99704-9_15

configurations" [7] hence neglecting the product development aspect for providing 'truly' customized products [8]. Accordingly, not all products can be assembled to order or completely be built on a modular concept, some customers require customizations that affects the design of the product, and the products hence need to be engineered-to-order (ETO). Hence, moving from an era of mass-production of stock items to mass-customization of unique product; the engineer-to-order (ETO) approach is gaining in importance and many companies are finding that the engineering effort involved in the ETO typology is overwhelming their traditional systems [9].

Another issue not covered by literature but prominent at our business partners is that many manufacturers have to handle multiple manufacturing strategies [10] simultaneously; they might carry one line of high volume standard products (MTS), one line of low volume standard products (MTO) while giving the customers the possibility to adapt exiting products (CTO) or order pure customizations (ETO). These companies do not have the same prerequisites as 'pure' ETO companies that traditionally manufacture capital goods with extremely low buying frequency such as customized installations, airplanes or ships [11] since the function receiving the orders need to be able to differentiate customized orders from standard orders. Customized orders includes different information for each order and the customer requirements is represented by the 'customer-order specific information' (COSI) [12, 13]. Furthermore, they need to differentiate between the manufacturing dimension and the engineering dimension of customization, in line with Rudberg and Wikner [14].

The purpose of this paper is to define competitive scenarios where platform constraints are combined with COSI freedom for efficient customizations.

2 Methodology

To fulfil the purpose of the paper, a multi-method approach is adopted. In line with Hevner *et al.* [15] we build upon the design science method where the design cycle is initiated with the development of a conceptual framework describing the relationship between commonality and distinctiveness. The purpose of analytical conceptual research is to add new insights into traditional problems through logical relationship building. These studies usually employ case study examples to illustrate these conceptualizations [16]. The next step in the design cycle will hence be to 'assess' the framework using empirical data.

3 Theory

3.1 Manufacturing Situations

The point in the manufacturing flow when the customer order is received is referred to as the customer order decoupling point (CODP) [10]. The CODP separates the forecast-driven flow from the customer-order-driven flow in the supply chain (by Käkelä and Wikner [17] referred to as separating speculation driven activities from commitment driven activities). Hence the position of the CODP, results in different product–market situations or manufacturing situations. This is commonly referred to as make-to-stock (MTS) assemble-to-order (ATO), make-to-order (MTO), and engineer-to-order (ETO) [18]. ETO can be seen as a special case of MTO. In both cases all of the production flow is driven by actual customer orders. However, in the ETO case both the design and engineering activities are driven by customer orders, but these activities are not a part of the production flow. In that sense it is possible to separate an engineering dimension (ED) from the production dimension (PD) [19], see Fig. 1.

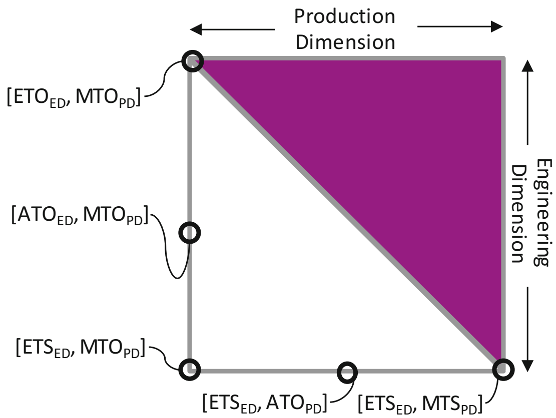


Fig. 1. The two-dimensional CODP space, based on [19]

The term ETO_{ED} is used to depict the situation when a new product is designed and engineered to order. On the other hand, the situation when a product is designed before the company gets an actual customer order could be interpreted as if the product design is already "in stock". Thereby, this situation is termed "engineer-to-stock" (ETS_{ED}). In this sense, a second dimension of decoupling points, referred to as the engineering dimension, covering the continuum between ETO_{ED} and ETS_{ED} is defined.

Furthermore, only after the customer order is received, it is suitable to adapt the product to customer requirements, i.e. to customize the product [20]. However, this does not imply that everything that is manufactured after the CODP is by default customized, but everything manufactured before the CODP should be standardized [21].

3.2 Customization

According to Lampel and Mintzberg [22] there is a continuum of customization strategies ranging from pure standardization via segmented standardization, customized standardization, and tailored customization to pure customization, see Fig. 2.

Käkelä and Wikner [17] further define three categories of solution spaces where the single-point discrete solutions space corresponds to MTS/MTO or mass-production, the multiple-point discrete solutions space corresponds to ATO or mass-customization and the continuous solutions space corresponds to ETO or individualization.

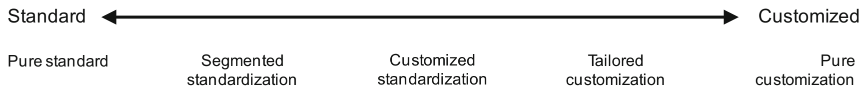


Fig. 2. The customization spectrum, based on [22]

3.3 Platforms

Robertson and Ulrich [6] argue that the platform approach is a way of achieving successful mass-customization and define a platform as "the collection of assets that are shared by a set of products". These assets are divided into the four categories; components, processes, knowledge and people and relationships. The challenge is to balance commonality and distinctiveness and still be competitive, which is also emphasized by [23, 24] including competitiveness as a key element of platform fundamentals.

3.4 Postponement

The concept of suspending differentiation activities until after the customer order is received in order to increase certainty is referred to as postponement [25]. The concept promotes that the differentiation of goods in terms of form, time, and place can be postponed to as late as possible Yang *et al.* [26].

3.5 Combining Postponement, Positioning of the CODP, and Customization

Gosling *et al.* [27] have further developed a framework by Yang and Burns [28], combining manufacturing situations [10], different postponements strategies [25], and different levels of customization [22] based on the operating processes of manufacturing (from design to distribution), see left side of Fig. 3.

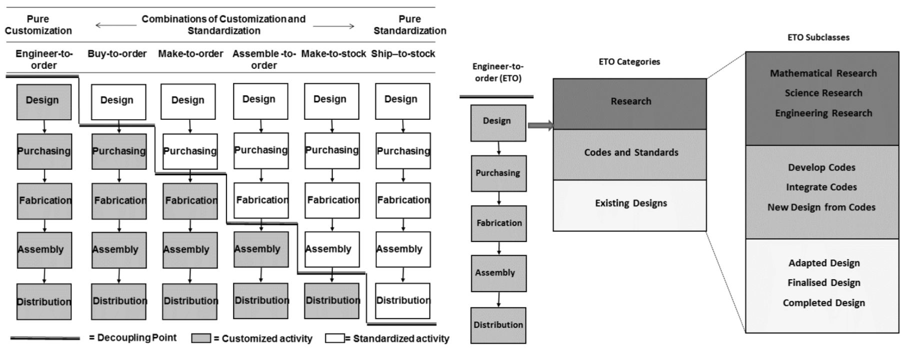


Fig. 3. Refining and unpacking the ETO supply chain, based on [22, 27, 28]

The development focuses on the ETO-situation when the customer is allowed to customize also the design phase. This phase is then broken down into nine ETO subclasses, see right side of Fig. 3. The resulting framework in Fig. 4 illustrates a spectrum of customization strategies, classifying different engineering decoupling points (EDP) thus providing a basis for considering the level of customization and standardization in design activities, as well as considering those activities that are speculative and those that are performed to a specific customer order.

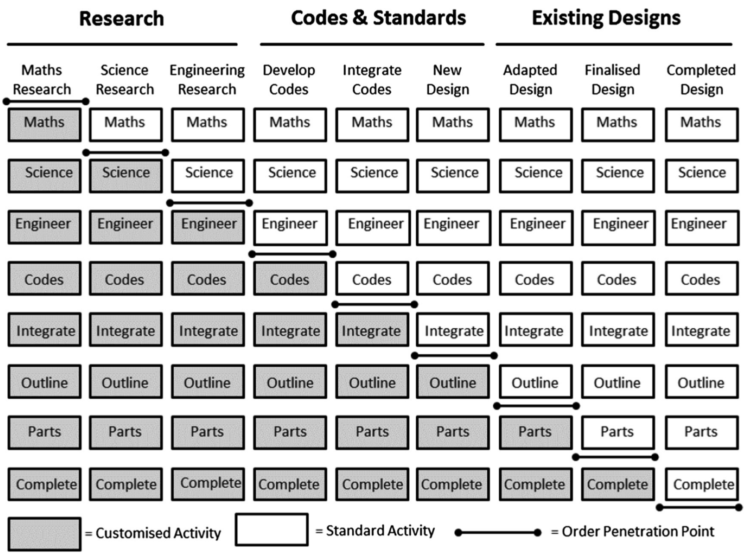


Fig. 4. The EDP-framework, based on [27]

4 Results

By extending the EDP-framework and in line with [17], the ETO scenario can be described as a continuous solution space where the customizations are individualized.

The customer order specific information (COSI) triangle in Fig. 5 hence represents the competence needed to understanding and fulfilling the customer needs [29].

In order to define scenarios where platform constraints are combined with COSI freedom for efficient customizations, five distinct scenarios are created, where scenario 1 represents the highest level of freedom and hence the unlimited possibilities for customization. Scenario 5 on the other hand represents solutions or configurations where pre-defined solutions spaces are used to fulfill the customer requirements (Fig. 6).

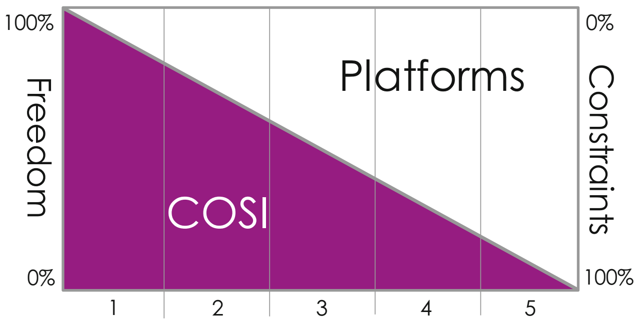


Fig. 5. The freedom-constraints continuum for customized orders

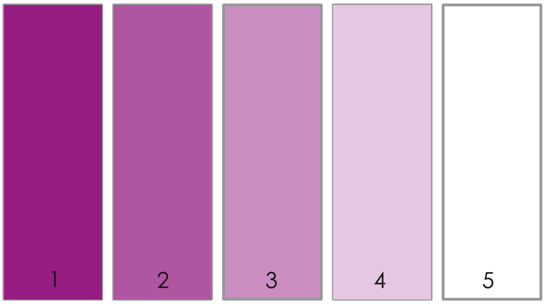


Fig. 6. Scenarios combining platform constraints with COSI freedom for efficient customizations.

5 Conclusion

A risk with using a product platform approach is the trade-off between commonality and distinctiveness [6]. Examples from the car industry shows that lower-end models can cannibalize on the higher-end models if the distinctiveness is not large enough [30] while other examples show that if post-order COSI is incorporated into the platform, then an incoherent platform will emerge. Thus, when the scenarios are validated with support from empirical data, in line with [15], there should also be a train of thought developed regarding the continuous management of both COSI and the platform. Otherwise there is a risk of different company specific scenarios shifting towards either end of the spectra. While both ends of the spectra may be hazardous for an ETO-company in terms of either, a too wide product offer, diminishing efficiency or, a slimmed down efficient production where products are made to standard but not desired on the market. Therefore, the scenarios present an opportunity for ETO-companies to assess the current product mix and, whether they are moving towards any of the ends of the spectra. Moreover, it becomes important when regarding the employment of multiple production strategies in order to cater to an array of customer segments and still maintain efficiency.

5.1 Further Research

To classify and characterize customer orders for the different scenarios, empirical data must be gathered for different ETO-oriented companies. Such data can also add information on the suggested resolution of five (5) levels regarding the anticipated number of scenarios. Additionally, on a longer horizon, in line with the previous discussion a strategy should be developed regarding the management of the scenarios. Further, it would be of interest to investigate if the suggested model is aligned with the trade-offs presented by Gosling *et al.* [27], i.e. that lead times decrease from scenario 1–5 as well as the level of uncertainty from customer requirements.

The conceptual model presented in Fig. 5 suggests that the dependency between COSI and the platform is linear. However, practitioners should be aware that in reality the relation can be both steeper or flatter depending on the products offered.

Acknowledgements. This study has been carried out within the research project The Whispering Game that is financed by the research environment SPARK at Jönköping University, the Knowledge foundation, and the six participating companies.

References

1. Heikkilä, J.: From supply to demand chain management: efficiency and customer satisfaction. J. Oper. Manag. **20**(6), 747–767 (2002)
2. Kotler, P., Armstrong, G., Saunders, J., Wong, V.: Principles of Marketing, 3rd European edn. Prentice Hall, London (2001)
3. Holweg, M., Pil, F.K.: Successful build-to-order strategies start with the customer. MIT Sloan Manag. Rev. **43**(1), 74 (2001)
4. Gosling, J., Naim, M.M.: Engineer-to-order supply chain management: a literature review and research agenda. Int. J. Prod. Econ. **122**(2), 741–754 (2009)
5. Du, X., Jiao, J., Tseng, M.M.: Understanding customer satisfaction in product customization. Int. J. Adv. Manuf. Technol. **31**(3–4), 396–406 (2006)
6. Robertson, D., Ulrich, K.: Planning for product platforms. Sloan Manag. Rev. **39**(4), 19 (1998)
7. Ulrich, K.T., Eppinger, S.D.: Product Design and Development. McGraw-Hill, New York City (2000)
8. Yassine, A., Kim, K.-C., Roemer, T., Holweg, M.: Investigating the role of IT in customized product design. Prod. Plann. Control **15**(4), 422–434 (2004)
9. Sackett, P.J., Maxwell, D.J., Lowenthal, P.L.: Customizing manufacturing strategy. Integr. Manuf. Syst. **8**(6), 359–364 (1997)
10. Hoekstra, S., Romme, J. (eds.): Integral Logistic Structures: Developing Customer-Oriented Goods Flow. Industrial Press, New York (1992)
11. Konijnendijk, P.A.: Coordinating marketing and manufacturing in ETO companies. Int. J. Prod. Econ. **37**(1), 19–26 (1994)
12. Wortmann, J.C., Muntslag, D.R., Timmermans, P.J.M. (eds.): Customer-Driven Manufacturing. Chapman & Hall, London (1997)
13. Bäckstrand, J., Lennartsson, M.: The whispering game - project plan. Jönköping University, Sweden (2016)
14. Rudberg, M., Wikner, J.: Mass customization in terms of the customer order decoupling point. Prod. Plann. Control **15**(4), 445–458 (2004)

15. Hevner, A.R., March, S.T., Park, J., Ram, S.: Design science in information systems research. MIS Q. **28**(1), 75–105 (2004)
16. Wacker, J.G.: A definition of theory: research guidelines for different theory-building research methods in operations management. J. Oper. Manag. **16**(4), 361–385 (1998)
17. Käkelä, N., Wikner, J.: Defining solutions spaces for customizations. In: Moon, I., et al. (eds.) APMS 2018. IFIP AICT, vol. 535, pp. 95–100. Springer, Cham (2018)
18. Sharman, G.: The rediscovery of logistics. Harv. Bus. Rev. **62**(5), 71–79 (1984)
19. Wikner, J., Rudberg, M.: Integrating production and engineering perspectives on the customer order decoupling point. Int. J. Oper. Prod. Manag. **25**(7), 623–641 (2005)
20. Amaro, G., Hendry, L., Kingsman, B.: Competitive advantage, customisation and a new taxonomy for non make-to-stock companies. Int. J. Oper. Prod. Manag. **19**(4), 349–371 (1999)
21. Giesberts, P.M.J., van der Tang, L.: Dynamics of the customer order decoupling point: impact on information systems for production control. Prod. Plann. Control **3**(3), 300–313 (1992)
22. Lampel, J., Mintzberg, H.: Customizing customization. Sloan Manag. Rev. **38**(1), 21–30 (1996)
23. Simpson, T.W., Siddique, Z., Jiao, R.J.: Product Platform and Product Family Design: Methods and Applications. Springer, Heidelberg (2006). https://doi.org/10.1007/0-387-29197-0
24. Meyer, M.H., Lehnerd, A.P.: The Power of Product Platforms. Simon and Schuster, New York City (1997)
25. Pagh, J.D., Cooper, M.C.: Supply chain postponement and speculation strategies: how to choose the right strategy. J. Bus. Logist. **19**(2), 13–33 (1998)
26. Yang, B., Burns, N.D., Blackhouse, C.J.: Postponement: a review and an integrated framework. Int. J. Oper. Prod. Manag. **24**(5), 468–487 (2004)
27. Gosling, J., Hewlett, B., Naim, M.M.: Extending customer order penetration concepts to engineering designs. Int. J. Oper. Prod. Manag. **37**(4), 402–422 (2017)
28. Yang, B., Burns, N.: Implications of postponement for the supply chain. Int. J. Prod. Res. **41** (9), 2075–2090 (2003)
29. Engström, A., Wikner, J.: Identifying scenarios for ambidextrous learning in a decoupling thinking context. In: Lödding, H., Riedel, R., Thoben, K.-D., von Cieminski, G., Kiritsis, D. (eds.) APMS 2017. IAICT, vol. 514, pp. 320–327. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-66926-7_37
30. André, S.: Supporting the utilization of a platform approach in the engineer-to-order supplier industry. Jönköping University, School of Engineering (2017)

Barriers and Success Factors for Continuous Improvement Efforts in Complex ETO Firms

Emrah Arica(✉), Kristoffer Magerøy,
and Marta Therese Mathisen Lall

Department of Economics and Technology Management,
SINTEF Technology and Society, Trondheim, Norway
emrah.arica@sintef.no

Abstract. This paper focuses on the factors that may influence the implementation of continuous improvement efforts, in an Engineer-to-Order (ETO) manufacturing setting. In general, one-of-a-kind production nature and temporary organizational structures of ETO firms may hinder the successful implementation of continuous improvement programmes. This study investigates this issue deeper through a single case study in a producer of offshore oil platforms and outlines the barriers and success factors for continuous improvement in ETO manufacturing.

Keywords: Engineer-to-Order · Continuous improvement
Project-based manufacturing

1 Introduction

Complex Engineer-to-Order (ETO) manufacturing is characterized by low volumes, low standardization, high engineering complexity, long lead times, and temporary project-based organizations [1]. This archetype of ETO products are the traditional "one-of-a-kind" products such as construction of ships, oil platforms, and nuclear plants [2]. High-cost countries have long been upholding a competitive advantage in complex ETO businesses with their highly skilled work force and tradition of innovating. Nevertheless, sustaining this competitive advantage is becoming more and more challenging with the increasing ability of low-cost countries to produce complex ETO products in lower costs. It has therefore become of vital importance to improve the cost efficiency of the ETO production operations for high-cost countries.

The application of lean principles to complex ETO settings is therefore receiving a significant attention in recent research studies [3]. One of the central principles of lean phenomena is "continuous improvement" which can be defined as an ongoing and systematic approach to perform improvements on products, services, and processes [4]. These improvements can be incremental or breakthrough. While research shows that most corporate change programmes fail [5], complex ETO characteristics imply even bigger challenges for continuous improvement programmes. One of a kind projects, temporary organizations and project teams, price-oriented tendering and different types of variabilities are some of the challenging characteristics of the complex ETO firms [6]. Besides the unique characteristics of the ETO industry, the human and organizational

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 124–130, 2018.
https://doi.org/10.1007/978-3-319-99704-9_16

factors that are built in long tradition of ETO/one-of-a-kind production also play an important role to hinder ETO companies for successful implementation of continuous improvement programs. This paper focuses on investigating these characteristics and factors, by posing the following research question: *How do the characteristics of ETO firms influence the successful implementation of continuous improvement efforts?* The paper is structured as follows. First, the research methodology is described, which is followed by the description of the case company. The results of the case study are presented in the next two sections: barriers and success factors of continuous improvement. The paper is concluded by the discussion and future research.

2 Research Methodology

The literature is scarce and contains mainly too general information about continuous improvement challenges for complex ETO firms. This issue necessitates conducting field-based studies that can extract deeper insights from practice to literature. As such, this study involves a single case study that is conducted to explore the barriers and success factors for continuous improvement in ETO manufacturing. Qualitative case studies enable generating deeper understanding of the phenomenon within its real-world context and generate new knowledge and theory [7]. The case company is selected from an ongoing industrial research project that focuses on developing a company-specific production improvement programme for the company. The qualitative data is mainly collected through semi-structured interviews with the following participants from the company:

1. The leader of method and technology department that is responsible for developing the detailed method for construction, and sequences of activities.
2. The responsible person for developing the main method and discipline methods for construction.
3. The responsible person for strategy, development, and improvement projects within construction.

Interview guide focused on collecting data about the continuous improvement practices and projects. Collected data was analysed by using a coding and categorization scheme that was based on the following four criteria: (i) concepts that was used often, (ii) interesting and important information, (iii) the interviewee stated explicitly that it was important, (iv) the information matches with the literature. Results of the case study is summarized below in the following sections.

3 Description of the Case Company

The case company plan and execute demanding EPCI projects. EPCI is an abbreviation for engineering, procurement, construction and installation, and is a common form of contracting agreement within offshore construction. The case company is a contractor of such projects which means they partly do the work through own labour and partly by subcontracting. The company performs several EPCI projects in parallel, where each project is in a different phase. When it comes to design, engineering, and procurement the company is dependent on an engineering partner doing most of it, while construction involve a large number of subcontractors, suppliers, staffing companies as well as own yard facilities, leaders and operators. These subcontractors also shift from one project to another. Installation could be part of project agreements or as options contracts. Hence, it is not only the product itself, the oil platform, that is highly complex, the project organization and its value chain is also highly complex. There are three types of continuous improvement projects performed in the company: (i) long-term strategic projects, (ii) medium-term investment projects, (iii) short-term improvement projects. Most of the projects are medium term investment projects that lasts from two months to one year, with different degree of involvement from departments. Continuous improvement projects consist of the following phases: initialize, investigate, design, implement, and execute the improvement. Each department is responsible for its continuous improvement projects. Most improvement suggestions are initiated top down from leaders. Leaders come up with improvement ideas, list them, and prioritize them according to a standard procedure in a meeting.

4 Barriers for Continuous Improvement in ETO

Following barriers were identified through the case study.

The Project and Construction Take the Attention and Capacity: The ongoing project and construction work may take most of the attention and capacity in the project. This is highly understandable as construction is the process where complex customer requirements are converted to an actual product and deals with strict deadlines. This can lead to lack of capacity and focus allocated for improvements even though there is a desire to perform improvements. Many obligatory works need to be done and prioritized over improvements, such as work tasks, documentation, and human resource management. Improvements give premises and savings over long term; however, people are more concerned with their existing tasks. It can be difficult to show the short-term premises of improvements.

Autonomous and Temporary Project Organization with Varying Competences and Interests of People: Different projects involve different project teams, with autonomous structures in decision making. On one hand this approach is needed to make timely and flexible decisions. On the other hand, the project teams have high authority to adjust their way of working in accordance with the project needs, which brings difficulties to transfer best practice from one project to another. In addition to this factor, people have different competences and approaches that influence the success of the project and improvements. This applies to all levels from project leaders down to supervisors. Some individuals are very open for creating best practices, while some are not so good at documenting their experiences and learnings. A common perception is that "this project is different, improvements from other projects do not apply here". As in many project organisations, this issue results in valuable tacit knowledge, while challenges exist for transferring it between projects.

The Authority, Competence, and Culture of Management Team: There is a lot of authority and power in project manager positions and those who hold such positions are used to lead large projects with high degree of self-determination and skills. When operations are not standardized, the project success is then even more dependent on project manager's personal skills. This may cause that some project managers are reluctant to standardization, as considered by some of the other employees.

Complex Organizational Structure: Matrix organization with projects and discipline departments aims at cross functional communication and flexibility to allocate resources. However, this structure causes slower execution of improvement projects and make communication more complicated. Process ownership is not straightforward. It is not certain who gets involved in an improvement project, and who is responsible for implementing the results in new projects. The outcome is that decisions must be taken higher in the hierarchy than elsewhere needed.

Local Focus and Lack of Knowledge Sharing Across the Organization and Value Chain: Many works with continuous improvement, however, some do it cross-functional. Likewise, the capability of understanding thorough processes, sequences and holistic thinking is difficult. It is easy to discuss single processes, but any discussion of the whole can meet resistance due to high complexity. An example of lack of knowledge sharing within the case company is that the improvements carried out are to a little extent mediated to project managers and bidding teams in early project planning phases. If not communicated on early stages, the improvement will likely not be implemented in the project.

Collaboration Model with Supply Chain Partners: Diverse types of collaboration models with partners can make it difficult to perform improvements. This is also dependent on the type of improvement. For example, in a joint venture model it can be a substantial challenge to change the practices. The partner can decline the use of resources and time if it is a considerable change.

5 Success Factors for Continuous Improvement in ETO

Based on the discussions with the case study participants, the following success factors were identified.

Thorough Clarification of the Scope and Implementation of the Project: Experiences from the earlier successful improvement projects indicate that people get better committed when they know more about the improvement and how it will contribute to their everyday work. It is also suggested to take incremental improvement steps rather than having big ambitions.

Culture for Organizational Support, Involvement, and Ownership: All the three interviewees emphasized that people from construction shop floor should be involved in the improvement projects, in a structured and systematic way. A possible approach to realize this factor is to choose a representative from construction, who has the ownership and responsibility of improvement projects at construction. The representative can improve the communication between departments, get feedbacks from parts, contribute to decisions, improve the involvement of shop floor, and bring improvement ideas from construction shop floor to the managerial levels. The shop floor people can see the improvement potentials, working closer to the actual workplace. This approach can also contribute to the engagement of the construction shop floor.

Prioritizing Process Improvement Before Technological Improvements: Most enterprises hurry into finding technological solutions for their process-related and managerial problems. Prior to a technological improvement, a process improvement step should be taken in a holistic manner. One of the most challenging issue in complex ETO companies is the complex organizational structure with many disciplines, departments, and groups of people that should cooperate and communicate effectively. There is much to gain in streamlining the processes and value stream in such complex organizational settings before looking at the appropriate technological support.

Training of Project Managers: The interviewees were agreed on that improvements have a higher chance to succeed with managers that have the engagement for improvement, innovations, and new technologies. Besides the process improvement initiatives, leadership improvement initiatives, such as lessons learned for leaders, should be established. The personal development programs for leaders should include the continuous improvement topic.

Easy and Intuitive Communication of Improvements: In such project-oriented ETO organizations, the project team has the authority to choose if they want to apply the improvement suggestions from other projects, as stated earlier. However, such improvement suggestions are usually written in project reports which is often overseen due to lack of time. This fact necessitates easy and intuitive solutions to communicate the improvement suggestions, such as providing a shortlist of lessons learned. The project leaders should be followed up by going through the shortlist with them and making them to take a deliberate choice to apply or not one by one. As such, the most important improvements can be communicated directly.

Improvement Supporting Partnership Model with the Value Chain Actors: Contract models with customers and partners should encourage improvement projects and leverage them through the whole value chain.

6 Experiences from Previous Improvement Projects

This chapter provides experiences from two improvement projects, exemplifying some of the barriers and success factors identified in the previous chapters. The first example can be considered as successfully implemented, while the second one has failed in terms of applying the improvement across the whole organization.

Improvement Project One – Developing an Operation Room for Monitoring and Control of Operations: In one of the large construction projects, the method and technology department has introduced a concept called operation room that aids the monitoring, coordination, and control needs of the project. The leader of the improvement project involved the construction department effectively and provided training about the operation room. There was a long planning process before the improvement project started. The scope and responsibilities were clarified to everyone. There was a reluctance from the people to implement it in the beginning, however people became more and more engaged when they saw that it was aiding their daily work tasks. The communication and feedback practices were facilitated among all levels of management and shop floor. The improvement project has received good feedback from people and were leveraged in the following projects. This case mainly exemplifies the importance of involving all relevant parties, clarifying the scope of the improvement, and intuitive communication.

Improvement Project Two – Improvement of the Work Instructions: In one of the construction projects, the company found out that the work instructions should be specified more to utilize the worker capacities better. This improvement project has also involved all relevant parties from the company. The project resulted in a good quality of work instructions. However, the instructions could not be implemented in another construction project because the manager of the other project was sceptical about the new instructions. The improved instructions were then used in another large construction project as the manager of that project saw the necessity of the detailed instructions. This case mainly exemplifies the impact of the project manager's authority and culture on implementation of improvements.

7 Conclusion

This paper discussed the barriers and success factors to perform continuous improvement projects in complex ETO manufacturing, through a single case study. While a single case study poses limitations in terms of the generalisability of these findings, it also provides deeper understanding of the studied phenomena. Hence, the results of this study should be considered to provide preliminary contributions to the limited body of knowledge in continuous improvement in ETO firms, and to the research question posed. Future research should focus on conducting more case studies in relevant complex ETO environments to validate and enrich the findings of the study, with the aim of increasing the success rate of the continuous improvement projects in ETO firms.

References

1. Semini, M., Haartveit, D.E.G., Alfnes, E., Arica, E., Brett, P.O., Strandhagen, J.O.: Strategies for customized shipbuilding with different customer order decoupling points. Proc. Inst. Mech. Eng. Part M J. Eng. Marit. Environ. **228**(4), 362–372 (2014)
2. Willner, O., Powell, D., Gerschberger, M., Schönsleben, P.: Exploring the archetypes of engineer-to-order: an empirical analysis. Int. J. Oper. Prod. Manag. **36**(3), 242–264 (2016)
3. Powell, D., Strandhagen, J.O., Tommelein, I., Ballard, G., Rossi, M.: A new set of principles for pursuing the lean ideal in engineer-to-order manufacturers. Procedia CIRP **17**, 571–576 (2014)

4. Morgan, J.M., Liker, J.K.: The Toyota Product Development System, vol. 13533. Productivity Press, New York (2006)
5. Aiken, C., Keller, S.: The irrational side of change management. McKinsey Q. **2**(10), 100–109 (2009)
6. Höök, M., Stehn, L.: Applicability of lean principles and practices in industrialized housing production. Constr. Manag. Econ. **26**(10), 1091–1100 (2008)
7. Eisenhardt, K.M., Graebner, M.E.: Theory building from cases: opportunities and challenges. Acad. Manag. J. **50**(1), 25–32 (2007)

Engineering Change Management in the Engineer-to-Order Production Environment: Insights from Two Case Studies

Natalia Iakymenko(✉), Anita Romsdal, Marco Semini, and Jan Ola Strandhagen

MTP Valgrinda, NTNU, S.P. Andersens vei 5, 7031 Trondheim, Norway
{natalia.iakymenko,anita.romsdal,marco.semini, ola.strandhagen}@ntnu.no

Abstract. Engineering changes (ECs) are part of any Engineer-to-order (ETO) project. The engineering change management (ECM) literature provides various tools, methods and best practices, and this study investigates ECM practices in the ETO production environment. Through two exploratory case studies, we identify five main ECM challenges; EC impact analysis, EC data management, internal and external collaboration and communication, and EC post-implementation review. Both companies have implemented the main ECM steps recommended in literature but there are considerable weaknesses in the execution of the post-implementation review process. More ETO cases are needed to confirm the findings and investigate how ECM tools and approaches vary by different dimensions.

Keywords: Engineering change · Change management · Engineer-to-order

1 Introduction

Engineering changes (EC) will often occur throughout the entire product life-cycle of a product [1]. ECs are modifications to structure, behaviour and function of a technical artefact that have already been released during the design process [2, 3]. Such modifications can be triggered by customers, suppliers, governmental bodies, a company's internal departments, and by market drivers such as technology. A single change often causes a series of downstream changes across the company, from design and engineering departments, to supply, procurement, manufacturing and post-manufacturing stages. The implementation of engineering change management (ECM) is argued to reduce negative impacts such as cost and time overruns [3]. ECM refers to the organization, control, and execution of ECs, and covers the entire product life cycle from the selection of a concept to the wind-down of production and support [2]. The formal ECM process usually consists of the following stages: identify change, assess its impacts, implement change, and review the process [4]. For each of the stages, a number of studies have been conducted to develop support tools and methods to predict, evaluate, and control ECs [2]. Research has found that ECM varies by industrial sector [5], suggesting that the application of tools, approaches and techniques

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 131–138, 2018.
https://doi.org/10.1007/978-3-319-99704-9_17

vary by production volume (one-offs versus mass production), the degree of customer involvement, the degree of internal and external uncertainty, and the inherent product complexity.

In the engineer-to-order (ETO) production environment, a product is designed, engineered and produced after a customer order has been received. Typical ETO products include ships, offshore platforms and power generation plants. Each product is typically unique and has a high level of complexity. In such production environments, ECs are common and inevitable, and ETO companies must be able to accommodate ECs throughout the project duration, even during physical production [6]. Efficient management of ECs is therefore critical to meet targets for cost, quality and schedule. The purpose of our study is therefore to perform an exploratory investigation into ECM in the ETO production environment. Two case studies were used to address the following research questions: (1) how is ECM currently performed in typical ETO companies?, and (2) what challenges do they face in their ECM? After a description of our research methodology, the paper briefly introduces the ECM topic in general and within the ETO production environment specifically. Then the main insights from the case studies are described, before the paper concludes with some general discussion and suggestions for further research.

2 Research Methodology

In order to investigate ECM practices and challenges in the ETO production environment, an explorative case study was performed in two Norwegian ETO companies. ECM literature was used to develop an interview guide. The questions were designed firstly to map the ECM processes of the companies and secondly to identify challenges of ECM in each stage of the ECM process. The questions covered the following ECM topics: ECM procedures and activities, documentation, communication, responsibilities, and strategies and techniques at each stage. The interview guide was used to interview three representatives from Company A (two project managers and one production planner) and two representatives from Company B (project managers). The first author carried out all the interviews, and to the extent possible, the same questions were asked to all the company representatives in order to increase the reliability of the collected data. All interviews were recorded, transcribed and sent to the respective interviewees for review and confirmation. In addition, documentation from the companies' quality systems was collected, including descriptions of change management procedures, change order forms, and change evaluation sheets.

The NVivo software was used to store and analyse the case data. Descriptive codes were assigned to data chunks to detect recurring patterns in the interviews and the company documents [7]. A narrative description of the ECM processes was created, as well as a tabular listing of ECM challenges in each company. The challenges include both specific challenges mentioned by the company representatives in the interviews and challenges identified by comparing company data to ECM literature, noting when company processes, procedures, etc. deviated from practices suggested in literature.

3 Engineering Change Management

A generalized model for ECM can be divided into four steps: identify change, assess its impacts, implement change, and review the process [4]. At the identification stage, a request for the change must be made and all necessary information about the change needs to be captured. Next, the impact of the EC must be assessed and the EC approved [4]. It is important to understand the effects of change propagation not only on engineering drawings, but also on the downstream activities of production, supply and procurement. The focus of previous research on EC propagation has mainly been on the engineering phase, without proper consideration of implications for the physical production phase or associated supply chain [8].

The implementation of an EC occurs immediately after it has been confirmed or it can be phased out [9]. The EC should be communicated to the affected functions as soon as possible and implemented by making the best use of resources [4]. One major problem in EC implementation is to ensure that only the current documentation is available to all functions and departments [10]. Finally, the EC should be reviewed to see if the initial estimations were correct, and the knowledge that was gained during the EC implementation process should be gathered and centrally stored for analysis and use in future EC implementations [4].

In addition to the four steps of the ECM model, various management strategies and techniques for efficient and effective ECM have been proposed. These strategies include establishment of cross-functional EC boards or committees for evaluation and approval of changes, establishment of formal change impact analysis, separate meetings and prioritization rules and principles for change assessment, concurrent cross-company change processes with data sharing, and monitoring and controlling of ongoing engineering changes (for more on this, see Storbjerg et al. [11]).

ECM is particularly challenging in the ETO production environment. ETO products are produced in low volumes (often volumes of one), and have a deep and wide product structure [12]. Customers are involved throughout design, engineering and manufacturing, and there are virtually no constraints on the customers with respect to incorporating their individual preferences [12], often resulting in a high number of ECs. In ETO, design, engineering, manufacturing and procurement processes are often carried out almost concurrently to adhere to the delivery schedule [13, 14]. In a make-to-stock (MTS) production environment, the EC implementation process usually takes place through a gradual product development process, where changes are accumulated and realized in the next product version [9]. This method is not applicable in the ETO environment, where ECs are introduced to the current customer order and cannot be postponed to the next order. This means that ECs can affect components that have already been manufactured, assembled, ordered from a supplier, or even delivered and installed – potentially leading to rework, demolition and even scrapping.

4 Findings from Case Studies

4.1 Introduction to Case Companies

Case company A is a Norwegian ship production company that produces offshore support vessels (OSV) and has recently added cruise vessels to its portfolio. The company acts as ship designer, shipyard, and main equipment supplier, and delivers both highly customized and so-called catalogue vessels. For catalogue vessels, design and most parts of the engineering is done before a specific customer is known. Catalogue vessels do not allow for ECs from customers so this study focused only on the company's customized vessel segment. The delivery time for customized vessel is on average two years, and one project can experience tens or even hundreds of significant ECs.

Case company B is located in Norway and belongs to a large international industrial manufacturing firm. The company produces power electronic equipment such as propulsion systems, uninterruptible power supply (UPS) systems, and low voltage distribution systems. The product complexity and customization level varies, but all of the products are customized to some extent. The delivery time varies from 16 to 24 week, and the amount of ECs is much lower than in Company A, usually not exceeding 10 ECs per project.

4.2 Company ECM Processes

Both the case companies use the ISO9000 standard to control the change management system. The companies' ECM procedures are described in their internal quality systems. In both companies, the ECM consists of the following steps: change identification, change evaluation, change order request to customer and change implementation. The EC process typically begins when the project manager is notified about a needed change. In response to the change requests, project manager makes a rough estimation of the EC. Depending on the size of the change and potential disciplines affected, relevant project team representatives are brought in to work on the EC. The team might consist of representatives from engineering, production, planning, and purchasing departments. Each team representative assesses the change impacts in terms of materials and person-hours required. Based on the output from the project team, the project manager creates a formal Change Order Request (COR) that is sent to the customer for confirmation. The COR describes the change and consequences such as delivery time and contract cost. Next, a dialogue with the customer takes place to achieve consent and a deadline for customer response is specified in the COR. If the customer replies to the COR after the deadline, the companies can re-evaluate it and send a revised version with a new deadline. This is done because engineering, production and procurement has progressed during this time, and the EC might therefore have bigger impacts than initially estimated. After the COR is confirmed by the customer, the relevant departments are notified about the EC, and drawings, material lists and production plans are updated in the respective IT systems.

The case companies apply the formal change process described above to large ECs initiated by customers. ECs caused by internal mistakes and errors in engineering and production are typically fixed locally by the affected disciplines and are consequently not documented as change orders.

4.3 Insights on Company ECM Challenges

EC Impact Analysis

It is important for a company to estimate the impacts of an EC on their activities in order to make sure that there is enough time, materials and resources to implement the change in question. Both case companies emphasized that the scope of a change has a tendency to exceed what was agreed in the COR because the ECs incur bigger consequences than initially estimated. There are several reasons for this kind of erroneous EC impact estimations. Often, ECs are introduced after production has already started. The impact of adding a part or a component to a product is relatively easy to estimate. However, when an EC requires rework and demolition, estimation gets more complicated. For example, adding a new pipe to the produced vessel is relatively easy to calculate; it will consist of labour and material costs. However, if adding a new pipe involves demolition of the work previously done by e.g. electricians and carpenters, the calculation needs to include the amount of scrapped material and the person-hours used for rework. Furthermore, in production it is often difficult to identify if delays occur due to an EC or other disturbances, such as materials shortages and delivery delays.

An EC on one part of the product can propagate to other parts and components. Engineers working on changes might overlook such propagations. When unaccounted propagations pop up during production, experienced production workers are often able to find new solutions and handle issues by themselves without involving engineers, designers or managers. Although such production worker expertise is an advantage for the company, if the information on production non-conformances is not communicated upstream, it will be lost and not accounted for the next time a similar EC occurs.

Change impact assessment in both companies is based on the personal experience and expertise of the project managers and the project teams. This means that experienced managers are able to assess the impacts of ECs fairly well. However, practice has shown that their assessments can also be incorrect, indicating that the project team would likely benefit from access to support tools and methods for making more accurate estimations.

EC Data Management

After an EC is confirmed, the relevant change documentation is updated, such as engineering drawings, project plans and schedules, activity and components lists, and production and purchasing plans. This documentation is updated in standalone IT systems sequentially, which takes time. This can have considerable consequences in the ETO production environment, where production is constantly progressing and the later production is notified about change, the more rework it will require. We also found that the engineering discipline coordinators in Company A do not have access to the IT planning tools. The project activity lists are exported from the planning tool to Excel spreadsheets. Each coordinator corrects the list according to the new EC. The planners record the updated activity lists in the planning tool manually based on the Excel lists from coordinators, leading to unnecessary information handling.

In both companies, ECs caused by mistakes and errors in engineering and production are fixed internally, and if they do not have influence on contractual specifications, they do not go through the formal ECM procedure. Hence, information about internal ECs and their impacts is not documented and not available for future use. Even though ECs caused by customer requirements are formally documented, information on such ECs changes is also not easily accessible. The project manager and project team use Excel spreadsheets and Word files to calculate impacts of ECs. These files are stored locally on the project team's PCs and are not centrally available.

Internal Collaboration and Communication
In both companies, there is usually informal communication between the team representatives. Company A often holds separate meetings to discuss EC requests, while Company B reviews changes as part of weekly status meetings. The project manager decides who will be involved in the change impact assessment process. This means that disciplines not involved in the process can receive late notification. Early notification to production and purchasing about potential ECs would enable shifting production activities to other parts of the product or postponing procurement of affected parts and components to avoid rework and scrapping.

External Collaboration and Communication
Communication with customers and suppliers in the companies is mainly done through e-mail and phone. Relationships with suppliers in the ETO production environment are usually established for the duration of one project, so large investments in integrated IT systems for communication does not make sense.

Some specific collaboration and communication problems were identified for Company A since they often do not have a direct relationship with all of their suppliers. For example, in one of the projects, the ship owner contracted Company A to design the vessel and contracted another shipyard to build the vessel. The customer also purchased the main engines before the project started. After the project started, the contract with the engine supplier was transferred to the shipyard. Consequently, Company A could only interact with the engine supplier through the shipyard to receive technical specifications when ECs occurred. Such a line of communication can delay information, leading to delays in the production and delivery of drawings.

Language barriers and lack of experience of external shipyards was also mentioned as a challenge by Company A when working on ECs. Often, vessels are only designed by Company A in one such project, the vessel was built by Chinese shipyard. When engineering drawings were updated due customer initiated ECs, it took several weeks to translate the drawings into Chinese. In addition, when design problems occurred during construction, the shipyard employees did not have the skills to solve them locally.

EC Post-implementation Review
The main purpose of the post-implementation review is to evaluate an EC after it has been implemented, assess if the initial impact estimation was correct, identify mistakes made at each ECM stage and prevent similar mistakes in the future. Both companies indicated that they do not perform post-implementation reviews of ECs. They state that it is very difficult to know the impact of an EC on production even after it has been

implemented. Tracking the exact number of person-hours and materials used in production for each ECs would require a lot of additional administrative work.

Summary of ECM Challenges in Case Companies

Table 1 summarises the challenges identified and described above.

Table 1. ECM challenges in the case companies

ECM challenge	Description	Company
EC impact analysis	EC impact analysis is mainly based on personal experience	A, B
	Difficulties in estimating impacts on production and supply chain after production has started	A, B
EC data management	Various standalone IT systems need to be updated to implement an EC	A, B
	Internal ECs are not documented as ECs	A, B
	Calculations of change impact estimations are not stored centrally	A, B
Internal coord. and comm.	Production and purchasing representatives are involved only after an EC has been approved	A, B
External coord. and comm.	Communication with customers and suppliers is done by e-mail and phone	A, B
	No direct communication with some suppliers	A
	Language barriers and lack of experience of third-party suppliers	A
EC post-implementation review	No post-implementation review process	A, B

5 Conclusions and Further Research

This study has provided some insights into ECM practices and challenges in the ETO production environment. The exploratory study showed that both case companies have implemented the main ECM steps recommended in literature into their formal ECM processes. However, both cases showed considerable weaknesses in the execution of the post-implementation review, where neither company is using available documentation on historic ECs to predict, estimate or avoid future ECs. In addition, internally generated ECs are not documented, thus the company cannot analyse their frequency, nature and impact to learn and avoid similar problems in the future. The high reliance on employees experience and expertise in the management of ECs further means that the companies are highly vulnerable to employee turnover or absenteeism. In the future, we will add more case studies to confirm the findings from the study. Further, we plan to use the dimensions of Eckert et al. [5] to analyse the cases on differences in ECM tools and approaches with regards to product complexity, degree of customer involvement, degree of internal and external uncertainty, etc.

While challenges such as data management, collaboration, impact analysis, etc. are common for all types of industries (as was shown in previous research), the propagation of ECs to the manufacturing and procurement processes is especially important in the ETO production environment. Hence, there is a need to study such propagations in more detail, as well as develop appropriate ECM tools and techniques to support in the ECM process.

References

1. Morris, A., Halpern, M., Setchi, R., Prickett, P.: Assessing the challenges of managing product design change through-life. J. Eng. Des. **27**(1–3), 25–49 (2016)
2. Hamraz, B., Caldwell, N.H., Clarkson, P.J.: A holistic categorization framework for literature on engineering change management. Syst. Eng. **16**(4), 473–505 (2013)
3. Jarratt, T., Clarkson, J., Eckert, C.: Engineering change. In: Clarkson, J., Eckert, C. (eds.) Design Process Improvement, pp. 262–285. Springer, London (2005). https://doi.org/10.1007/978-1-84628-061-0_11
4. Jarratt, T., Eckert, C.M., Caldwell, N.H., Clarkson, P.J.: Engineering change: an overview and perspective on the literature. Res. Eng. Des. **22**(2), 103–124 (2011)
5. Eckert, C., Clarkson, J., de Weck, O., Keller, R.: Engineering change: drivers, sources, and approaches in industry. In: Proceedings of ICED 2009, the 17th International Conference on Engineering Design, Product and Systems Design, Palo Alto, CA, USA, vol. 4 (2009)
6. Semini, M., Haartveit, D.E.G., Alfnes, E., Arica, E., Brett, P.O., Strandhagen, J.O.: Strategies for customized shipbuilding with different customer order decoupling points. Proc. Inst. Mech. Eng. Part M: J. Eng. Maritime Environ. **228**, 362–372 (2014)
7. Miles, M.B., Huberman, A.M., Saldana, J.: Qualitative data analysis. SAGE, Thousand Oaks (2013)
8. Iakymenko, N., Romsdal, A., Strandhagen, J.O., Semini, M.: Managing engineering changes in engineer-to-order environment: challenges and research needs. In: IFAC Symposium on Information Control Problems in Manufacturing (INCOM 2018), Italy (2018)
9. Nadia, B., Gregory, G., Vince, T.: Engineering change request management in a new product development process. Eur. J. Innov. Manag. **9**(1), 5–19 (2006)
10. Wright, I.: A review of research into engineering change management: implications for product design. Des. Stud. **18**(1), 33–42 (1997)
11. Storbjerg, S.H., Brunoe, T.D., Nielsen, K.: Towards an engineering change management maturity grid. J. Eng. Des. **27**(4–6), 361–389 (2016)
12. Stavrulaki, E., Davis, M.: Aligning products with supply chain processes and strategy. Int. J. Logist. Manag. **21**(1), 127–151 (2010)
13. Han, J., Lee, S.-H., Nyamsuren, P.: An integrated engineering change management process model for a project-based manufacturing. Int. J. Comput. Integr. Manuf. **28**(7), 745–752 (2015)
14. Bertrand, J., Muntslag, D.: Production control in engineer-to-order firms. Int. J. Prod. Econ. **30**, 3–22 (1993)

Product-Service Systems Customer-Driven Innovation and Value Co-creation

Economic Assessment of PSS Value Networks – An Algorithmic Approach

Khaled Medini[1(✉)], Xavier Boucher[1], Sophie Peillon[2], and Hervé Vaillant[3]

[1] Mines Saint-Etienne, Univ. Clermont Auvergne, CNRS, UMR 6158 LIMOS, Institut Henri Fayol, 42023 Saint-Etienne, France
{khaled.medini,boucher}@emse.fr

[2] Mines Saint-Etienne, Univ. Lyon, COACTIS EA4161, Institut Henri Fayol, 42023 Saint-Etienne, France
peillon@emse.fr

[3] Mines Saint-Etienne, Univ. Lyon, CNRS, UMR 5600 EVS, Institut Henri Fayol, 42023 Saint-Etienne, France
vaillant@emse.fr

Abstract. Product-Service Systems (PSS) are one of the business innovation drivers in terms of increasing the value for the customer and for the actors involved in PSS provision. This paper reports on a framework for assessing the economic value out of PSS provision considering a multi-actor perspective. The originality of the proposed framework is twofold: enabling an attribution of the costs (and revenues) to the actors involved in the value network, and considering the peculiarities of the use phase in cost and revenue calculation, i.e. impact of PSS contract duration and of the intensification of the product use through take-back systems.

Keywords: Customer-centric · Actors · Economic assessment Algorithmic

1 Introduction

Manufacturing industry is increasingly shaped by fierce competition and demanding customers. Subsequently, the focus on an attractive offering and on customer loyalty took the lead over traditional price war. Product-Service Systems (PSS) are one of the innovation drivers of the business in terms of increasing the value for the customer and for the actors involved in PSS provision (Baines et al. 2007; Meier et al. 2010; Beuren et al. 2013). A PSS can be seen as "*a system of products, services, networks of players and supporting infrastructure that continuously strives to be competitive, satisfy customer…*" (Goedkoop et al. 1999). The inherent PSS complexity requires a close collaboration among its stakeholders. This allows for properly defining the value transfer scheme(s) throughout the PSS provider network and with regard to the final customer (Beuren et al. 2013; Brehmer et al. 2018). Within such a process, each actor needs to have a deep understanding of the value proposition (Baldassarre et al. 2017). Consequently, PSS actors require an overview of the subsequent PSS potential benefits and

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 141–149, 2018.
https://doi.org/10.1007/978-3-319-99704-9_18

risks, particularly in terms of costs and expected revenues for each of the value network actors (Datta and Roy 2010; Estrada et al. 2017). This means that an assessment is needed to be conducted in parallel with the iterative process of defining value proposition scenarios (Medini et al. 2014; Baldassarre et al. 2017).

This paper reports on a framework for PSS economic value assessment considering a multi-actor perspective. The originality of the proposed framework lies in enabling an attribution of the costs (and revenues) to the actors involved in the value network, and considering the peculiarities of the use phase in PSS economic assessment, i.e. impact of PSS contract duration and of the intensification of the product use through take-back systems. The remainder of the paper is organised as follows: Sect. 2 provides somes insights into the literature related to PSS value network dimension and economic assessment. Section 3 reports on a framework for PSS economic assessment. Section 4 reports on an illustrative example. A brief conclusion is presented in Sect. 5.

2 Multi-actor Economic Assessment of PSSs

While PSS offers are likely to maximize the value for both customer and provider, they usually involve several actors, each supporting one or more phases of the product and/or service life cycle (Meier et al. 2010; Cavalieri and Pezzotta 2012). Thus, the value creation goes beyond a single company perspective and relies on a co-creation process involving different stakeholders to meet customers' demands while ensuring satisfactory value for each of the stakeholders (Ramaswamy and Ozcan 2014; Baldassarre et al. 2017; Smith and Wuest 2017). Authors such as Medini et al. (2014) approached the various value transfer alternative schemes through the notion of scenario. A scenario refers to an assignment of a set of activities to a set of actors to deliver a given PSS. The scenarios are defined by the PSS actors based on a set of guidelines easing the generation and filtering of the ideas (Andriankaja et al. 2018). Complementarily, Desai et al. (2017) use actors' maps to visually represent PSS actors and their interrelationships. Basically, an actors' map uses input from the stakeholders collected during workshops. Further research works about value capture and representation in multi-stakeholders perspective can be found in (Brehmer et al. 2018). Basically, these works contribute towards the definition of a common understanding of how the value will be created and captured by each of the actors. However a comprehensive value assessment requires a multiperspective analysis of the value proposition for each of the actors, and even iteratively testing the predefined scenarios (Medini and Boucher 2016; Baldassarre et al. 2017).

From an economic perspective, the assessment of the value in PSSs (particularly use oriented and result oriented (Tukker and Tischner 2006)) is hindered by several challenges including the time dimension underpinning the integration of product and service, the system view spanning across organization boundaries, the assessment object (product, service, both, etc.), and the uncertainty associated with PSS performance (Settanni et al. 2014; Estrada et al. 2017). In the literature on (use and result oriented) PSS costing, most of the publications fall under one of the following categories; conceptualization and review papers, and papers introducing (quantitative or qualitative) costing models (Settanni et al. 2014; Medini et al. 2015; Medini and Boucher 2016). In reference to the second stream, research works build on existing methods such as Life Cycle Costing (LCC), Activity Based Costing (ABC), and Game Theory, or extend the scope of existing approaches to bridge one or more of the PSS costing challenges (Settanni et al. 2014).

Although several authors underlined the need for a cross-organization perspective for assessing PSS economic value (relying on cost and revenue analysis), operational frameworks attempting to address such a need are still scarce. Further on, the time dimension is only partially addressed and the typical means for calculating costs relies on cost inference or retrospective models (i.e. derive statistically relationships between cost variables based on historical data) rather than attribution models (i.e. establish a causal link between cost variables prior to the cost estimate) (Datta and Roy 2010; Settanni et al. 2014).

3 A Framework for Systematic Economic Assessment of PSS Configurations

This section reports on an operational framework for assessing different value network configurations from an economical point view spanning over costs and revenues. The framework follows the general steps of the Through Life Costing (TLC) methodology (Settanni et al. 2014), uses Activity Based Costing (ABC) logic for calculating costs of product and service related activities, allocates the costs and revenues to the value network actors, and introduces an algorithmic approach to address PSS peculiarities during its operation. The methodological guidance underpinning the framework as well as the algorithmic approach for computing the indicators, are detailed in the following paragraphs. We follow TLC general steps to describe our framework, namely, functional unit identification, scope definition, knowledge elicitation and system visualization, and cost modelling and calculation.

Functional unit is seen as *a quantified performance of the delivery system in fulfilling its identified function*. Since the purpose of the current framework is to provide a systematic assessment without redefining the functional unit for each assessment project, the contracts are assumed to represent a comprehensive vision of the quantified performance. The contract is an agreement between two or more actors specifying obligations of parties to each other (Meier et al. 2010). Within a PSS, several contracts may occur: e.g. PSS contracts between a provider and customer, product and/or service purchasing contracts between PSS provider and suppliers.

Scope definition aims to define the boundaries of the assessment, that is, the actions performed and managed by people in organizations, the outcomes of the actions and the relationships between them (Settanni et al. 2014). Scope definition is derived from answering following questions: What PSS offerings? What required activities for PSS provision? Who is involved in the PSS?

Knowledge elicitation is based on collecting progressively and iteratively information about PSS during the (re)definition of a given offering. This process is supported by questionnaires and face-to-face meetings. Figure 1 shows a simplified overview of the cost elements that direct both the interviews and the visualisation. Visualisation consists in instantiating the concepts of Fig. 1 depending on the context. The instantiation refers to describing a given case study consistently with those concepts. In this sense, the instances provide valuable insights for the subsequent cost modelling step.

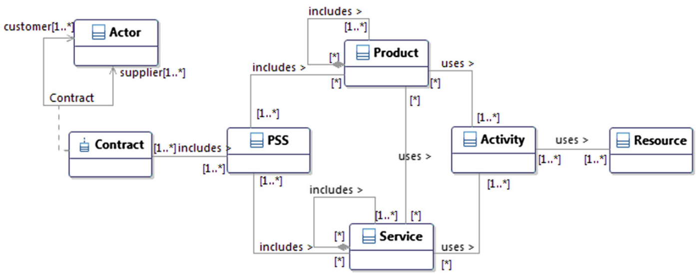


Fig. 1. Structure of cost elements

Cost and revenues modelling and calculation rely on one initial operation namely *contract assignment* and 4 main iterative and parallel operations as follows: *contract management*, *contract services execution*, *contract material requirements calculation, and component replacement*. *Contract assignment* is the initial calculation operation and it consists in assigning the available contracts (differentiated according to duration, PSS type, included services) to a demand profile specifying the number of required contracts by every single period throughout a given time horizon. *Contract management*, *contract services execution*, *contract material requirement calculation*, and *component replacement* are detailed in the following simplified 4 algorithms, which provide only a brief overview of main variables, procedures and functions (variables initialization is not presented).

Contract management is illustrated by Algorithm 1 which shows how contract status is updated according to current simulation period and to its starting date and duration; the way product are recovered upong contracts termination; and how the revenues are generated for the provider. While Algorithm 1 allows for updating current simulation period, Algorithms 2–4 are executed for each simulation period and for each ongoing contract, and are triggered by Algorithm 1.

Algorithm 1 – Contrats management

```
while (current period < simulation periods) do
    for each (contract ∈ assigned contracts) do
        if (contract start date + contract duration = current period) then
            contract ← closed contract
            if (contract product age < product life time)
                product stock ← product stock + contract product
        else if (contract start date == current period) then
            contract ← ongoing contract
            if (contract ∈ PSS contracts ) then
                update provider revenues (contract rent)
            if (contract ∈ Product oriented PSS contracts ) then
                update provider revenues (product sales, service sales)
    for each (contract ∈ ongoing contracts)
        update the age of the embeded products (product age, current period)
        current period ← current period +1
```

Contract service execution operation is reported on in Algorithm 2, which presents the way revenues and costs related to the service execution are taken into account and allocated to the service provider and customer.

Algorithm 2 – Contract services execution

```
for each (contract ∈ ongoing contracts) do
    if (ongoing contract services ≠ Ø) then
        for each (service ∈ ongoing contract services) do
            while (execution number < service frequency) do
                launch service related activities
                update cost for ongoing service provider (activities costs)
                if (service customer != service provider)
                    update revenues for service provider (service sales)
                    update costs for service customer (service provider revenues)
                executation number ← executation number +1
```

Contract material requirements calculation is illustrated by Algorithm 3 which shows how product provision is managed: the 'new' product is either taken from the stock or produced upon calculating the material requirements based on the PSS configuration (i.e. product quantity in the PSS), then the costs and revenues are generated for the product provider. Costs supported by the customer are updated based on the revenues of the provider.

Algorithm 3 – Contract material requirements calculation

```
for each (product ∈ ongoing contract) do
    if (product stock > raw requirement) then
        product stock ← product stock - raw requirement
    else
        net requirement ← raw requirement – product stock
        launch provision activity (product, net requirement)
        update costs for product provider
    if (ongoing contract ∈ sales contracts) then
        update revenues for product provider (product selling price)
        update costs for product customer (provider revenues)
```

Component replacement process is described by Algorithm 4, where both component and product are referred to by *product*. First, the remaining lifetime of the product is calculated based on the product lifetime and age (updated following Algorithm 1). Then the number of required replacements is derived from the remaining lifetime and the duration of the simulation period. Replacement cost is then calculated based on the number of replacements and unit costs. The subsequent step consists in assigning the costs and revenues to the actors (service provider, product customer), depending on wether the replacement is ensured by a service or not.

Cost updates mentioned in the above algorithms follow a bottom up procedure flowing from activity costs identification up to cost assignment to the actors. First, activity costs are calculated based on resources' unit costs and quantities, if available, or using activity unit cost provided by domain experts (aggregate value considering the resources' unit costs and quantities). The contribution of a given activity to the cost of a given actor is derived from the unit activities' costs and the required volume of the product or service. The revenues are basically calculated based on the information provided in the contract, in particular contract rent, selling price in case of product oriented PSS, and service unit cost (cost for the customer).

Algorithm 4 – Components replacement

```
for each (product ∈ ongoing contract) do
    product remaining liftime ← product lifetime – product age
    if (product remaining lifetime < simulation period) then
        replacement cost ← unit replacement cost × round up (simulation period / product remainging lifetime)
        if (product replacement ∈ services) then
            execute replacement service
            update costs for service provider (product replacement cost)
            update revenues for service provider (product replacement cost)
            update costs for product customer (service provider revenues)
        else
            update costs for product customer (replacement cost)
```

4 Illustrative Example

This section highlights briefly the operationality of the framework in terms of implementation and use. The framework is implemented into a software platform using the PHP language. In the following, we report on the use of the platform in the context of a PSS design project aiming to provide an industrial cleaning solution based on an autonomous cleaning robot and a set of services. The actors involved are a solution provider (A1), a battery system provider (A2), and a customer who is a big company in the meat transformation sector (A3). The case study was performed by the time only a prototype of the equipment is available. It is unit cost is estimated to around 100 k€. Around nine services have been identified as appropriate by the project consortium and have been included in the simulation. These services are classified into 4 main groups which are depicted in Table 1.

Table 1. Service groups and cost estimates

Service group	Cost estimates
Customer co-design	700€
Installation services	1200€
Equipment cleaning	400€
Maintenance	900€

Figure 2 presents some of the results generated in two different PSS scenario with the same example. The two upper charts report on the evolution of cumulative costs and revenues of each actor in a use oriented PSS scenario. While the two others relate to a result oriented one. The results are shown for ten simulation periods, a period refers to one year. The demand has been generated randomly with values ranging from five to fifteen contracts a year, each of which is a 5 year contract.

A2 economic assessment is quite similar over the two situations as its main role consists in selling a battery systems to A1 regardless of the PSS type. In reference to A1, both the costs and revenues are higher in the result oriented scenario. However the revenues increase is more significant than the costs increase, and the subsequent net-profit is therefore higher. This is because in the result oriented scenario, A1 takes over the cleaning activity and thus generates revenues out of it, in addition to the equipment depreciation and maintenance services. For the customer (A3) only purchasing costs are calculated as this is sufficient for him to assess the offerings. A3 costs increased significantly between the two scenarios because in the use oriented scenario A3 ensures the cleaning process and bears its related costs, while in the result oriented scenario, he pays A1 for the full cleaning service. Thus, in order to evaluate the two scenarios from A3 viewpoint, cleaning costs in the first scenario should also be considered, that is to say, only the difference between cleaning costs supported by A3 in scenario 1 and scenario 2 is required to compare these sceanrios.

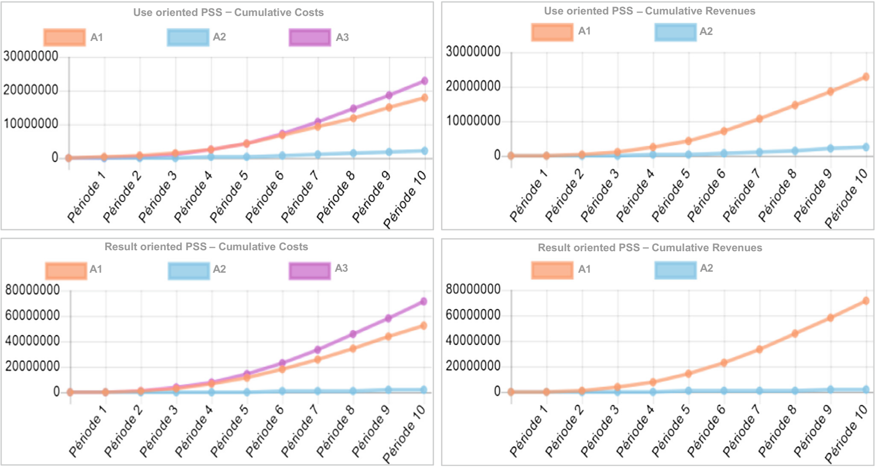


Fig. 2. An excerpt from the simulation results

5 Conclusion

The proposed framework extends existing research works (e.g. TLC, ABC) through enabling an attribution of the costs and revenues to the different actors involved in the PSS value network and considering the peculiarities of the use phase, especially product/component replacement and services included in the contract and which occur throughout the contract duration (e.g. maintenance).

Within the limit of the current paper, only an illustration of the applicability of the proposed approach has been provided. Further validation requires additional case studies with detailed data about the PSS in order to further discuss and analyse the results. A sensitivity analysis would also be very useful for assessing the robustness of the results. More general improvements of the framework include taking into account uncertainty and non-monetary metrics such as environmental ones.

References

Andriankaja, A., Boucher, X., Medini, K.: Method to design integrated product-service systems based on the extended functional analysis approach. CIRP J. Manuf. Sci. Technol. **21**, 120–139 (2018)

Baines, T.S., Lightfoot, H.W., Evans, S., Neely, A., Greenough, R., et al.: State-of-the-art in product-service systems. Proc. Inst. Mech. Eng. Part B: J. Eng. Manuf. **221**(10), 1543–1552 (2007)

Baldassarre, B., Calabretta, G., Bocken, N.M.P., Jaskiewicz, T.: Bridging sustainable business model innovation and user-driven innovation: a process for sustainable value proposition design. J. Clean. Prod. **147**, 175–186 (2017)

Beuren, F.H., Ferreira, M.G., Gitirana, G., Miguel, P.C.: Product-service systems: a literature review on integrated products and services. J. Clean. Prod. **47**, 222–231 (2013)

Brehmer, M., Podoynitsyna, K., Langerak, F.: Sustainable business models as boundary-spanning systems of value transfers. J. Clean. Prod. **172**, 4514–4531 (2018)

Cavalieri, S., Pezzotta, G.: Product-service systems engineering: state of the art and research challenges. Comput. Ind. **63**, 278–288 (2012)

Datta, P., Roy, R.: Cost modelling techniques for availability type service support contracts: a literature review and empirical study. CIRP J. Manuf. Sci. Technol. **3**, 142–157 (2010)

Desai, A., Lindahl, M., Widgren, M.: Actors and system maps: a methodology for developing product/service systems. In: Matsumoto, M., Masui, K., Fukushige, S., Kondoh, S. (eds.) Sustainability Through Innovation in Product Life Cycle Design, pp. 217–232. Springer, Heidelberg (2017). https://doi.org/10.1007/978-981-10-0471-1_15

Estrada, A., Romero, D., Pinto, R., Giuditta, P., Lagorio, A., Rondini, A.: A cost-engineering method for product-service systems based on stochastic process modelling: Bergamo's bike-sharing PSS. Procedia CIRP **64**, 417–422 (2017)

Goedkoop, M., van Halen, C., te Rielen, H., Rommes, P.: Product service systems, ecological and economic basics. Report for Dutch Ministries of Environment (VROM) and Economic Affairs (EZ), The Hague (1999)

Medini, K., Moreau, V., Peillon, S., Boucher, X.: Transition to product service systems: a methodology based on scenarios identification, modelling and evaluation. In: Camarinha-Matos, L.M., Afsarmanesh, H. (eds.) PRO-VE 2014. IAICT, vol. 434, pp. 143–150. Springer, Heidelberg (2014). https://doi.org/10.1007/978-3-662-44745-1_14

Medini, K., Boucher, X., Peillon, S., Da Silva, C.M.: Product-service systems value chain configuration – a simulation based approach. Procedia CIRP **30**, 421–426 (2015)

Medini, K., Boucher, X.: Configuration of product-service systems value networks – evidence from an innovative sector for sludge treatment. CIRP J. Manuf. Sci. Technol. **12**, 14–24 (2016)

Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems. In IPS2. CIRP Ann. – Manuf. Technol. **59**, 607–627 (2010)

Ramaswamy, V., Ozcan, K.: The Co-creation Paradigm. Stanford University Press, Stanford (2014)

Settanni, E., Newnes, L.B., Thenent, N.E., Parry, G., Goh, Y.M.: A through-life costing methodology for use in product-service-systems. Int. J. Prod. Econ. **153**, 161–177 (2014)

Smith, N., Wuest, T.: Identifying key aspects of success for product service systems. In: Lödding, H., Riedel, R., Thoben, K.-D., von Cieminski, G., Kiritsis, D. (eds.) APMS 2017. IAICT, vol. 513, pp. 231–238. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-66923-6_27

Tukker, A., Tischner, U.: Product-services as a research field: past, present and future. Reflections from a decade of research. J. Clean. Prod. **14**, 1552–1556 (2006)

Modularity in Product-Service Systems: Literature Review and Future Research Directions

Maria Stoettrup Schioenning Larsen(✉), Ann-Louise Andersen, Kjeld Nielsen, and Thomas Ditlev Brunoe

Department of Materials and Production, Aalborg University, Aalborg, Denmark
schionningm@gmail.com

Abstract. Modularity is a well-known concept that has been widely applied in both product and service design, respectively, for efficiently creating and offering variety to serve heterogeneous customer demand. However, the application of modularity in the design of a product-service system in which products and services are integrated is less addressed in previous research, despite servitization being a differentiating factor and promising strategy in many manufacturing companies. Thus, the purpose of this paper is to review state-of-the-art research on the development of modular product-service systems. The literature review assesses development methods for modular product-service systems proposed in previous research and categorizes these in regard to the development steps proposed, the research method applied, focus of the product-service systems, and the industry in which the research is conducted. Among others, the literature review concludes that research tends to focus on modular service development in the product-service system and the proposed methodologies for modular product-service system development mainly consists of four generic steps. Based on the findings of the literature review, areas of interest for future research are proposed.

Keywords: Modularity · Product-service system · Servitization
Literature review

1 Introduction

In today's fiercely competitive global market, customers are increasingly expecting offerings customized to their individual needs and preferences [1]. Manufacturing companies are therefore subject to requirements of serving highly heterogeneous demand as well as differentiating product offerings from competitors to stay competitive. As a result, many manufacturing companies have transitioned from solely producing and providing physical products towards implementing servitization strategies, where services are added to products in order to increase revenue, the value provided to customers and the customers' dependency towards the company [2, 3]. However, with the increased tendency towards customization, servitizing companies must develop further to accommodate the diverse and personalized needs of the customers in an efficient way. Consequently, customizing the product-service system (PSS) to

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 150–158, 2018.
https://doi.org/10.1007/978-3-319-99704-9_19

accommodate these needs is pertinent. Though, in the attempt to fulfill the individualized needs of customers, this often results in increased costs [1], which is undesirable. One method to tackle the paradox of customization and low costs is through modularization of the PSS [4, 5] in which the modular PSS is composed of standard modules, that are combined to meet the individualized needs of the customers [6]. Literature on modularity prescribes that companies can obtain benefits such as enhanced variety, higher flexibility, cost reductions, reduction of system complexity and improvement in product development time through modularity [7, 8]. Modularity has previously been applied in software development [9], product development [8–10], production system development [8, 9, 11–13], organization and supply chain development [8], and service development [8, 9, 14]. Though, much research is directed towards either product modularity or service modularity, whereas less research exists in relation to modularity in a PSS environment [15] i.e. a modular architecture which covers both products and services in a PSS. According to Ulrich and Eppinger [10], a property of a modular architecture is that the interactions between modules are well-defined as opposed to an integral architecture. Therefore, since PSSs consist of integrated products and services, the development of a modular PSS should consider the mutual influencing factors among products and services in a PSS [16] for which reason existing research on developing product and service modularity, respectively, cannot be applied as they do not consider the interaction between products and services in PSSs. Thus, this paper seeks to investigate the scarce state-of-the-art literature in this field of research.

The paper is structured as follows: Sect. 2 presents the applied literature search methodology, Sect. 3 reveals the findings of the literature review, Sect. 4 discusses the findings of the literature review and research gaps are emphasized. Finally, Sect. 5 concludes on the findings of the research paper and proposes viable future research directions.

2 Methodology

The objective of this paper is to review existing research on development of PSS modularity. Therefore, a literature search protocol was developed to identify previous research contributions relevant for the literature review. The search protocol is illustrated in Fig. 1.

To uncover relevant literature for the review, a systematic literature search has been conducted. In the first phase of the literature search, four block search strings were searched through five scientific databases delimited to the time span from 2008 until present. If possible, the search was restricted to concerning abstract. Only peer-reviewed as well as English-language articles were selected for further assessment. The search engine results were excluded in two steps based on a qualitative screening of the following criteria: (1) modularity in a PSS or servitization context should be the central theme, and (2) development of a modular PSS should be in focus. In the first step of the exclusion process, the papers were reviewed and excluded based on title and abstract. In the second step, the papers, which passed the initial screening, were evaluated based on a full text screening. The excluded papers primarily addressed service modularity in service business and non-modular development of PSSs. The selected papers were

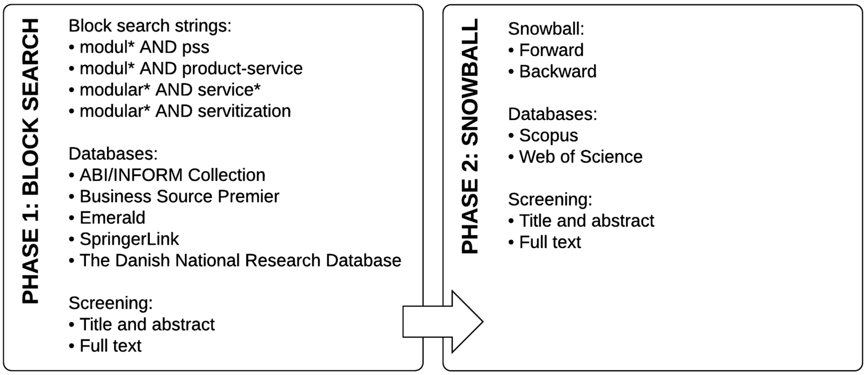


Fig. 1. Literature search protocol

afterwards subjected to a snowball approach both backward and forward in which the references in the articles identified in the first phase (backward) and references to these articles (forward) were screened. Firstly, the articles were assessed based on title and abstract. If the articles passed this screening, the full text was screened for relevance.

3 Literature Review

The literature search protocol resulted in 10 articles applicable for this paper, which were analyzed according to four parameters. Given that PSS is highly relevant in industry, the objective with the first two parameters is to clarify whether modularity of the PSS is equally relevant for all types of industries. Furthermore, it is desired to investigate to what extent state-of-the-art is linked to relevance in industry and thereby to what extent contributions from contextual understanding has been included in the development phase of the research. Therefore, the first parameter (Research's relation to industry) assesses the integration between research and industry in the applied research method, whereas the second parameter (Product/industry) assesses which product(s) or industry the research has been (A) developed towards in general and (B) validated on. To understand how modular PSSs are developed, steps in the proposed modular PSS development methodologies in the reviewed literature are identified. The third parameter (Steps in proposed modular PSS development methodology) therefore summarizes the main steps of the methods proposed for PSS modularity. This analysis is supported by an analysis of tools related to the proposed steps. Due to limited space, the results of this analysis have not been included in this paper. However, the list of tools related to the proposed methods for all reviewed articles can be obtained by inquiry to the authors. To identify the scope in the PSS of the proposed PSS development methodology and thereby identify whether the proposed development methodology considers the integration between product and services in the PSS, the focus in the PSS of the proposed method is assessed in the fourth parameter (Focus in PSS). The results are recapitulated in Table 1. The findings of the analyses are discussed in the next section.

Table 1. Results of the literature review

Ref.	Research's relation to industry	Product/industry (A) Full paper, (B) Case study	Steps in proposed modular PSS development methodology	Focus in PSS
[6]	Validated in case study	(A) None, (B) Power transformer	1. Service module partitioning "top-down", 2. Physical module partitioning "top-down", 3. Service module partitioning "bottom-up", 4. Establish the modular platform of PSS	PSS (product and services)
[17]	Validated in case study	(A) Product with many parts and advanced technologies, (B) Air-material services	1. Value demands of customers, 2. Service modularity, 3. Service configuration	Service in PSS
[18]	Validated in case study	(A) None, (B) Compressor rotor	1. Service components identification, 2. Correlation analysis for service components, 3. Service module partition	Service in PSS
[19]	Validated in case study	(A) Complex machines, (B) Machining manufacturer	1. Analysis of market and customer requirements, 2. Concept development, 3. Establish optimal business model, 4. Service module design, 5. Delivery and implement service	Service in PSS
[16]	Validated in case study	(A) None, (B) Civil aircraft manufacturer	1. Decompose functions of PSS into functional modules, 2. Simultaneous development of product modularization and service modularization based on functional modules	PSS (product and service)
[20]	Validated in case study	(A) None, (B) Power transformer	1. Collect service needs, 2. Determine service demand category, 3. Find solutions for each service need and build rough structure, 4. Configure and plan principal solution, 5. Service solution evaluation	Service in PSS
[21]	Validated in case study	(A) None, (B) Engineering machine manufacturer	1. Determine PSS family functions, 2. Modularize PSS, 3. Assign and integrate modules	PSS (product and services)
[4]	Industrial research	(A) None, (B) Elevator manufacturer	1. PSS requirements identification and analysis, 2. Technical attributes and conflicts solving, 3. PSS modularization, 4. PSS configuration and concept selection	Service in PSS

(*continued*)

Table 1. (*continued*)

Ref.	Research's relation to industry	Product/industry (A) Full paper, (B) Case study	Steps in proposed modular PSS development methodology	Focus in PSS
[22]	Validated in case study	(A) None, (B) Elevator manufacturer	1. Describe customers' needs and wants, 2. Determine level of granularity, 3. Gather service components, 4. Assign interactions, 5. Create service modules	Service in PSS
[23]	Validated in case study	(A) CNC, (B) Economical turning center	1. Physical module division, 2. Service module division, 3. Integration of modular PSS, 4. Configuration modeling of PSS	PSS (product and service)

In the reviewed literature, services are defined based on their relations and dependencies to products [4, 6, 16–19, 23]. This distinction has implied, that some authors use terms like product-service [17], product-extension service [18] and industrial service [19] when referring to services in a product-service system, whereas other authors have incorporated product and service into one, common term, e.g. integrated service product [6] or integrated service-oriented product [23]. In the remaining of this paper, all these definitions will be subject to the term service. When referring to PSS, a reference is made to those systems consisting of one product and one or more services.

4 Discussion

4.1 Development Methodology, Tools, and Focus in Product-Service System

The majority of the research concentrates on service modularity in PSS, which might be a result of researchers adapting service modularity research from a service business context to a PSS context instead of letting the interaction between products and services being the primary subject. Besides, since service modularity is a newer field of research as opposed to product modularity [15], this may also explain why researchers have focused their attention on service modularity in PSS and not modularization of both products and services. Moreover, since product modularity is more widespread, researchers may also think of product modularity as a step, which many companies have already gone through and that service modularity is considered the next step after product modularity and thereby see product and service modularity as two separate, yet consecutive development phases, just like the development of a PSS in which the products are designed first, followed by the design of services related to the products. The increased focus on services in PSS is also reflected in that the proposed methods in most of the analyzed articles mainly consist of four generic steps which are all related to service modularity in the PSS instead of both service and product modularity in the PSS. The generic steps reflect the development methodology of modular products as proposed by Ericsson and Erixon [24]. The four generic steps can be described as follows. First, customer requirements are identified to ensure that the customer's needs are met [20]. In the second step, customer requirements are translated into service specifications which can be understood and used in the design phase [4] of the service modularization, which is the third step. At last, the module structure is defined in a configuration model supporting the service configuration, which composes the fourth step.

A few articles [18, 23] analyze the company's existing services and use these as input for modularization, and thereby assume that existing services fulfill customers' needs. According to Salvador et al. [25], one of three fundamental capabilities for mass customization is to identify the attributes of which customer needs diverge, and it might therefore be questioned whether one would achieve good results with the use of existing services as input, since it might be difficult to identify the attributes where customers' needs diverge. Though, the generic method reflects the three fundamental capabilities of mass customization as proposed by Salvador et al. [25], where solution space development is reflected in the first two steps. Robust process design is considered through the third step, and choice navigation is handled in the last. This is not surprising, since the three capabilities determine a company's ability to mass customize its offerings [25] and therefore are essential for the development of a modular PSS. However, only few articles [4, 17, 20] account for all four steps and most articles therefore do not consider all three capabilities in the proposed development methods. Further research may therefore focus on methods in which all four steps are considered.

Some articles recommend tools for those steps which are included in the proposed development methods. This is not unexpected since the research field is situated between research on service modularity in service business and research on product modularity. A minority of the research [6, 23], which takes both product and service modularity into consideration combines the separate product and service modules into one common module, which reflects the integration existing between products and services in a PSS. However, the reusability of modules by applying this method is questioned, since the opportunity to reuse modules seems to disappear which entails that a new module design phase must be initiated whenever new products or services are to be developed instead of reusing existing modules, which is deemed to be one of the main benefits of modularity [7, 24, 25]. As future research area, the field of integration between product and service modularity in PSS therefore seems promising.

As seen in Table 1, most reviewed research solely focuses on one service in the PSS. In addition to this, none of the analyzed research contributions considers services across products in PSSs. Applying such narrow scope in the development of modules, decreases the reusability of modules in other cases, since the modules have been developed for one specific case. Furthermore, as research tends to focus on a single service, too much complexity might have been omitted from the development process. For instance, the production process of a service is easy to define when only one service is taken into consideration in the modularization process since the production process of the service is defined in the development of the modules, whereas the production process of a service which is combined by few, standard modules from a larger pool of modules are probably not possible to predefine as it will depend on the main goal of the customer's need to be satisfied. Broadening the scope of services in future research might therefore contribute with valuable insight in the literature.

4.2 Research's Relation to Industry, and Product/Industry Focus

A tendency exists in the literature to research related to complex products. Case studies and specifications of research have been aimed at companies producing and selling products which are considered complex in their structure such as machines, elevators, and power transformers. Thus, since services are related to products in this field of research, research on less complex product structures may benefit the research field.

The majority of the concepts proposed in literature are developed from a theoretical point of view and afterwards validated in a case study, which means that contributions from contextual understanding in the development phase of the research is missing. Therefore, future research might benefit from applying an industrial research strategy to contribute with knowledge of not only modular PSS development, but also on how these can be effectively developed in different industrial contexts.

5 Conclusions

Servitizing companies must adapt to the market's increasing expectations of customized and personalized solutions. A method to accommodate these requirements is through modularization of the company's PSS. Therefore, the aim of this research was to review existing research on developing a modular PSS. The proposed methods in reviewed research mainly consist of four generic steps which are: (1) Identify customer requirements, (2) translate customer requirements into service specifications, (3) construct services modules, and (4) setup configuration model. Though, only limited research proposes development methods in which all four steps are considered. Thus, future research should contribute with methods, which consider all four steps in a structured way including supportive tools for each step. Furthermore, a lack of research on integration between product and service modularity in a PSS context has been identified which therefore form basis for further research. Focus in existing research has been aimed at modularizing one service in a PSS and further research in PSS modularity may therefore benefit from broadening the scope and considering multiple products and services. So far, research has had a tendency towards being related to complex products and composed from a theoretical point of view. Therefore, future research may benefit from being conducted on less complex products and from an industrial point of view.

References

1. Gilmore, J.H., Pine, B.J.: Markets of One: Creating Customer-Unique Value Through Mass Customization, 1st edn. Harvard Business School Press, Boston (2000)
2. Baines, T., Lightfoot, H., Benedettini, O., Kay, J.M.: The servitization of manufacturing: a review of literature and reflection on future challenges. J. Manuf. Technol. Manag. **20**, 547–567 (2009)
3. Curiazzi, R., Rondini, A., Pirola, F., Ouertani, M.-Z., Pezzotta, G.: Process standardization to support service process assessment and re-engineering. Procedia CIRP **47**, 347–352 (2016)
4. Song, W., Sakao, T.: A customization-oriented framework for design of sustainable product/service system. J. Clean. Prod. **140**, 1672–1685 (2017)
5. Lyons, A.C., Mondragon, A.E.C., Piller, F., Poler, R.: Mass customisation: a strategy for customer-centric enterprises. In: Lyons, A.C., Mondragon, A.E.C., Piller, F., Poler, R. (eds.) Customer-Driven Supply Chains, pp. 71–94. Springer, London (2012). https://doi.org/10.1007/978-1-84628-876-0_4
6. Li, H., Ji, Y., Gu, X., Qi, G., Tang, R.: Module partition process model and method of integrated service product. Comput. Ind. **63**, 298–308 (2012)
7. Storbjerg, S.H., Brunoe, T.D.: Analysis of enabling factors in realizing modularization benefits. In: Anisic, Z., Freund, R. (eds.) Proceedings of the 5th International Conference on Mass Customization and Personalization Central Europe, MCP-CE 2012, pp. 104–111 (2012)
8. Bask, A., Lipponen, M., Rajahonka, M., Tinnilä, M.: The concept of modularity: diffusion from manufacturing to service production. J. Manuf. Technol. Manag. **21**, 355–375 (2010)
9. Voss, C.A., Hsuan, J.: Service architecture and modularity. Decis. Sci. **40**, 541–569 (2009)
10. Ulrich, K.T., Eppinger, S.D.: Product Design and Development, 6th edn. McGraw-Hill Education, London (2015)
11. Andersen, A.-L., Brunoe, T.D., Nielsen, K., Rösiö, C.: Towards a generic design method for reconfigurable manufacturing systems. J. Manuf. Syst. **42**, 179–195 (2017)
12. Bejlegaard, M., Brunoe, T.D., Nielsen, K.: Application of module drivers creating modular manufacturing equipment enabling changeability. Procedia CIRP **52**, 134–138 (2016)
13. Joergensen, S.N., Nielsen, K., Joergensen, K.A.: Reconfigurable manufacturing systems as an application of mass customisation. Int. J. Ind. Eng. Manag. **1**(3), 111–119 (2010)
14. Sundbo, J.: Modulization of service production and a thesis of convergence between service and manufacturing organizations. Scand. J. Manag. **10**, 245–266 (1994)
15. Brax, S.A., Bask, A., Hsuan, J., Voss, C.: Service modularity and architecture – an overview and research agenda. Int. J. Oper. Prod. Manag. **37**, 686–702 (2017)
16. Wang, P.P., Ming, X.G., Li, D., Kong, F.B., Wang, L., Wu, Z.Y.: Modular development of product service systems. Concurr. Eng. Res. Appl. **19**, 85–96 (2011)
17. Wang, P.P., Ming, X.G., Wu, Z.Y., Zheng, M.K., Xu, Z.T.: Research on industrial product-service configuration driven by value demands based on ontology modeling. Comput. Ind. **65**, 247–257 (2014)
18. Song, W., Wu, Z., Li, X., Xu, Z.: Modularizing product extension services: an approach based on modified service blueprint and fuzzy graph. Comput. Ind. Eng. **85**, 186–195 (2015)
19. Yu, M., Zhang, W., Meier, H.: Modularization based design for innovative product-related industrial service. In: Proceedings of 2008 IEEE International Conference on Service Operations and Logistics, and Informatics, IEEE/SOLI 2008, vol. 1, pp. 48–53. IEEE, Beijing (2008)

20. Li, H., Ji, Y., Li, Q., Yang, M., Evens, S.: A methodology for module portfolio planning within the service solution layer of a product–service system. Int. J. Adv. Manuf. Technol. **94**, 1–22 (2018)
21. Chen, D., Chu, X., Li, Y.: Applying platform design to improve product-service systems collaborative development. In: Camarinha-Matos, L.M., Afsarmanesh, H. (eds.) PRO-VE 2014. IAICT, vol. 434, pp. 107–116. Springer, Heidelberg (2014). https://doi.org/10.1007/978-3-662-44745-1_10
22. Sakao, T., Song, W., Matschewsky, J.: Creating service modules for customising product/service systems by extending DSM. CIRP Ann. – Manuf. Technol. **66**, 21–24 (2017)
23. Sheng, Z., Liu, C., Song, J., Xie, H.: Module division and configuration modeling of CNC product-service system. Proc. Inst. Mech. Eng. Part C: J. Mech. Eng. Sci. **231**, 494–506 (2017)
24. Ericsson, A., Erixon, G.: Controlling Design Variants, 1st edn. Society of Manufacturing Engineers, Southfield (1999)
25. Salvador, F., de Holan, P.M., Piller, F.T.: Cracking the code of mass customization. MIT Sloan Manag. Rev. **50**, 71–78 (2009)

Mass Customization as a Productivity Enabler in the Construction Industry

Kim Noergaard Jensen(✉), Kjeld Nielsen, and Thomas Ditlev Brunoe

Department of Materials and Production, Aalborg University, Aalborg, Denmark
knj@mp.aau.dk

Abstract. Mass customization (MC) has improved productivity in the manufacturing industry, and it may be applicable in the construction industry, even though only limited literature for the implementation of MC is present.

This paper focus on how MC as a strategy can apply to the construction industry improving the overall productivity. This is done by analyzing the three fundamental capabilities of MC to determine their potentially contribution to improving the productivity relative to the well-known phases of a construction project. Any such contribution affect directly the productivity of a company as well as whole industry, and this paper points out where to seek for improvements to increasing the productivity in the construction industry by using MC as a strategy.

Keywords: Mass customization · Productivity improvements
Construction industry · Project phases

1 Introduction

Most industries are subject to the increasing pressure coming from uncertainties of external factors like globalization, new market conditions, and new technology affecting the manufacturing and construction industry. Fulfilling customer specification through flexibly offering product families with many variants is the main market strategy [10], and customers' demands of verity in products leads to improvements of competitive advantages [20]. Fast introducing of new products have become the rule more than the exception, which may require considerable development investments and rollout costs [5]. The productivity in the Danish construction industry has doubled over fifty years, whereas the productivity of the manufacturing industry has increased six times (1966 to 2016) [9]. The same trend applies to countries in Scandinavian and Europe for the last twenty years indicating that the productivity gap is industry specific [15]. Productivity is measured as output per performed working hour for the entire economy [9].

Companies searches for initiatives meeting the competition, and the construction industry focus on lean construction, six sigma, TQM, digitalization, BIM, standardization trying to reduce costs in order to increase productivity [16, 22]. Construction productivity has been on the agenda for many decades revealing that project success depends on cost, time and quality as the most important key performance indicators. The construction industry is subject for conflicting objectives as increasing demand for

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 159–166, 2018.
https://doi.org/10.1007/978-3-319-99704-9_20

customized products, reduction of energy consumption, enhancement of cost efficiency; encouraging the construction industry to focusing on alternative improvement strategies [19]. New manufacturing philosophies, business processes reengineering, ICT, and development of production processes and correlated processes [11] are focus areas for improving the productivity. Some companies has undergone a transition process of offering customized products [24] “at a price near mass production” [3] under the strategy called mass customization [17] to meet the higher demand of product variety [1, 6, 14]. Manufacturing companies focus on modularization, prefabrication [21], configuration and changeable manufacturing [2, 25] aiming at exploiting the three fundamental capabilities of MC [21]:

1. Solution Space Development. Companies must understand their customer and their needs of products and services, by identifying valuable product attributers, and hereafter developing products and services that effectively can adapt to these individual requirements through standardization, product platforms, modularization, etc.
2. Choice Navigation. Companies must be able to guide their customer to identifying their own problems and solutions by selecting or configuring the product or service matching requirements, while minimizing complexity and burden of choice.
3. Robust Process Design. Companies must have a flexible and robust value chain design and mastering the ability to efficiently reuse or recombine existing organizational and value chain resources to fulfill the differentiated customers’ need.

The essence of MC is the focus on customers problems, the requirement and demand of products and services by offering exactly enough variety in product range so nearly everyone finds what they want [19]. The success of a MC systems depends on external and internal factors, which justifies the use of MC as a competitive strategy and supports the development of MC systems; these six success factors are: (1) Customer demand for variety and customization must exist; (2) Market conditions must be appropriate; (3) Value chain should be ready; (4) Technology must be available; (5) Products should be customizable; (6) Knowledge must be shared [23].

The construction industry is characterized as delivering complex projects at various locations exposed to unpredictable weather conditions and seasonality, which differ from to the manufacturing industry [3, 4]. The construction industry’s demand for customization in terms of individual architecture, function, quality, timeframe, environment, may seem challenging to handle with e.g. standardization, mass production, and modularization [7]. MC has not been explored in the construction industry, thus, only limited literature is currently present, but as the construction industry makes produces products with high variety, the utilization of the three fundamental capabilities of MC may result in higher productivity like in the manufacturing industry [7, 17].

This paper focuses on how the three fundamental capabilities of MC potentially can improve the productivity over the phases of a construction project in order to prioritize further improvement initiatives in the use of MC in the construction industry.

1.1 Research Questions

An initial review of MC in the construction industry revealed only a limited amount of literature dealing with MC, which indicate that further research is needed in order to understand clearly, how MC as a strategy can facilitate improving productivity of the construction industry.

Research Questions
The purpose of this paper is to analyze MC as a strategy improving the productivity of the construction industry by looking into the three fundamental capabilities of MC to clarify how they contributes to the productivity in the phases of a construction project. The research question of this paper is: RQ1: How can the three fundamental capabilities of MC potentially contribute to the productivity increase in the construction industry?

2 Methods

Research question 1 is addressed by analyzing the three capabilities of MC in order to clarify how they potentially can affect the productivity of a construction project. Entities in the value chain both individually and interconnected are of particular interest utilizing of the three fundamental capabilities of MC. Initially parties of a construction project will be defined, after which the phases of a typical construction project will be clarified in order to determine where the three fundamental capabilities of MC interfere.

3 Result

The entities involved in Architecture, Engineering and Construction (AEC) projects consist of architects, engineers, consultants and advisors; construction company and external parties working on site; suppliers of materials delivered to the site, tools and machinery applied on site; manufactures of prefabricated elements to be delivered on site; and the construction owner. Availability of standards and tools are the prerequisites for a successful cooperation between entities, and therefore the foundation for applying MC improving the productivity. Any construction project, can only be achieved by handling the customer's needs as an integrated process across the design and construction phases of a project involving entities of the value chain, which seems possible by using ICT and available standards (BIM/IFC) [15].

Construction projects are often structured individually from project to project, and from company to company seen from a management perspective. Nevertheless, there seems to be a certain conformity about four overall project lifecycle phases; design [D], construction [C] and operations [O], and demolition [D]. These phases may be subdivided into sub-phases, and further subdivided into activities, sub-activities and tasks, etc. However, this paper deals with the following six phases: ***(1) plan***, involving management activities like planning, monitoring, leadership, etc., starting the project and evolving during the entire project; ***(2) design***, including product development activities concerning architecture and engineering, ***(3) construct***, comprising physical activities taking place off-site and on-site related to manufacturing, assembly, montage; ***(4) hand-over***, dealing with activities associated with reviewing project deliverables meeting agreed contract; ***(5) maintenance***, relating to daily operations/maintenance of the product; ***(6) demolition***, is the final stage of a product including activities related to destruction and reusing. Some phases overlaps each other, and especially the planning phase seems to interfere with all phases during the entire project from cradle to grave as an iterative process changing character during the project lifecycle.

The three fundamental capabilities of MC will be mapped accordingly to these six phases clarifying where MC has a positive or negative contribution to productivity.

3.1 Solution Space Development (SSD)

As a part the Solution Space Development (SSD) a mass customizer must identify the needs of its customer, and define where the customers are different and where they care about the differences, e.g. product attributers clarifying what to offer. The foundation is a knowledgebase of preferences, needs, desires, satisfaction, motives of the potential customers and users of the products or services. However, this may seem as a fundamental change for ETO companies as it may limiting the product offerings to customers, which indeed should not be the case as the knowledgebase is dynamic and adaptable always trying to reflect the needs of the customers. The essential part is to understand the needs of the customers and to decide, whether and how these are being meet.

SSD includes three approaches to development capabilities: “Innovation tool kits”, “Virtual concept testing”, and “Customer experience intelligence” [21]; which are considered as guidance direction and not a limitation to the work related to clarifying the solution space that companies want to develop and deliver to the customers.

“Innovation tool kits, implies the software that enables large pools of customers to translate their preferences into unique product variants, allowing each customer to highlight possibly unsatisfied needs” [21]. Such solutions or toolkits will obviously help companies and customers strengthen their collaboration opportunities about project deliverables focusing their effort on correct fulfillment of needs, quality issues, and limitation of reworks caused by misunderstandings of design and requirements specifications. Therefore, this approach would potentially have a productivity impact on the phases: plan, design, construct.

“Virtual concept testing, covers an approach for efficiently submitting scores of differentiated product concepts to prospective customers via virtual prototype creation and evaluation” [21]. For the majority of the products developed by AEC projects are possible to be virtual illustrated and evaluated beforehand to strengthen the customer experience of the intended project deliverables increasing clarity of design and reducing misunderstandings leading to rework. Therefore, this approach would potentially influence the tasks related to the phases: plan, design, construct, and hand-over in terms of reducing hours spent.

“Customer experience intelligence, represent a tool for continuously collecting data on customer transactions, behaviors or experiences and analyzing that information to determine customer preferences” [21]. Establishing of such tools are evolving due to present data gathering and analytic possibilities, sensor technology for capturing data, and the increasing usage of Internet of Things (IoT). However, data gathering initiatives about the usage of the product as a whole or in terms of modules, equipment will increase knowledge about user behaviors or experiences to be used in terms of strengthen the collaboration process aiming at making better products at a lower time consumption leading to a potentially productivity increase in the phases: plan, design, and construct.

3.2 Robust Process Design

Robust Process Design (RPD) is the firms' capability reusing existing organizational and value-chain resources to deliver customer solutions with high efficiency and reliability, so increased variability in customers' requirements will not significantly influence the operational efficiency [18]. For ETO companies this include integration of business processes related to the engineering and the production value-chain involving internal and external entities of the supply chain. As MC is a value based concept, it is essential to integrate across the value chain to achieve full effect of MC [12, 23]. Thus, willingness and cooperation possibilities across the value chain is one of the success factors of application of MC, therefore standards and tools applicable within the construction industry is of particular interest. RPD cover three approaches to development capabilities: "Flexible automation", "Process modularity", and "Adaptive human capital" [21] considered as guidance issues rather than limitation of the work related to creating robust processes used to develop and deliver products to customer.

"Flexible automation, includes automation that is not fixed or rigid and can handle the customization of tangible or intangible goods" [21]. Each project is subject to a series of serial and parallel processes taking place in all phases without exception, e.g. activities necessary for making the design, the requirement specifications, and in general ensuring other mutual clearance of interests, or fulfilling manufacturing processes taking place on-site or off-site. Therefore, flexibility in processes and atomization of processes are enablers of customization in order to reducing time consumption potentially leading to a productivity increase in all of the six project phases.

"Process modularity, covers segmenting of existing organizational and value-chain resources into modules that can be reused or recombined to fulfill differentiated customers' needs" [21]. Any attempt to modularize whether it covers organizational or value-chain resources being able to efficiently handle customization and variation will provide readiness for serving customers' needs efficiently and thereby increase the productivity. Prefabrication has become popular mostly because of its ability to improve the productivity in terms e.g. increasing quality, decreasing cost, and accelerating speed of delivery, etc. Dedicated organizational flexible teams applied inside or outside the company are enablers of bringing key competences in play in terms of utilizing the right skills at the right time. The same advantages appears when rethinking the value chain into 'flexible modules' to be combined in order to serve customers' needs the most efficient way. Therefore, this approach indicate a productivity connection to primary the following phases: plan, design, and construct.

"Adaptive human capital, is about developing managers and employees who can deal with new and ambiguous tasks" [21]. Humans are the intellectual capital of the company ensuring any actions to happen and making the right decisions at the right time. Employees in the construction industry are used to deal with new and ambiguous tasks as this has always been the nature of the construction industry. However, the construction industry seems conservative in many ways, especially in terms of adapting new ways of doing things in particularly coming from the manufacturing industry like the MC strategy. Nevertheless, this adaptive attitude is a necessity to bring into play to successful implementing MC or parts of it for harvesting the productivity gains. Therefore, it can be argued that this approach apply indirectly to all phases.

3.3 Choice Navigation

Choice Navigation (CN) is about supporting customer in identifying their needs, specifying the wanted solution using simple, effective and user-friendly product configuration system [13]. CN aims at finding the right level of choices as to many options can reduce customer value instead of increasing it [8] leading to postponing buying decision. The increasing development of new efficient and user-friendly IT solutions supporting the users in their decision-making process will optimize ETO companies' opportunities of presenting their solution space, which is beneficial for the customers decision making process, and for the ETO companies' transition process towards a higher ratio of the three MC capabilities. CN can be divided into three approaches to development capabilities: "Assortment matching", "Fast-cycle, trial-and-error learning", and "Embedded configuration" [21], and these approaches are considered as guidance and not necessary representing all issues related to CN, also termed product configuration, as basis for taking in and handling new orders efficiently.

"Assortment matching, deals with software matching characteristics of an existing solution space (that is a set of options) with a model of the customer's needs and then makes product recommendations" [21]. Product configuration tools has evolved towards intuitive and user-friendly solutions enabling interactive user-dialog specifying and creating unique product configurations done in compliance with the solution space. Implementing such solutions require enormous effort, but the time savings are tremendous as it helps the customer and parties in the value chain during the entire configuration process potentially leading to e.g. reducing time consumption in the design phase, increasing quality, and reducing rework, thus it has positive effect on the productivity in the phases: plan, design, and construct.

"Fast-cycle, trial-and-error learning, is an approach that empowers customers to build models of their needs and interactively test the match between those models and the available solutions" [21]. Many customers have a strong idea of what they want, but having investigating possibilities enriching them during the clarifying process as they can play around with different options evaluating their needs. Such tools has a positive productivity effect in the phases: plan, design, and construct, as it takes the customer to a higher level of understanding, and clarifying their needs minimizing design misunderstandings e.g. saving time, increasing quality, and reducing rework.

"Embedded configuration, deals with products that "understand" how they should adapt to the customer and then reconfigure themselves accordingly" [21]. Many manufactures of homes and interior designers has created reconfigurable solutions in a way to accommodating many different purposes meeting various customers' needs.

Such flexible and changeable approaches extend the usage and the functionality, and thereby the value of the products, since the customer may relate to multiple uses of the product. This may strengthen the competition position as it may lead to an easier decision making process for the customer, thus such products seems productivity neutral unless the embedded configuration concept allows fewer products.

Figure 1 summarizes how the approaches to development capabilities of the three capabilities of MC [21] affect the productivity in the six phases of a construction project.

		Construction Industry - Project Phases					
Capabilities of MC	**Approaches to development capabilities**	**Plan**	**Design**	**Construct**	**Hand-over**	**Maintenance**	**Demolition**
Solution Space Development	Innovation Tool Kits	X	X	X			
	Virtual Concept Testing	X	X	X	X		
	Customer Experience Intelligence	X	X	X			
Robust Process Design	Flexible Automation	X	X	X	X	X	X
	Process Modularity	X	X	X			
	Adaptive Human Capital	X	X	X	X	X	X
Choice Navigation	Assortment Matching	X	X	X			
	Fast-cycle, trial-and-error learning	X	X	X			
	Embedded Configuration						

Fig. 1. Mapping capabilities approached to project phases

4 Conclusion

This paper deduce a potentially productivity connection from each of the development approaches of three fundamental capabilities of MC into the six phases of a construction project (Fig. 1). Even though, it does not clarify how to harvest productivity gains it indicate that MC is applicable in the construction industry and it justify that further work along with the three capabilities of MC is beneficial to carry out.

References

1. Aigbedo, H.: A note on parts inventory and mass customization for a two-stage JIT supply chain with zero-one type of bills of materials. J. Oper. Res. Soc. **60**(9), 1286–1291 (2009)
2. Andersen, A., Brunoe, T.D., Nielsen, K., et al.: Towards a generic design method for reconfigurable manufacturing systems - analysis and synthesis of current design methods and evaluation of supportive tools. J. Manuf. Syst. **42**, 179–195 (2017)
3. Batchelor, R.: Henry Ford, Mass Production, Modernism, and Design, vol. 1. Manchester University Press, Manchester (1994)
4. Bohnstedt, K.D.: Enabling facilitation of mass customization via partnering in the construction industry. In: Brunoe, T.D., Nielsen, K., Joergensen, K.A., Taps, S.B. (eds.) Proceedings of the 7th World Conference on Mass Customization, Personalization, and Co-Creation (MCPC 2014), Aalborg, Denmark, February 4th - 7th, 2014. LNPE, pp. 179–188. Springer, Cham (2014). https://doi.org/10.1007/978-3-319-04271-8_16
5. Chryssochoidis, G.M., Wong, V.: Customization of product technology and international new product success: mediating effects of new product development and rollout timeliness. J. Prod. Innov. Manag. **17**(4), 268–285 (2000)

6. da Silveira, G.J., Fogliatto, F.S., Fendyur, A.: Is mass customization a global phenomenon? Empirical evidence from an exploratory study, January 2012
7. Dean, P., Tu, Y., Xue, D.: An information system for one-of-a-kind production. Int. J. Prod. Res. **47**(4), 1071–1087 (2009)
8. Desmeules, R.: The impact of variety on consumer happiness: marketing and the tyranny of freedom. Acad. Mark. Sci. Rev. **2002**, 1 (2002)
9. dst.dk: Dansk Statistik (2013). Www.Dst.Dk
10. ElMaraghy, H., Schuh, G., ElMaraghy, W., et al.: Product variety management. CIRP Ann. Manuf. Technol. **62**(2), 629–652 (2013)
11. Fagerberg, J.: Technological progress, structural change and productivity growth: a comparative study. Struct. Change Econ. Dyn. **11**(4), 393–411 (2000)
12. Fogliatto, F.S., da Silveira, G.J.C., Borenstein, D.: The mass customization decade: an updated review of the literature. Int. J. Prod. Econ. **138**, 14–25 (2012)
13. Franke, N., Piller, F.: Value creation by toolkits for user innovation and design: the case of the watch market. J. Prod. Innov. Manag. **21**(6), 401–415 (2004)
14. Haug, A., Ladeby, K., Edwards, K.: From engineer-to-order to mass customization. Manag. Res. News **32**(7), 633–644 (2009)
15. Jensen, K.N., Nielsen, K., Brunoe, T.D., Larsen, J.K.: Productivity, challenges, and applying mass customization in the building and construction industry. In: Hankammer, S., Nielsen, K., Piller, F., Schuh, G., Wang, N. (eds.) Customization 4.0. Springer Proceedings in Business and Economics. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-77556-2_34
16. Lisstrand, J., Sikell Lundin, P.: För en ökad användning av digitala verktyg i byggproduktionen: en studie om vad som krävs för att byggbranschen ska digitaliseras i takt med omvärlden (2017)
17. Pine, B.J.: Mass Customization: The New Frontier in Business Competition. Harvard Business School Press, Boston (1993)
18. Pine, I., Joseph, B., Victor, B.: Making mass customization work. Harv. Bus. Rev. **71**(5), 108–117 (1993)
19. Piroozfar, P.A., Piller, F.T.: Mass Customisation and Personalisation in Architecture and Construction. Routledge, London (2013)
20. Salvador, F., Forza, C., Rungtusanatham, M.: How to mass customize: product architectures sourcing configurations. Bus. Horiz. **45**(4), 61–69 (2002)
21. Salvador, F., De Holan, P.M., Piller, F.: Cracking the code of mass customization. MIT Sloan Manag. Rev. **50**(3), 71–78 (2009)
22. Schevers, H., Drogemuller, R.: Converting the industry foundation classes to the web ontology language, p. 73 (2005)
23. Silveira, G.D., Borenstein, D., Fogliatto, F.S.: Mass customization: literature review and research directions. Int. J. Prod. Econ. **72**, 1–13 (2001)
24. Walcher, D., Piller, F.T.: The Customization 500, 1st edn. Lulu Press, Aachen (2011)
25. Wiendahl, H., ElMaraghy, H.A., Nyhuis, P., et al.: Changeable manufacturing-classification design and operation. CIRP Ann.-Manuf. Technol. **56**(2), 783–809 (2007)

How Can Hackathons Accelerate Corporate Innovation?

Myrna Flores[1,2(✉)], Matic Golob[2], Doroteja Maklin[2], Martin Herrera[3], Christopher Tucci[1,2], Ahmed Al-Ashaab[4], Leon Williams[4], Adriana Encinas[4], Veronica Martinez[5], Mohamed Zaki[5], Lourdes Sosa[6], and Karina Flores Pineda[2]

[1] École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland
myrna.flores@epfl.ch
[2] Lean Analytics Association, Carona, Switzerland
[3] CEMEX, Monterrey, Mexico
[4] Cranfield University, Bedford, UK
[5] University of Cambridge, Cambridge, UK
[6] London School of Economics and Political Science, London, UK

Abstract. In recent years, the way corporates innovate has changed significantly. Going from 'behind closed doors' innovation to open innovation where collaboration with outsiders is encouraged, companies are in the pursuit of more effective ways to accelerate their innovation outcomes. As a result, many companies are investing to create more entrepreneurial environments, which not only empower employees to proactively propose and test new ideas, but also reach beyond company walls to involve many others in the co-creation of new solutions. In this paper, we outline the most notable benefits of hackathons from the perspective of large organizations, and present the benefits and a methodology for organizing hackathons, i.e. competition-based events where participants work in small teams over a short period of time to ideate, design, rapidly prototype and test their ideas with a user-centric approach to solve a determined challenge. This paper also provides a brief insight into the CEMEX Hackathon, which was organized following the aforementioned methodology.

Keywords: Co-creation · Hackathon · Open innovation · Design thinking Lean

1 Introduction

Not long ago, industrial leaders believed that the greatest opportunity to leave the competition behind was to invest heavily in internal R&D. The idea was to have vast R&D resources, leading talent and strong, top-level support carry out all innovation activities behind closed doors, until new products - the seeds of the innovation process - were mature enough and ready to be launched to the market (Fig. 1: Closed Innovation). It was believed that only those companies would be able to keep up with the pace of change and innovation [24]. Fast forward 30 years or so, the situation in most industries is quite different. Companies around the world have moved, or are moving,

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 167–175, 2018.
https://doi.org/10.1007/978-3-319-99704-9_21

from inward-focused, ‘closed’ innovation to open innovation as proposed in Fig. 1. Opening up the innovation process and making its walls permeable, decisively encourages the use and exchange of external ideas, technologies, knowledge, talent, resources and more [7]. In part, this can be achieved through the organization of co-creation events that are often referred to as hackathons, ideathons or innovation days. Once industry-specific coding sprints, they recently overtook the world of entrepreneurs, startups and, lately, large corporations [1, 9, 12, 21]. The word hackathon is composed of two parts: *hack* and *marathon*. The term *hack* refers to the creative problem-solving, designing, prototyping and tackling of the challenge, while the word *marathon* indicates the intensity of the event. Briefly, a hackathon is an event with an element of competition, where participants work in teams over a short period of time to ideate, collaborate, design, rapidly prototype, test, iterate and pitch their solutions to a determined challenge. And since hackathons are time-limited events, they best fit the earliest stages of the lean innovation process, where the market is unknown or not well-defined yet, and many ideas are welcome to be tested using user-centric and Lean Startup concepts.

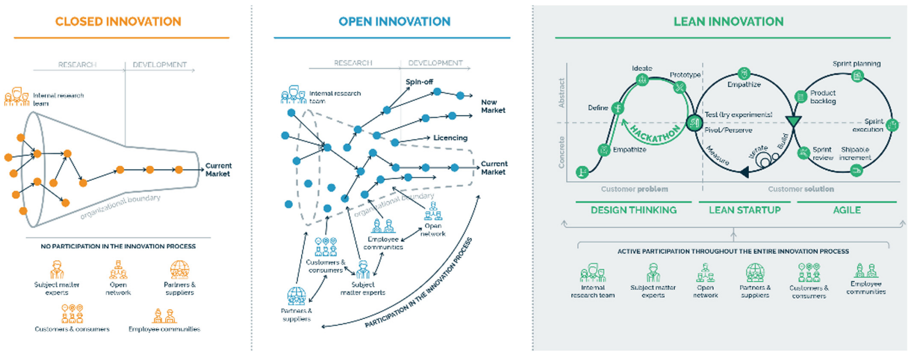


Fig. 1. Comparing the closed innovation, open innovation and lean innovation processes (adapted from [7, 14, 18])

Chesbrough [7] described open innovation as a concept where valuable ideas can come from both inside as well as outside the company, and can, similarly, be pushed to the market from inside as well as outside the company. Open innovation assigns the same priority to external ideas and routes to the market as to internal ones. The open innovation environment actively seeks for collaborations, reaching far outside the company’s R&D in order to co-create with partners, suppliers and even customers [6].

The Lean Innovation Model [13], developed by the Lean Analytics Association (LAA), relies on over 5 years of research, where various innovation and product development models and industrial cases of successful implementations of lean innovation practices in leading companies were studied, analyzed and synthetized. One of the aims of the Lean Innovation Model is to provide a framework to help practitioners discover the various innovation practices, approaches and tools. One key practice to enable Open Innovation is the hackathon.

Hackathons leverage the creative and intellectual capacity of the crowd to generate a range of ideas that are crossing the company's boarders in order to not only accelerate innovation and refresh the portfolio of ideas, but to bring employees from different departments closer together [12, 21]. Table 1 compares the benefits of organizing a hackathon proposed by different authors, including those identified during the organization and execution of the CEMEX Hackathon, which was organized according to the four building blocks of the Lean Innovation Model and the methodology in Fig. 2.

Table 1. Innovation benefits resulting from organizing a hackathon

#	BENEFITS	SUM	[25]	[23]	[17]	[4]	[1]	[12]	[21]	CX
	BUILDING BLOCK 1: STRATEGY & PERFORMANCE									
1	**Accelerates innovation**	**6**	✓		✓	✓	✓		✓	✓
2	Corporate brand promotion	2	✓							✓
3	Earlier engagement with customers & potential users	3					✓	✓	✓	
4	Alignment with leaders to identify the challenge	1								✓
5	Clearly defines the underlying problems	5				✓	✓	✓	✓	✓
6	Vision, company's commitment and the hackathon challenge is co-developed by leaders	2						✓		✓
7	Establishes criteria to assess the teams & ideas	2	✓							✓
	BUILDING BLOCK 2: SKILLED PEOPLE & COLLABORATION									
8	Talent engagement & recruitment	3		✓					✓	✓
9	Increases employee morale & relationship building	4					✓	✓	✓	✓
10	Facilitated events using Design Thinking require minimum or none prior experience from participants	1								✓
	BUILDING BLOCK 3: EFFICIENT PROCESS & KNOWLEDGE-BASED ENVIRONMENT									
11	**Provides a creative & stimulating environment**	**6**	✓		✓	✓	✓		✓	✓
12	**Enables rapid development & the testing of ideas**	**7**	✓		✓	✓	✓	✓	✓	✓
13	Provides a time-intense innovation environment	2	✓							✓
14	IP development	3	✓						✓	✓
15	Uses a simple, yet impactful innovation process	3	✓				✓			✓
16	Frontloads the innovation process	3						✓	✓	✓
17	Fuels the company's innovation pipeline with already somewhat validated and prioritized ideas	2					✓			✓
18	User-centric lean innovation tools and techniques	1								✓
	BUILDING BLOCK 4: CONTINUOUS IMPROVEMENT AND CHANGE									
19	Intensive co-creation & radical collaboration	3					✓		✓	✓
20	**Enables organizational change**	**6**	✓		✓	✓	✓		✓	✓

[1] Altringer, 2013; **[4]** Briscoe & Mulligan, 2014; **[12]** Di Fiore, 2013; **[17]** Li & Johnson, 2015; **[21]** Spaulding & Caimi, 2016; **[23]** Trainer et al., 2016; **[25]** Uffreduzzi, 2017; **[CX]** CEMEX Hackathon

By integrating several practices identified with the Lean Innovation Model as a framework and using findings from the literature as well as our experience in organizing hackathons [16], a step-by-step methodology for the preparation and execution of hackathons has been developed. We also provide a brief overview of the CEMEX Hackathon, which was organized following the methodology outlined in this paper.

2 Methodology for Organizing Corporate Hackathons

As described in the introduction of this paper, hackathons are co-creation events purposefully designed to utilize diverse mindsets, tackle complex challenges and create new business opportunities. However, to provide such an environment, any hackathon needs to be carefully planned, executed and wrapped up. From selecting the venue [11, 19] to appointing the facilitator, determining the program [2] and selecting the awards [3], every detail influences the creativity and innovation potential of the participants.

A literature review highlighted some of the core areas of organizing co-creation events, covering mainly generic hackathons and not corporate ones [8, 15, 20, 22]. Although most steps are transversal, the reasons, the planning and the alignment approach tend to differ. In addition, most of the literature still focuses on industry-specific events, largely on software development and digital technologies.

To ensure hackathons deliver benefits for the host-company as well as the participants attending, the LAA team defined a three-stage methodology that covers in detail: (1) the pre-hackathon planning, (2) the execution, and (3) the post-hackathon stage. The steps of the proposed methodology are represented in Fig. 2.

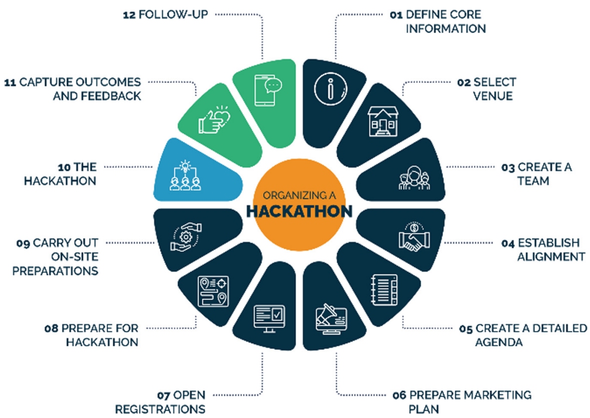


Fig. 2. Methodology for organizing co-creation workshops in a corporate setting [16]

2.1 Pre-hackathon Stage (Planning)

The planning stage is the first and most critical stage when organizing a hackathon. It consists of 9 steps (as observed in Fig. 2), starting from (1) defining the core information such as the aim and objectives, the expected outcomes, the theme or topic, the challenge, the date and duration, the target group (participants), the location and the budget. Having pinned these details down, a suitable (2) venue needs to be identified and a (3) team must be formed. While smaller hackathons need less time and people to organize, larger hackathons (100+ participants) require a dedicated or “core” team [8]. Hackathons do require an extended team, including facilitators, subject matter experts, presenters and workshop leaders, judges and technical and support teams. Each individual plays a specific role before and, especially, during the event. For example, facilitators will be involved in planning the program in the pre-hackathon stage and will be leading teams of participants through the design and problem-solving process during the execution stage. The core team will co-determine the evaluation criteria and protocol for the awards ceremony, identifying judges who, during the hackathon, will be carefully observing and evaluating how teams work and the ideas they develop. For more specific challenges, subject matter experts are needed to advise teams during the hackathon, help them with specific questions or dilemmas, and provide insights, knowledge and experience, thus enabling teams to develop better prototypes [15]. To ensure such a diverse group of people works together smoothly and delivers value, (4) team alignment must be achieved (including alignment with the host company).

Hackathons also require a process to ensure the expected results are indeed obtained in such a short time. Coding and software development hackathons typically consider the Scrum process to ‘walk through’ a design cycle. On the other hand, business and corporate hackathons usually follow a design thinking methodology to guide the teams through the day(s). Design thinking works extremely well in the business hackathon setting, because it starts by deep-diving into the problem (challenge) through user interviews, observation and research. This provides strong foundations, rooted in real, human needs, to build ideas and prototypes on. Design Thinking is a human-centered approach used to creatively and holistically solve complex problems in an iterative and collaborative manner [5]. The design thinking process created by the Stanford Design School [10] is structured into five-phases: Empathize, Define, Ideate, Prototype, and Test. The following two steps of the hackathon organization methodology focus on (6) the promotion and marketing of the hackathon, and (7) handling the registrations. Whether the hackathon is being organized for an internal (in-company), external (open to the public) or mixed audience, getting the right participants will have an impact on the quality of the outcomes. Both activities need to be planned well ahead of the actual date of the event in order to ensure the news reach the largest audience [15].

During the final (8) preparation, the team will ensure that all presentations and speeches are ready, prototyping material is available, templates and visual guides are printed, and that the pre-work for participants is selected and distributed. A day or two before the actual event, (9) on-site preparations are required.

2.2 The Hackathon Stage (Execution)

After the official welcome and the initial presentation of the hackathon challenge, teams start working on the Empathize phase, where participants conduct a preliminary research on the topic and engage with end-users and other stakeholders through interviews. Moving to the second phase, teams try to make sense of what they just learned through the interviews and research, by defining the problem they are going to address. While the hackathon provides the challenge, the underlying problem is identified through the analysis of data collected in the Empathize phase. With a clear problem statement, teams enter the third phase where they start brainstorming about potential ideas that could solve that problem and continue by ranking these ideas. The important notion at this stage is that ideation is not so much about the quality, but rather about the quantity of ideas. This is where teams should explore anything from conventional to entirely blue-sky options. What follows is a series of iterations, where teams start by developing a prototype for the selected idea, before testing it with the stakeholders (Fig. 3).

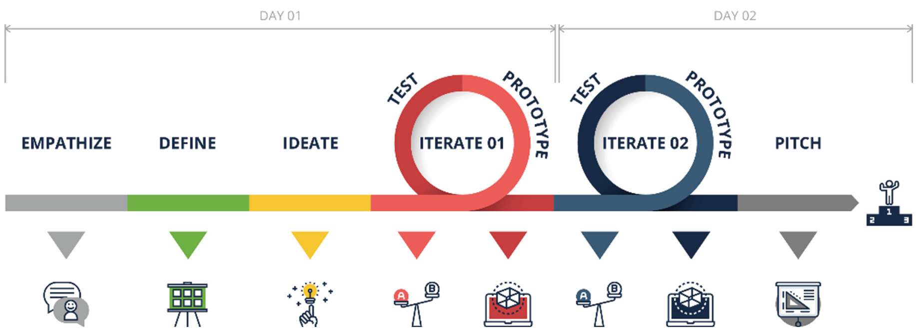


Fig. 3. Design thinking processes proposed for a two-day hackathon event [16]

2.3 Post-hackathon Stage (Reflection)

Hackathons are high-energy events, which is the reason why the post-hackathon work is often neglected. However, it is strongly recommended to also invest time in this last phase, where the organizing team organizes lessons learned sessions to analyze ideas, patterns and prototypes, and set in motion the wheels for establishing a project or projects based on the winning solutions.

3 Case Study: The CEMEX Hackathon

The first CEMEX Hackathon organized by the Lean Analytics Association in collaboration with CEMEX was held in Cambridge, UK on Feb 9–10, 2018. It provided the perfect setting to motivate over 100 participants to develop ideas and co-create prototypes of solutions to solve the challenge of how to mobilize and engage employees in the innovation ecosystem at CEMEX.

Teams (composed of CEMEX employees and students) were assigned facilitators from 3 Universities (EPFL, Cambridge University and Cranfield University) and the LAA team to guide them through the two days of the design thinking process, while one CEMEX employee per team was selected to document and store the generated knowledge. Teams started the journey with interviews of employees and contextual research. Using the insights generated in the first step of the *Design Thinking* method, teams built the *persona* and developed an *empathy map* for that persona in order to determine the underlying problem they would focus on to solve the hackathon challenge. In the following step, teams used various brainstorming techniques as devised by facilitators, to come up with as many ideas as possible, before reviewing and ranking them. The most promising idea was prototyped in the fourth step, mainly through the use of paper prototyping, storytelling, roleplaying, wireframing and mockuping. The teams had the opportunity to work with three artists from the Starfish Taylor to better visualize their ideas. At the end of the day, each team was given 2 min to demonstrate their prototypes to the judges and other teams, who provided their feedback through a voting system. The teams kicked off the morning of the second day with a discussion about the feedback received and a revision of their prototypes. All prototypes had to be completed by the end of the lunch, when teams were given time to prepare their final pitches and demonstrations. The hackathon closed after an international jury conveyed, unanimously selected the three winning teams, and announced the winners at the awards ceremony. The winning team received 3,000 GBP and the opportunity to develop their solution further in CEMEX.

During both days, all participants demonstrated a great level of interest and motivation for innovation and collaboration. Participants from over 15 countries, 9 CEMEX offices and 9 Universities, collectively generated approximately 1300 high-level ideas, used over 10,000 post-it notes, created 24 prototypes in total, and delivered 13 pitches. Michel Andre, UK Country President at CEMEX, one of the hackathon's key stakeholders, sponsor and judge of the hackathon said, "What a learning experience! Incredible engagement and passion demonstrated by all participants! Several great ideas being incorporated in our innovation model".

4 Conclusion

With a growing popularity amongst entrepreneurial individuals as well as larger organizations, hackathons provide a means to accelerate innovation. In this paper, we propose a methodology which provides a step-by-step guide covering the planning, execution and reflection activities which enable organizations to prepare an event that delivers value, helps change the innovation landscape and empowers participants and employees to act on the resulting ideas.

However, organizing a corporate hackathon entails challenges and needs an unwavering commitment from all the people involved. Hackathons are not a standard business practice yet and, therefore, require strong collaboration, continuous communication and transparency. The second main challenge worth pointing out is the framing of the challenge and its presentation to the target audience. Framing the challenge in the right way and maintaining continuous and transparent communication is critical to a successful organization of a corporate hackathon.

Building on the proposed methodology, we believe that future research should look into individual areas in depth to provide more specific and comprehensive advice, while continuing to measure the benefits and challenges of organizing corporate hackathons.

Acknowledgements. The authors thank the CEMEX team for their support, commitment and strong engagement during the three stages of the proposed methodology for organizing their first CEMEX Hackathon in Cambridge, UK on Feb 9th & 10th 2018. We also express our gratitude to the Starfish Taylor artists for making sure ideas came to life with professional visual communication tools, thus fueling the teams' creativity. Last but not least, we would like to thank the CEMEX employees and students who were energized to co-develop their amazing out-of-the-box solutions, proving that Hackathons can indeed deliver valuable results.

References

1. Altringer, B.: A new model for innovation in big companies (2013). http://hbr.org/2013/11/a-new-model-for-innovation-in-big-companies. Accessed 04 Apr 2018
2. Amabile, T.M., Khaire, M.: Creativity & role of the leader. Harv. Bus. Rev. **86**(10), 100–109 (2008)
3. Bays, J., Goland, T., Newsum, J.: Using prizes to spur innovation (2009). https://goo.gl/Hg5GnQ. Accessed 04 Apr 2018
4. Briscoe, G., Mulligan, C.: Digital innovation: the hackathon phenomenon. QMRO (2014)
5. Brown, T.: Design thinking. Harv. Bus. Rev. **86**, 84–92 (2008)
6. Chao, R.: The Ins and Outs of Open Innovation (2012). www.forbes.com/sites/darden/2012/05/06/the-ins-and-outs-of-open-innovation-3. Accessed 04 Apr 2018
7. Chesbrough, H.W.: Open Innovation: The New Imperative for Creating and Profiting from Technology. Harvard Business School Press, Brighton (2006)
8. Cisco: IoE Student Hackathon Playbook (2015). http://honim.typepad.com/files/1.0-ioe-student-hackathon-playbook.pdf. Accessed 02 Apr 2018
9. Cobham, D., Gowen, C., Jacques, K., Laurel, J., Ringham, S.: From AppFest to entrepreneurs. In: Proceedings of INTED 2017, pp. 522–529 (2017)
10. d.school: Tools for taking action (2013). http://dschool.stanford.edu. Accessed 05 Apr 2018
11. Dam, R., Siang, T.: Create some space – for ideation sessions and design thinking (2018). https://goo.gl/VsZL5R. Accessed 04 Apr 2018
12. Di Fiore, A.: Make Your Next Innovation Jam Work (2013). http://hbr.org/2013/01/learning-how-to-jam. Accessed 04 Apr 2018
13. Flores, M., Golob, M., Maklin, D., Tucci, C.L., Flores, K.: Lean Product Development Best Practices: Ten industrial success stories. LAA, Carona (2017)
14. Gartner: Enterprise architecture and technology innovation leadership vision for 2017 (2016). https://goo.gl/NyjosJ. Accessed 06 Apr 2018
15. Info Support: Hackathon playbook (2017). www.infosupport.com/wp-content/uploads/Playbook-Hackathon.pdf. Accessed 04 Apr 2018
16. LAA: The CEMEX Hackathon (2018). http://lean-analytics.org/the-cemex-hackaton. Accessed 06 Apr 2018
17. Li, L.M., Johnson, S.: Hackathon as a way to raise awareness and foster innovation for stroke. Arq. Neuro-Psiquiatr. **73**(12), 1002–1004 (2015)
18. Optimus BT: Fostering open innovation & knowledge communities (2010). https://goo.gl/nMTMVU. Accessed 05 Apr 2018
19. Rattner, D.M.: How to use the psychology of space to boost your creativity (2017). https://goo.gl/ydUZFd. Accessed 04 Apr 2018
20. Rissola, G., Kune, H., Martinez, P.: Innovation camp methodology handbook (2017). https://goo.gl/SXzT7z. Accessed 04 Apr 2018

21. Spaulding, E., Caimi, G.: Hackathons aren't just for coders (2016). https://hbr.org/2016/04/hackathons-arent-just-for-coders. Accessed 04 Apr 2018
22. Tauberer, J.: How to run a successful hackathon: a step-by-step guide (2016). https://hackathon.guide. Accessed 04 Apr 2018
23. Trainer, E.H., Kalyanasundaram, A., Chaihirunkarn, C., Herbsleb, J.D.: How to hackathon: socio-technical tradeoffs in brief, intensive collocation. In: CSCW 2016, San Francisco, pp. 1118–1130 (2016)
24. Tucci, C.L., Afuah, A., Viscusi, G.: Creating and Capturing Value through Crowdsourcing. Oxford University Press, New York (2018)
25. Uffreduzzi, M.: Hackathon as emerging innovation practice: exploring opportunities and challenges through 8 in-depth case studies. Politecnico di Milano, Milano (2017)

Smart Supply Chain – Development of the Equipment Supplier in Global Value Networks

Martina Schiffer(✉), Michael Luckert, Hans-Hermann Wiendahl, and Benedikt Saretz

Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Nobelstraße 12, 70569 Stuttgart, Germany
martina.schiffer@ipa.fraunhofer.de

Abstract. Digitization and its effect on markets, production conditions, and intercompany interaction forces companies to adapt continuously in order to stay competitive. Factory equipment suppliers are especially affected by this development. Their customers expect them to digitalize their products and at the same time, request new service-based approaches in short periods. Ultimately, they are taking a new role within the automotive supply chain. With their smart products and solutions, factory equipment suppliers build the fundament to digitalize their customers. As suppliers of smart solutions, they will gain strategic importance in global value creation networks and smart supply chains. This paper examines the transformation of the equipment suppliers through the progressive networking of supply chains, using the automotive industry as an example. It shows how their new strategic role within the supply chain is developing and what requirements consequently arise.

Keywords: Global supply chain · Smart supply chain · Industry4.0
Smart factory · Automotive · Plant vendor development

1 Introduction

The topic of smart supply chains is becoming increasingly important as globalization progresses. The management of global value chains offers companies the opportunity to improve their processes continuously. In addition, it enables new digital business models based on digital services. For this, the central prerequisite is the availability of real-time production, product, and logistical processes data along the supply chain. In a first step, this concerns the equipment suppliers, who enable the digitalization of their customers with smart products and solutions. Due to this, factory suppliers in close-knit value-adding networks and global supply chains will gain strategic importance in the future. Current developments in this area can be easily observed in the automotive sector, since global procurement and production have been established here for a long time. This industry is changing dynamically due to new competitors and trends such as mass customization or electro mobility.

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 176–183, 2018.
https://doi.org/10.1007/978-3-319-99704-9_22

Using the German automotive industry as an example, this paper shows how the role of equipment suppliers is changing as supply chains become increasingly networked. Building on this, this study derives implications from the individual companies and describes how factory equipment suppliers in particular are increasingly integrated into their supply chains. The results are based on a two-stage survey, which involved equipment suppliers, OEMs, Tier1 and Tier 2/n suppliers.

2 Related Works

The global automotive industry is undergoing radical changes and confronting companies with increasingly complex challenges at ever-shortening intervals [1]. When buying a new car, the gaining importance of electro mobility, the increasing individualization of vehicles at constant costs, decreasing delivery times or new competitors such as Waymo or Uber are becoming important criteria for customers [2]. Considering the shortening product life cycles, the level of reaction speed of both the automobile manufacturer and the associated global supply chain protagonists is important for the future competitiveness of automobile manufacturers [3]. On the one hand, the goal is to expand the existing high process stability while reducing the amount of capital tied up in the entire process. On the other hand, it is important to make use of the technological opportunities rising as the digitalization proceeds.

Digitalization not only allows the reduction of inventories through increased transparency, but also enables individual product data to be shared and used along the global supply chain [1, 4, 5]. Important requirements for this are smart products and services offered by the factory suppliers. Their increasing range of services is more and more perceived as a success factor in the course of networked value creation.

As a result, equipment suppliers are not only gaining importance as suppliers of relevant production data, but are also opening up the potential for production optimization. They are increasingly prepared to not only sell their products, but also to operate, maintain, and dispose of them on behalf of the customer [6]. In the context of smart supply chain management these activities are becoming increasingly important for automobile manufacturers, as the required time windows are largely predictable [7–9]. The high market power of the original equipment manufacturers (OEMs) requesting these new services from their equipment suppliers drives the role change of the equipment supplier within the global supply chain structure.

3 Methodic Procedure

In order to be able to make as precise a statement as possible on the development of the role of the supplier, a multi-stage approach was chosen. In the first step, a structural analysis of the automotive industry over the levels Tier 2/n, Tier 1 and OEM is conducted. Additionally, current technological and social trends are identified at a high aggregation level and relevant fields of action are derived accordingly.

In the second step, the current activities of the individual actors in these fields of action are examined and classified with regard to their potential for change in the supply chain. In addition, the expected developments during the next five to ten years are surveyed in expert interviews. At the same time, the current focal points of the activities and expectations of the suppliers are taken up from their points of view.

In the third and final stage, the findings obtained through individual surveys are confirmed and expanded by a group of 17 high-level executives and as a result, development theses are derived.

These theses are validated in an online survey with 167 participants from 79 different companies. In total, the participants are assigned to the individual stages of the supply chain as follows (Fig. 1):

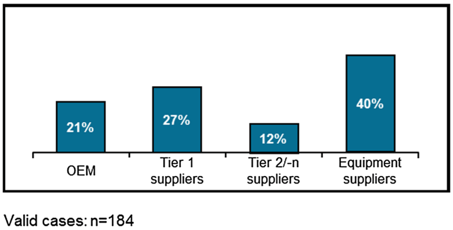


Fig. 1. Classification of the participants

4 Results

The automotive industry is currently undergoing profound change. For a long time, manufacturers focused on the continuous improvement of existing technologies and the optimization of traditional business models. Currently the four main observable areas driving the transformation are:

- Digitalization of the manufacturing process
- Assistance systems and autonomous driving in connected vehicles
- Search for alternative drive concepts, in particular electric mobility
- New mobility concepts, especially in the area of car sharing.

Many of those surveyed expect politicians to influence the sales market, Fig. 2: The promotion of electro mobility, driving bans on internal combustion engines, stricter exhaust emissions values, and changes in the laws governing autonomous driving will significantly change the framework conditions. However, the timing and scope are currently very unclear, which increases the uncertainty for all parties involved.

The uncertain future of the internal combustion engine is the subject of intensive discussions among OEMs, the directly affected supplier sector, and the directly affected factory equipment suppliers. This has an impact above all on the strategic orientation of the companies. The expert interviews and the online survey confirmed that all respondents are intensively dealing with these issues (Fig. 3).

Many of those asked expect political interference on the sales markets worldwide. The promotion of electro mobility, driving bans, stricter exhaust emission value limits and changes in the laws governing autonomous driving will significantly change the current framework conditions. However, the period and scope of the changes

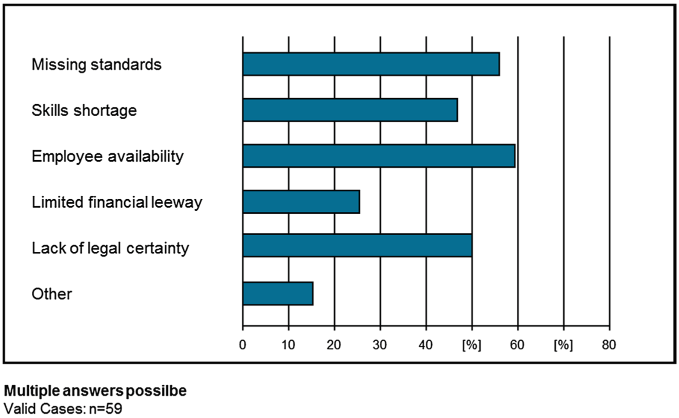


Fig. 2. Challenges of digitalization

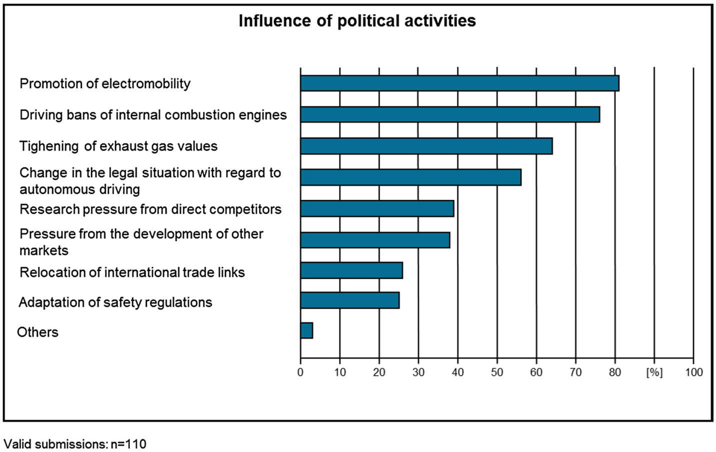


Fig. 3. Influence of political activities

mentioned is still unclear, which increases the uncertainty for all parties involved. Nevertheless, automobile manufacturers expect their vertical range of manufacturing to continue to decline.

In comparison, the equipment suppliers, usually the machine manufacturers assess their own changes driven by the ongoing digitalization in business and general conditions as particularly far-reaching. Both their new role in the automotive supply chain and the shorter technology life cycles are increasing the pressure to innovate on factory equipment manufacturers. In addition to this pressure, there is also an increasingly fierce competition with high costs. Digitalization itself opens up two strategic directions for equipment suppliers (Fig. 4):

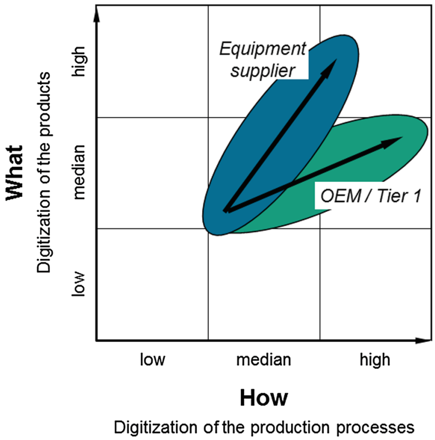


Fig. 4. Development trails of OEM/Tier1 and equipment suppliers

- Better process control: Digitalization increases the transparency of manufacturing and logistics processes, both in terms of real-time capability and in the depth of information. Both can make the processes more secure, but only if the information is shared.
- New business models: Digitalization supports remote operations. This enables a variety of operator models in which the equipment suppliers themselves bear the costs of acquisition, operation, maintenance and disposal. They can then invoice their customers for usage-related expenses.

Both directions increase the technical requirements of the products from the factory suppliers. They become the key provider of production data. At the same time, this also brings the independent value of operator data and their ownership and usage rights into the focus of the transfers.

Many equipment suppliers combine these approaches and see their dual role as factory operators and equipment suppliers as an opportunity. They use new concepts and solutions both internally, to improve their own production, and as demonstrators for a “factory of the future” to display their technological expertise to potential customers. Smart products from the suppliers will become the “digitalization enabler” - the indispensable prerequisite for a smart supply chain. From a technical point of view, digitalized processes allow for a higher transparency of the supply chain. Figure 5 shows the growing need of Tier 1/n suppliers for a high level of process knowledge and thus the importance of product digitalization for equipment suppliers. Digitalized products could also reduce the effort for production planning and control. However, this only becomes effective through a stronger exchange of information between supply chain actors for demand, capacity and order progress data. Automating the cross-company information exchange reduces the transaction costs associated with the transfer of information to the partners involved [1].

Because of the developments described above, the role and range of services offered by factory suppliers is undergoing sustainable change. This begins with the spread of the

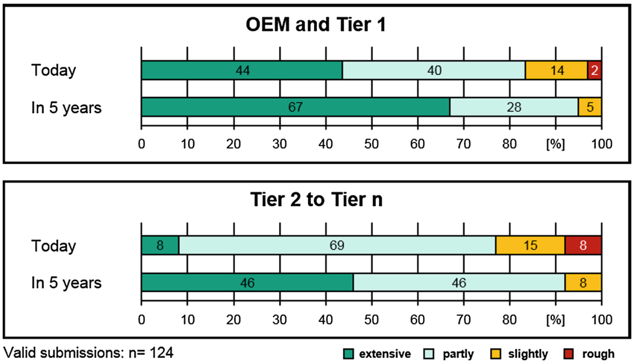


Fig. 5. Knowledge of OEM and Tier 1/n suppliers about the technical process parameters that essentially determine their product quality

operator (business) models, which are also increasingly becoming the standard for custom-made products and specialized equipment. As a result, OEMs are increasingly demanding that equipment suppliers contribute to continuous production improvements and expect new products to be instantly integrated into the existing production IT. Due to the described forward integration of automobile manufacturers, it is increasingly conceivable that some equipment suppliers will take over the operation and optimization of entire factories. This trend is reinforced by the development towards globally standardized and uniformly equipped factories. In connection with the extensive conversion to operator models in a global context and the increased transparency resulting from various smart supply chain approaches, there are various effects on global supply chains from the supplier's perspective. On the one hand, opportunities to return, recycle, and re-use products have to be organized, and the logistics chain developed for this purpose. On the other hand, there are strong changes with regard to the required delivery times. As shown in Fig. 6, delivery windows with the range of a week for new plants are often standard, but within the next 5 years this will become the exception, rather than the rule. Instead, the ranges will decrease to days first and finally to minutes.

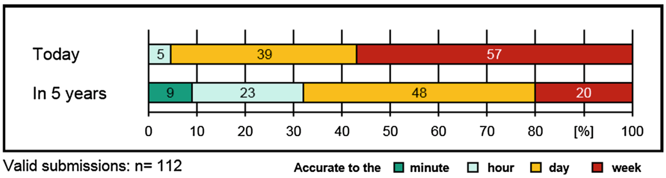


Fig. 6. Delivery time of equipment supplier for crucial parts

In the case of the operator models, topics such as installation and commissioning, maintenance, servicing, and replacement are taken over by the plant manufacturer. The ability to meet precise deadlines down to the hour must be strengthened, since these activities must be carried out in narrow time windows predefined by the customer.

Customers along the entire value chain expect shorter delivery times, but also attach increasing importance to hourly predictions of delivery dates. In addition, maintenance activities must be carried out within narrow, predefined time windows, because otherwise high contractual penalties are imminent. The demands on the supply chain of equipment suppliers are increasing accordingly. In the future, they will have to build up or expand their own competence in supply chain management, at least for the automotive sector. Operator models are also becoming increasingly standard for custom-made products. In summary, suppliers are increasingly integrated into the supply chain and are taking over the operational activities, thus becoming their customers' global strategic partners.

Even though the experts surveyed emphasize the benefits of the integration of equipment suppliers, there are various arguments that delay the developments described. Although operator models on the part of the customer reduce tied assets, it is difficult to quantify the other financial effects due to a lack of reference examples. In addition, uncertain legal relationships are named as a restriction. Due to the lack of standards for data exchange, the restraint in data exchange in Europe is an additional obstacle. Finally, there is the question of dependence on individual equipment suppliers and the safeguarding of one's own expertise.

5 Conclusion

This example from the automotive industry shows how the role of equipment suppliers in global supply chains is strengthened. New technologies and business models lead to greater process responsibility and risk assumption by equipment suppliers and reduce the number of customers' tied-up assets. The change described clearly shows that the digitization of suppliers is only possible through the smart products of the plant suppliers. Closely meshed supply chains increasingly integrate suppliers as independent players in their own value-added chain and require a high degree of adherence to delivery dates. As the variety of products increases, delivery times and windows are expected to shorten at the same time. This means that hourly or daily delivery windows become standard even for outfitters. In order to validate the informative value of the results presented here, further industries will have to be examined for these developments in the future. The exact role of the Tier2/n and Tier1 suppliers must be further questioned in detail. Furthermore, the question what kind of offers and services for equipment suppliers will actually be in demand in the future arises and which strategy promises success here.

References

1. Göpfert, I., Braun, D., Schulz, M. (eds.): Automobillogistik, 3rd edn. Springer, Heidelberg (2017). https://doi.org/10.1007/978-3-658-11103-8
2. Picot, A., Hopf, S., Sedlmeir, J.: Digitalisierung als Herausforderung für die Industrie – Das Beispiel der Automotive Branche. In: Burr, W., Stephan, M. (eds.) Technologie, Strategie und Organisation, pp. 87–112. Springer Gabler, Wiesbaden (2017). https://doi.org/10.1007/978-3-658-16042-5_5

3. Talkhestani, B., Schlögl, W., Weyrich, M.: Synchronisierung von digitalen Modellen. atp – edition Automoatiserungstechnische Praxis **59**, 62–69 (2017)
4. Kersten, W., Koller, H., Lödding, H.: Industrie 4.0 – Wie intelligente Vernetzung und kognitive Systeme unsere Arbeit verändern. GITO mbH Verlag, Berlin (2014)
5. Schuh, G., Anderl, R., Gausemeier, J., ten Hompel, M., Wahlster, W.: Industrie 4.0 Maturity Index. Die digitale Transformation von Unternehmen gestalten (acatech STUDIE). Herbert Utz Verlag, München (2017)
6. Pflaum, A., Schulz, E.: Auf dem Weg zum digitalen Geschäftsmodell. HMD Praxis der Wirtschaftsinformatik **44**, 1–18 (2018). Springer Fachmedien Wiesbaden
7. Kuhn, A., Hellingrath, B.: Supply Chain Management: Optimierte Zusammenarbeit in der Wertschöpfungskette. Springer, Heidelberg (2002). https://doi.org/10.1007/978-3-662-10141-4
8. Reichhuber, A.: Strategie und Struktur in der Automobilindustrie. Gabler, Springer Fachmedien Verlag, Wiesbaden (2010). https://doi.org/10.1007/978-3-8349-8496-8
9. Lödding, H.: Handbook of Manufacturing Control. Springer, Berlin Heidelberg (2014). https://doi.org/10.1007/978-3-642-24458-2

Mass Customization Capability Planning with Additive Manufacturing

Songi Kim and Bongju Jeong(✉)

Yonsei University, 50 Yonsei-ro Seodaemun-gu, Seoul 03722, Republic of Korea
bongju@yonsei.ac.kr

Abstract. Mass customization aims to manufacture large quantities of customized products at low costs comparable to that in mass production. However, the two operational objectives of mass customization, production flexibility and cost-efficiency, conflict with each other. In this circumstance, one of the famous prototyping technologies, additive manufacturing (AM), began to draw attention with its multiple function in the production system, which enables mass customizers to achieve the two contradictive objectives. This study defines mass customization capability planning (MCCP) as a production planning process which balances between production flexibility and cost-effectiveness. Also, the mathematical planning model of MCCP is developed to support it. Since the MCCP model includes stochastic parameters, a heuristic method is applied to the solution searching process. After, the MCCP model was validated by the experiment analysis.

Keywords: Mass customization capability planning · Mass customization Additive manufacturing

1 Introduction

The term mass customization was firstly mentioned as a process to provide product variety and customization with flexibility and quick responsiveness [1]. Among the various definitions, the predominant features of mass customization include product variety, flexibility, and cost-efficiency [2]. Early papers on mass customization try to classify mass customization into several levels [3, 4] and more recently, the optimal location of customer involvement in the production system [5, 6].

However, as the product variety increases, the mass customizer confronts the difficulty to balance two contrasting operational goals: production flexibility and cost-efficiency. From this viewpoint, operational capability of mass customization is understood as balancing trade-offs between the two operational goals [7]. Production flexibility, the ability to respond effectively to changing circumstances, enables mass customizer to change production setups in a short time, with a little effort. The second objective, cost-efficiency, of the mass customization comes from the mass production strategy. In the view of economy of scale, homogeneous items require less attention to managing them. In contrast, mass customization requires a much higher number of production set-ups and more diverse resources to produce various kinds of products.

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 184–192, 2018.
https://doi.org/10.1007/978-3-319-99704-9_23

Regarding this, this study deals with one of the most flexible manufacturing technology, additive manufacturing (AM). Adding materials enables to produce objects with a much more complex design so the technology is expected to play a crucial role to provide the manufacturing flexibility to the production system [8]. Initially AM was used to create prototypes before the products were developed [9]. However, AM processes recently broaden its functional boundary to the rapid tooling (RT) area to create tools which are necessary for the traditional fabrication procedure, injection molding, and to the rapid manufacturing (RM) area to manufacture end-use products right away. Most of the previous papers focused on figuring out which, among the three functions, could be the optimal choice for the production system. On the other hand, this study puts more weight of its ability to switch between the three functions freely, which can contribute to increasing the production system's flexibility.

In the previous research, most of the studies with mass customization capability focused on defining the term and investigating its relationship with other managerial factors such as with product modularity [10], organizational flatness, coordination, and product modularity [11], absorptive capacity [12], and quality management [13]. Instead of adopting qualitative manner, this study understands mass customization capability planning (MCCP) as a production planning issue. With this approach, the mathematical model is developed to support it. Also, a simple experimental analysis was carried out to validate the mathematical model.

2 Mass Customization Capability Planning

The concept of mass customization has emerged from the convergence of the two contrasting strategies: mass production and one-of-kind production (OKP). The first strategy, mass production, focuses on achieving cost-effectiveness with a few types of standard products. Since the number of product types is somewhat limited, it is able to forecast demands for the standard products with proper forecasting techniques. Under the OKP circumstance, however, there can exist an infinite number of product types. In addition, the customization level of each product may vary depending on the customer's requests and the firm's capability to produce customized products.

As a combination of the two strategies, mass customization produces both types of products. On the one hand, mass customizer must forecast the future demands of the standard products and establish a proper production plan for the products and the parts. On the other hand, the mass customizer must prepare its capability to deal with the customized demands since the customers' specific requirements are unknown until the actual demand occurs. This gives rise to the necessity for the mass customizer to include the customization capability planning as a new production planning step.

In this respect, MCCP aims to give a guideline so as to support the mass customizer's decision-making on its customization capability. As the nature of custom order bears uncertainty, the customization capability planning does not suggest an exact solution for the mass customizer. Instead, it offers a range of customization capability levels which helps to understand the impact of the custom demands and its proper capability levels to deal with it.

There is a significant difference in the decision variables between the MCCP model and the traditional capacity planning model. In addition to the capacity-related decision in the traditional models, the MCCP model decides the proper customization capability according to the custom demand forecast. Therefore, the important decision variables of the MCCP model are related to its customization capability: *the customization level* and *the custom order fulfillment ratio*.

A mass customizer decides its level of product variety by setting a proper customization level. By setting the customization level, the firm is able to produce customized products of which customization level locates within the customization limit. However, if there is a new order requiring a product with being more customized than the firm's customization limit, the firm faces a difficult situation where putting most of its capacity on that order. Second, the custom order fulfillment ratio depends on the number of customized products manufactured in the planning horizon.

The customization level and the custom order fulfillment ratio are related to each other. For example, a firm can either produce a large quantity of customized products with a low customization level or produce a small number of high-customized products. Therefore, it is difficult to evaluate which of the two strategies represents the higher customization capability since they are in the two different dimensions.

3 Mass Customization Capability Planning Model

3.1 Assumptions and Notations

Since the mathematical representation of MCCP does not exist before, this very first model is developed based on the detailed assumptions. First, demand information of both typical and custom order is known by long-term forecasting. However, only typical orders include detail profile of the products, such as bill-of-materials and part specifications. Long-term forecasting for custom orders is available only to predict customers' tendency to customize their products. The products are customized from the standard products. Parts can be customized, while BOM information for the final products is fixed. In addition, it is assumed that customers can customize both common parts and differentiated parts as well. Customized products are comprised of common parts, differentiated parts, and customized parts while standard products consist of common parts and differentiated parts. Regarding AM, it is assumed that all parts can be additively manufactured. The building time of AM machines is assumed to be affected by the building technique of the AM machine and the part design. Indices, parameters, and decision variables are represented in Tables 1, 2 and 3, respectively.

Table 1. Indices

i	Index of product $(i = 1, 2, \ldots, I)$
j	Index of part $(j = 1, 2, \ldots, J)$
l	Index of customized part originated from part j $\left(l = 1, 2, \ldots, Y_{jt}^{C}\right)$
k	Index of AM machine type related to building technique $(k = 1, 2, \ldots, K)$
m	Index of dedicated machines' possible function $(m = 1, 2, \ldots, M)$ (in this model, 1 for tooling and 2 for fabrication)
n	Index of effective design factor $(n = 1, 2, \ldots, N)$
s	Index of manufacturing step $(s = 1, 2, \ldots, S)$ (in this model, 1 for prototyping, 2 for tooling, and 3 for fabrication)
r	Index of raw material $(r = 1, 2, \ldots, R)$
t	Time periods $(t = 1, 2, \ldots, T)$

Table 2. Parameters

d_{it}^{TOTAL}	Forecasted total demand including the standard product i and customized product modified from the standard product i at period t
d_{it}^{ST}	Forecasted demands of the standard product i at period t
d_{it}^{CU}	Forecasted demands of the customized product i at period t *(stochastic value)*
n_{ij}	The number of the part j to manufacture a unit of standard product i
$t_{m}^{Set\_DM}$	Setup time of dedicated machine with function m
$t_{k}^{Set\_AM}$	Setup time of AM with building technique k
$t_{k}^{Post\_AM}$	Post processing time of AM with building technique k
t_{jm}^{NC}	Processing time of non-customized part j at dedicated machine m
$t_{jlm}^{C\_DM}$	Processing time of customized part (j, l) at dedicated machine m
$t_{jlk}^{C\_AM}$	Processing time of customized part (j, l) at AM machine with building technique k *(stochastic value)*
t_{i}^{ASSEM}	Assembling time of product i
$start_{js}$	Binary parameter whether customized part j starts at manufacturing step s *(stochastic value)*
n^{DM}	Mold life made by dedicated tooling machine
n_{k}^{AM}	Mold life made by AM technique k
p_{i}^{ST}	Unit price of standard product i
c_{j}	Unit cost of manufacturing part j
k_{m}^{DM}	Purchasing cost of a unit of dedicated machine m
k_{k}^{AM}	Purchasing cost of a unit of AM machine k
h	Holding cost of a part unit
w_{t}	Available working time in period t
rm_{jlr}^{C}	Binary parameter whether customized part (j, l) is supposed to be made with raw material r *(stochastic value)*
b_{mr}^{DM}	Whether dedicated machine at manufacturing step m can handle raw material r
b_{kr}^{AM}	Whether AM with building technique k can handle raw material r
α_{jl}	Effective design vector for customized part (j, l) *(stochastic value)*

(*continued*)

Table 2. (*continued*)

s_{jln}	Effective design subfactor n of customized part (j, l)
$M^{DM}_{m,0}$	Initial number of dedicated machines m
$M^{AM}_{m,0}$	Initial number of AM machines k
C^{UP}	Upper bound of customization limit

Table 3. Decision variables

X^{ST}_{it}	Number of standard product i manufactured in period t
X^{CU}_{it}	Number of customized product transformed from standard product i manufactured in period t
Y^{NC}_{jt}	Number of part j manufactured in period t
Y^{C}_{jt}	Number of customized part j manufactured in period t
Z_{jlkt}	Whether customized part (j, l) at period t is fabricated by AM machine k
W_{jt}	Whether part type j can be customized at period t or not (binary)
M^{DM}_{mt}	Number of dedicated machine m in period t
M^{AM}_{kt}	Number of AM machine with building technique k in period t
PM^{DM}_{mt}	Number of dedicated machine m purchased at the start of period t
PM^{AM}_{kt}	Number of AM machine k purchased at the start of period t
I_{jt}	Inventory level of part j at the end of period t
$MOLD^{NC}_{jt}$	Number of molds of non-customized part j manufactured by dedicated tooling machine in period t
WT^{DM}_{mt}	Working time of dedicated machine m in period t
WT^{AM}_{kt}	Working time of AM machine with building technique k in period t
$WT^{C\_DM}_{mt}$	Working time of dedicated machine m operating for customized parts in period t
C^{CU}_{it}	Customization level of product i
β_t	Service level (order fulfillment ratio) for custom orders at period t

3.2 Mathematical Model

The objective functions of MCCP model are to maximize the economic benefit during the entire planning periods as in Eq. (1), at the same time to maximize the total customization level of the products as in Eq. (2).

Maximize

$$\begin{aligned} f_1 = & \sum_{t=1}^{T}\sum_{i=1}^{I}\left(p_i^{ST} \times X_{it}^{ST} + p_i^{CU} \times X_{it}^{CU}\right) - \sum_{t=1}^{T}\sum_{j=1}^{J} h \times I_{jt} \\ & - \sum_{t=1}^{T}\sum_{m=1}^{M} k_m^{DM} \times PM_{mt}^{DM} - \sum_{t=1}^{T}\sum_{k=1}^{K} k_k^{AM} \times PM_{kt}^{AM} \\ & - \sum_{t=1}^{T}\sum_{m=1}^{M} e_m^{DM} \times WT_{mt}^{DM} - \sum_{t=1}^{T}\sum_{k=1}^{K} e_k^{AM} \times WT_{kt}^{AM} \end{aligned} \tag{1}$$

Maximize

$$f_2 = \sum_{t=1}^{T} \sum_{i=1}^{I} C_{it}^{CU} \tag{2}$$

Subject to

$$I_{jt} = I_{j,t-1} + Y_{jt}^{NC} - \sum_{i}^{I} \left\{ n_{ij} \times X_{it}^{ST} + n_{ij} \times X_{it}^{CU} - Y_{jt}^{C} \right\} \qquad \forall j, t \tag{3}$$

$$Y_{jt}^{C} = \sum_{i}^{I} n_{ij} \times X_{it}^{CU} \qquad \forall j, t \tag{4}$$

$$X_{it}^{ST} = d_{it}^{ST} \qquad \forall i, t \tag{5}$$

$$X_{it}^{CU} \le d_{it}^{CU} \qquad \forall i, t \tag{6}$$

$$\sum_{i}^{I} X_{it}^{CU} = \sum_{i}^{I} d_{it}^{CU} \times \beta_t \qquad \forall t \tag{7}$$

$$Y_{jt}^{C} \le W_{jt} \times big\, M \qquad \forall j, t \tag{8}$$

$$C_{it}^{CU} = \frac{\sum_j \left(n_{ij} \times W_{jt} \right)}{\sum_j n_{ij}} \qquad \forall i, t \tag{9}$$

$$C_{it}^{CU} \le C^{UP} \qquad \forall i, t \tag{10}$$

$$MOLD_{jt}^{NC} \ge \frac{Y_{jt}^{NC}}{n^{DM}} \qquad \forall j, t \tag{11}$$

$$\sum_{k=1}^{K} Z_{jlkt} = 1 \qquad \forall j, l, t \tag{12}$$

$$M_{mt}^{DM} = M_{m,t-1}^{DM} + PM_{mt}^{DM} \qquad \forall m, t \tag{13}$$

$$M_{kt}^{AM} = M_{k,t-1}^{AM} + PM_{kt}^{AM} \qquad \forall k, t \tag{14}$$

$$WT_{mt}^{C\_DM} = \sum_{j=1}^{J} \sum_{l=1}^{Y_{jt}^{CU}} \left(t_{jlm}^{C\_DM} \times \sum_{s=1}^{m+1} start_{js} \right) \qquad \forall m, t \tag{15}$$

$$WT_{kt}^{AM} = \sum_{j=1}^{J} \sum_{l=1}^{Y_{jt}^{CU}} \left\{ \left(t_{jlk}^{C\_AM} + t_{k}^{Set\_AM} + t_{k}^{Post\_AM} \right) \times Z_{jlkt} \right\} \qquad \forall k, t \tag{16}$$

$$WT_{mt}^{DM} = \sum_{j=1}^{J} \left(t_{jm}^{NC} MOLD_{jt}^{NC} + t_{m}^{Set\_DM} \right) + WT_{mt}^{C\_DM} \qquad \begin{matrix} \forall t \\ m = 1 \end{matrix} \tag{17}$$

$$WT_{mt}^{DM} = \sum_{j=1}^{J} \left(t_{jm}^{NC} Y_{jt}^{NC} + t_{m}^{Set\_DM} \right) t_{jm}^{NC} + WT_{mt}^{C\_DM} \qquad \begin{matrix} \forall t \\ m = 2 \end{matrix} \tag{18}$$

$$WT_{kt}^{AM} \le w_t \times M_{kt}^{AM} \qquad \forall k, t \tag{19}$$

$$WT_{mt}^{DM} \le w_t \times M_{mt}^{DM} \qquad \forall k, t \tag{20}$$

The customization level of the product i at period t is calculated from Eq. (9). Equation (10) ensures that the value of customization level can't be over than the upper bound of the customization level. Equation (11) ensures the number of molds used to fabricate un-customizable part j must be higher than the number of un-customizable part j divided by the mold life n^{DM}. Equation (12) ensures that only one of AM techniques is selected to proceed customized part l from part j at the period t. Equations (13) and (14) represent the number of machine m at period t is the sum of the number of machines at the previous period $t-1$ and the number of machines purchased at the start of the period t. Equations from (15) to (20) are the time-related capacity constraints of the manufacturing processes.

3.3 Solution Algorithm

The MCCP model requires a specific solution searching procedure since it includes probabilistic parameters and multi objectives, and the range of index l (index of customized part) is decided by the decision variable Y_{jt}^{C}. The solution searching procedure is divided into two parts: (1) to decide optimal MCCP plan and (2) to check the time-related capacity constraints of machines (Fig. 1). In terms of solving multi-objective problem, the algorithm controls the upper limit of the second objective (total customization level), finds optimal plan satisfying feasibility condition with the given value of the second objective, and relaxes the boundary of the second objective if the resulting solution is infeasible. To address the solution algorithm, an index p is defined as the iteration number.

One of the key elements of this algorithm is C^{UP}, the upper bound of customization level. The value of C^{UP} is renewed at every iteration p. The solution searching algorithm starts with $p = 0$. The first stage focuses on deciding optimal customization level which satisfies C_{p}^{UP}. In this stage, the mathematical model is applied except the equations which include index l such as Eqs. (12), (15), and (16). The second stage checks feasibility of the result of the first stage. If the solution can't satisfy the time-related capacity constraints, it must pass through another iteration with the iteration

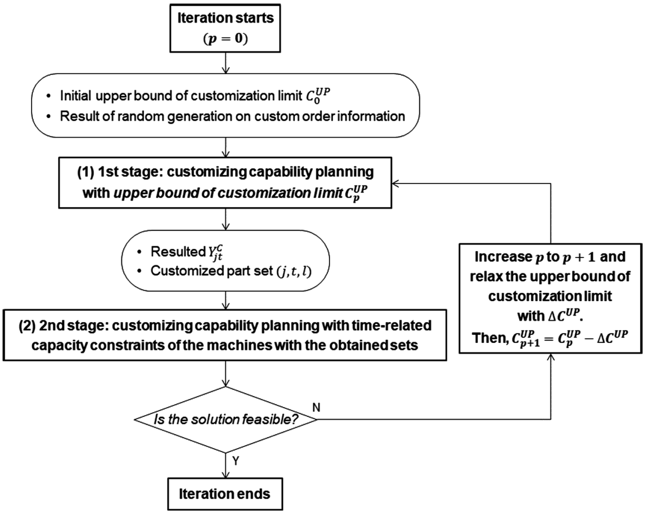


Fig. 1. Solution algorithm of the MCCP model

number $p+1$. With the increased iteration number, the upper bound of customization level C_{p+1}^{UP} has a value of $C_p^{UP} - \Delta C^{UP}$, which lowers the previous upper bound of customization level with ΔC^{UP}.

4 Experimental Analysis

To validate the MCCP model, a simple experimental analysis was carried out. It reflected the situation where the custom demand increased with linearly. Also, three manufacturing steps were considered: prototyping, tooling, and fabrication with consideration of the AM's possible function in production system. It was assumed that dedicated manufacturing technology corresponds to a certain manufacturing step. In this case, injection molding was assigned to fabrication, and machining was assigned to tooling. Meanwhile, AM processes were assumed to be capable of operating in all manufacturing steps. And, the five different AM processes included selective laser sintering, electron beam melting, laser metal deposition, fused deposition modeling, and stereolithography apparatus. The lengths of processing time, setup time, and post-processing time were assumed based on the characteristics of the processes. There were two types of products which consisted of two common parts and the other differentiated part. The demand of each product was randomly generated from normal distribution with its mean and standard deviation (which was set as 10).

The result showed that the customization level stayed same due to the lower demand increasing rate (0.2% per period). Meanwhile, the ratio of the number of customized products to the total number of products increased as the custom demand increases. In terms of the machines, three AM machines with SLS process were purchased to correspond to the increasing trend of custom demand.

5 Conclusion

To implement mass customization successfully, the mass customizer should balance between the two contrasting objectives: production flexibility and cost-efficiency. This study argues that the mass customization capability, defined as the ability to balance between the two objectives, must be planned as a long-term planning step. Based on the argument, the MCCP model is developed to support the mass customizer's decision-making process on its appropriate level of production flexibility, as well as the resulting profits. Also, heuristic method is used to search optimal boundary of the decision variables, especially the customization level and order fulfillment ratio.

References

1. Davis, S.: From 'future perfect': mass customizing. Plan. Rev. **17**(2), 16–21 (1989)
2. Pine, B.: Mass customizing products and services. Plan. Rev. **21**(4), 6–55 (1993)
3. Duray, R., Ward, P., Milligan, G., Berry, W.: Approaches to mass customization: configurations and empirical validation. J. Oper. Manag. **18**(6), 605–625 (2000)
4. Silveria, G., Borenstein, D., Fogliatto, F.S.: Mass customization: literature review and research directions. Int. J. Prod. Econ. **74**(49), 1–13 (2001)
5. Carr, S., Duenyas, I.: Optimal admission control and sequencing in a make-to-stock/make-to-order production system. Oper. Res. **48**(5), 709–720 (2000)
6. Rudberg, M., Wikner, J.: Mass customization in terms of the customer order decoupling point. Prod. Plan. Control **15**(4), 445–458 (2004)
7. Sawhney, R.: Implementing labor flexibility: a missing link between acquired labor flexibility and plant performance. J. Oper. Manag. **31**(1–2), 98–108 (2013)
8. Gero, J.: Recent advances in computational models of creative design. In: Pahl, P., Werner, H. (eds.) Computing in Civil and Building Engineering, vol. 21, pp. 21–30. Balkema, Rotterdam (1995)
9. Gibson, I., Rosen, D.W., Stucker, B.: Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital Manufacturing. Springer, New York (2010). https://doi.org/10.1007/978-1-4419-1120-9
10. Tu, Q., Vonderembse, M., Ragu-Nathan, T., Ragu-Nathan, B.: Measuring modularity-based manufacturing practices and their impact on mass customization capability: a customer-driven perspective. Decis. Sci. **35**(2), 147–168 (2004)
11. Zhang, M., Zhao, X., Qi, Y.: The effects of organizational flatness, coordination, and product modularity on mass customization capability. Int. J. Prod. Econ. **158**, 145–155 (2014)
12. Zhang, M., Zhao, X., Lyles, M., Guo, H.: Absorptive capacity and mass customization capability. Int. J. Oper. Prod. Manag. **35**(9), 1275–1294 (2015)
13. Kristal, M., Huang, X., Schroeder, R.: The effect of quality management on mass customization capability. J. Oper. Prod. Manag. **30**(9), 900–922 (2010)

Construct a Customized Product Service System Utilizing Multi-agent System

Cheng-Yen Chang, Chi-Hsuan Tsai, and Ming-Chuan Chu(✉)

National Tsing Hua University,
No. 101, Section 2, Kuang-Fu Road, Hsinchu 30013, Taiwan
fred831226@gmail.com, mcchiu@ie.nthu.edu.tw

Abstract. Over the years, the way customers measure value has changed drastically. If companies still focusing on pure product quality or cost, will gradually lose competitiveness. Considered as a solution to the strategy, the product service system combines tangible products, intangible services, and back-end support systems to reduce the risk of uncertainties and meet diverse customer needs. Although there are many studies on product service systems, there are still opportunities of improving design methods that can provide different content in response to changing need. In view of customization, this paper utilizing text analytic technique to capture PSS improving opportunity, and realizing customization with a MAS-based recommend system.

Keywords: Product service system · Multi-agent system
Recommender system · Text analytic

1 Introduction

Over past few decades, the way how customer measure values undergone great changes. Additional service or customer experience are gradually exerting influence on value chain. To address those issues, product service system (PSS), which combined both product and service for improving sustainability and competitiveness, is therefore heavily discussed and considered as an effective solution. However, due to the increased demand for customized products and the changing trends in customer demand, a more flexible and changing environment will have to be considered when designing PSS. By the ability of dealing changing environment, Multi-agent system (MAS) is considered as a tool for realizing customization. Additionally, to obtain the voice of customer in a changing environment immediately and systemically, design requirement is captured from Internet with text mining technique. To sum up, the aim of this study is utilizing text mining technique to uncover customer needs and redesign PSS, then provide customized PSS to user by a MAS-based recommend system. Section 2 is the review of past study on PSS and MAS. The framework of designing customized PSS is showed in Sect. 3, and with a preliminary result in Sect. 4. Finally, conclusion and future work are discussed in Sect. 5.

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 193–200, 2018.
https://doi.org/10.1007/978-3-319-99704-9_24

2 Literature Review

2.1 Product Service System and Configuration Approaches

Goedkoop *et al.* (1999) first defined PSS as "a marketable set of products and services capable of jointly fulfilling a user's needs"." In the last few decades, PSS has attracted much attention from research teams and industries due to its economic and sustainability potential (Tukker 2004), and it performance been proofed by many cases (Vezzoli (2003); Sakao (2009)). Baines *et al.* (2007) collect and summarize the definition of PSS, and emphasis is on the 'sale of use' rather than the 'sale of product'. Tukker (2004) then elaborate it and developed an eight archetypical model. The focus of recent research has been on designing the framework of PSS development, Wang *et al.* (2011) proposed a framework for product-service life cycle management and technologies of development. Amaya (2014) using lifecycle analysis to design for intensified use in PSS. Other research has also discussed what tools could be utilized in PSS design such as Song *et al.* (2015) proposed a method for service modularization through modified service blueprint and fuzzy graph, and Song and Sakao (2017) using TRIZ to identify and resolve services design. In summary, the literature on PSS design shows a variety of approaches. However, most of precious researches on PSS design are focusing on satisfying customer in general, without the consideration of customization. This study focused on this gap by providing a recommendation system for PSS customization.

2.2 Multi-agent System

Durfee and Lesser (1989) initially defined MAS as follow, "a loosely coupled network of problem solvers that interact to solve problems that are beyond the individual capabilities or knowledge of each problem solver". These problem solvers also named as agents, and each of them can be seen as a separate computer system or software. While each agent is designed to follow their own rule, they can also communicate, coordinate, and negotiate with others to reach agreement. Through interaction, MAS can process and integrate heterogeneous data sources and provide users with a consistent operating environment, which raise the efficiency and flexibility of problem solving.

From the emergence of MAS, it has been applied to many fields. Sun *et al.* (2001) introduced a distributed multi-agent environment for product design and manufacturing planning. Mishra *et al.* (2001) proposed a multi-agent framework for reverse logistics planning. Tsai and Chiu (2017) utilizing MAS and pervasive computing to construct a personalized PSS recommender system. Previous studies indicate that MAS has it potential to solve complex and dynamic problems. Many studies have applied MAS to construct a recommendation system. Nonetheless, few research focused on its potential for solving PSS customization problem, and how can it help in PSS improvement process.

3 Methodology

The framework of customized PSS design process consists of 3 parts and can be further segmented to 5 steps as shown in Fig. 1. Detailed instruction is discussed in following paragraph.

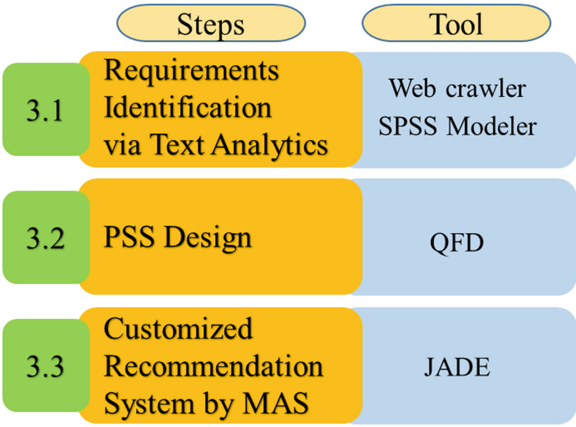


Fig. 1. Customized PSS design process

3.1 Requirements Identification

The beginning of designing customized PSS is to identify what's the customers' requirement. In recent days, customers are willing to share their experience on Internet, these kind of information has advantages of truthful, direct, unconcealed and easy to obtained, all the advantages of it leading Internet data a great potential to capture customer requirement instantly and easily.

With the help of developed web crawler software, decision makers are allowed to capture lots of information from Internet. However, the data captured from Internet are practically long, unclassified and segmented, and thus it need to be further analyzed for better understanding.

Text analytic technique is then utilized to decompose the long and segmented data obtained from step 1. For the purpose of discovering customers' requirements and what present PSS offered do they still unsatisfied, text analytic technique focus on extracting some satisfaction parameters such as good, excellent, bad, not perfect, unacceptable, etc. The result of analytics categorized the obtained data into two prospects - new service we need to developed and present service we need to improve.

3.2 PSS Design

After text analytic, the requirements of customers are clear and prepared for decision makers to design improved PSS accordingly. The concept of designing a customized

PSS is figuring out the potential service or solutions that can be offered to satisfy various customer, and finding the tradeoff between customer and PSS provider simultaneously. There are multiple techniques can be utilized in designing PSS as we reviewed in Sect. 2, including QFD, service blueprint, lifecycle assessment and so on. In this study, we simply utilized a requirement-solution matrix to demonstrate the PSS design process. It's only a simple demonstrate and can be further improved by decision makers.

3.3 Customized Recommend System

After the solution set was established, customized PSS recommend system needs to provide the best fit PSS solution for each customer with various requirement accordingly. With the aim of offering customized PSS precisely, recommend system requires certain parameters (age, gender, weather, schedule, etc.) design for better characterizing each individual.

Multi-agent system consists of different kind of agents, each agent follows their own rule and has the ability of communicating with others to search trade-off. The function of agents is varying, such as sensing and acquiring data, computing, comparing, etc. The framework and simple demonstration is shown in Fig. 2.

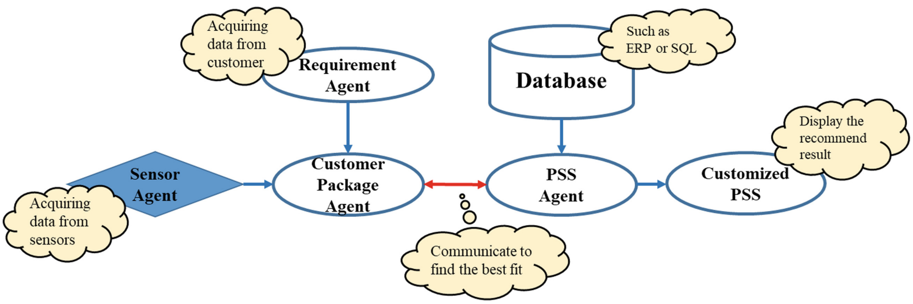


Fig. 2. MAS framework for recommend system

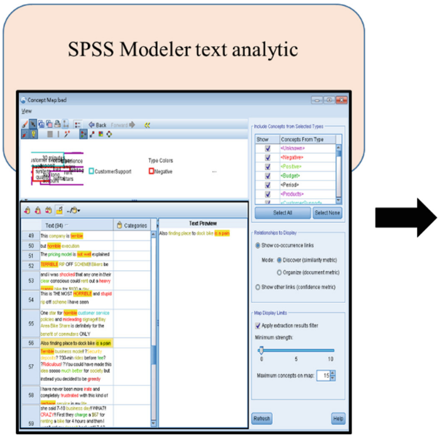
As decision variables stored in customer package agent, specific requirements information of each individual are obtained from either sensor (weather, schedule on smartphone, location, etc.) or customers (preference, gender, etc.). Then, PSS agent obtained product, service, system design data from the database. By communicating with customer package agent, PSS agent is allowed to calculate the best fit PSS solution for individual.

4 Preliminary Results

In this study, we conduct the PSS of bike rental business as a demonstration of the customized PSS recommend system designing process. With a survey into customers' comment on Internet, we discovered there's a gap between customer's expectation and poor performance of present PSS. The PSS redesign process of 5 steps discussed in Sect. 3, detailed demonstration is showed below.

4.1 Requirements Identification

We utilized WebHarvy software as a text mining tool to captured customers' review on bike rental system. We have totally mined 267 reviews in total from several websites. However, the initial mining results are prolix and unclassified for text analytic. To address this problem, the original data has been treated from 267 review to 2711 sentences. As our goal is to bridge the gap of customer's expectation, text analytics focus on the customers' satisfaction on present bike rental PSS. This study utilized SPSS Modeler as text analytic tool. The process and result is showed below (Fig. 3).



	Negative comments (worth to improve)	Positive comments (worth to develop)
station	1. Empty (46) 2. Too far (21) 3. No place to dock (44)	1. Company knows the pattern to rearrange the bikes between station. 2. Offering different types of bike. 3. App is useful to see the station condition.
bike	1. Broke (40) 2. Heavy (32)	4. Bike with basket is useful. 5. Good for tourist, every attractions have one station. 6. Bike has front/end light. 7. Can be used as exercise.
Rental service	1. Bad customer service (36) 2. Price model isn't explained well (44)	

Fig. 3. Text analytic process and result

4.2 PSS Design

For the goal is to establish a customized PSS recommend system with service design and MAS as solution, some assumptions have to be made. First, PSS design must have relation to the recommend system. Second, from the result of text analytics, the observation is that we have to design new service for negative comments, while the service demand of positive comments is pretty straight forward. Third, the feasibility of product/service design in following section are proved since some of companies are already providing. A simple evaluation of which function of MAS can dealt with customers' requirement is showed in Table 1 below.

Table 1. Requirement-function matrix

	Customer requirement	Product design	Service design	MAS sensors function	MAS recommend function
Worth to improve	Station is empty			V	
	Station is too far	V			
	Station has no place to dock			V	
	Bike is broken		V	V	V
	Bike is heavy	V			
	Bad customer service		V		
	Price model isn't explained well				V
Worth to develop	Knows the pattern to rearrange the bikes between station		V	V	
	Offering different types of bike.	V			V
	App is useful to see the station condition		V	V	V
	Bike with basket is useful	V			V
	Every attractions have one station	V			
	Bike has front/end light	V			V
	Can be used as exercise	V	V		V

4.3 Customized Recommend System

MAS design start with developing relative decision parameters in reply of customize for each customer. And through the calculation of agents to output the recommend result. The MAS model is designed as below (Fig. 4).

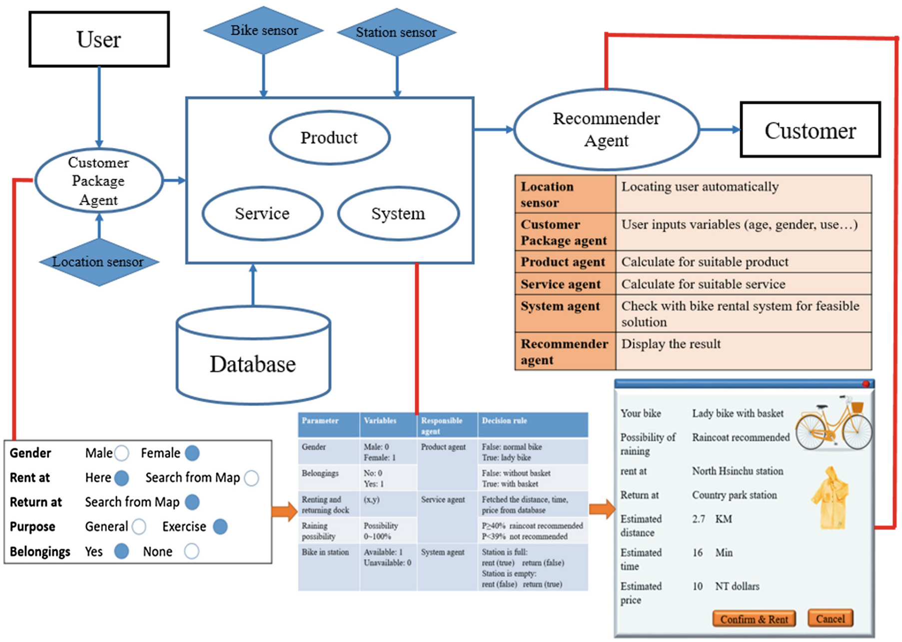


Fig. 4. Customized recommender system structure

While user start using the recommend system, they are asked to choose some parameters such as gender (male or female), purpose (for general transportation or for exercising), location (start and end point). Location parameters particularly can be fetched by location sensors. At the same time, PSS agent also fetched product data (types of bike, basket or not, etc.), service data (price model, nearest dock) and system data (if the dock is empty or full) from sensors and database.

After that, PSS agent follow certain rules assigned by designers to calculate the feasible solution which best fit the user. The rule can be in many forms by correlation coefficient, Boolean (true/false), decision tree, mathematical calculation or simply fetched the result in database. PSS agents will then calculate the recommend solution by their rule after fetched the parameters set by user and the product/service/system data from database.

4.4 Discussion

The whole process is within the goal of improving the performance of present PSS and providing customer a customized solution at the same time. First, compared to traditional way (questionnaire, phone survey, etc.), applying text mining techniques on requirement identification is a systematic and quick way to know the real voice of customers. However, this method only suitable when customer review data on Internet is sufficient and thus has it limitation.

Second, PSS design and customized recommend system design are altogether fulfilling what customer desired. Yet such design is very delicate due to PSS design in one hand has to fulfill customers' need, and have connection with MAS design in another. Additionally, the customize recommend function should be built on the foundation of which PSS is well-developed. To address this issue, the relation between PSS and decision rule of MAS must be processed simultaneously. In this case study, customized recommend system operates well is based on the fact that product, service and system of bike rental system is already developed and proved. But in other scenario, PSS design and improvement should be executed before customization.

5 Conclusion

For the way of customer define value has changed and the demanding of customization has risen, customized PSS is proved to be a competitive solution addressing for the problem. This study integrated several techniques to develop a customized PSS design framework with MAS-based recommend system. First, we utilizing text mining and analytic technique to capture the voice of customer. Based on the result, decision makers could improve and redesign the present PSS model. Finally, the MAS-based recommend system helps to realize the demand of customization.

The contribution of this paper is we suggesting a systematic and simple way of realizing customized PSS. Compared to other PSS design framework, utilizing Internet crawler and text analytic techniques could reduce lots of resource and effort, so as the MAS-based customized recommend system.

However, this study still has several limitations. First, the performance of recommend system haven't been measured in the study. Second, customized recommend system only works when PSS is well-developed. Third, the study (including MAS) is only a demonstration, and need to be improve with a real case and a well-developed recommend system. All limitation above can also be a direction for further study.

References

Amaya, J., Lelah, A., Zwolinski, P.: Design for intensified use in product–service systems using life-cycle analysis. J. Eng. Des. **25**(7–9), 280–302 (2014)

Baines, T.S., et al.: State-of-the-art in product-service systems. Proc. Inst. Mech. Eng. Part B: J. Eng. Manuf. **221**(10), 1453–1552 (2007)

Durfee, E.H., Lesser, V.R.: Negotiating task decomposition and allocation using partial global planning. Distrib. Artif. Intell. **2**(1), 229–244 (1989)

Goedkoop, M.J., Van Halen, C.J., Te Riele, H.R., Rommens, P.J.: Product service systems, ecological and economic basics. Report for Dutch Ministries of Environment (VROM) and Economic Affairs (EZ), vol. 36, no. 1, pp. 1–122 (1999)

Manzini, E., Vezzoli, C.: A strategic design approach to develop sustainable product service systems: examples taken from the 'environmentally friendly innovation' Italian prize. J. Clean. Prod. **11**(8), 851–857 (2003)

Mishra, N., Kumar, V., Chan, F.T.: A multi-agent architecture for reverse logistics in a green supply chain. Int. J. Prod. Res. **50**(9), 2396–2406 (2001)

Sakao, T., Sandström, G.Ö., Matzen, D.: Framing research for service orientation of manufacturers through PSS approaches. J. Manuf. Technol. Manag. **20**(5), 754–778 (2009)

Song, W., Sakao, T.: A customization-oriented framework for design of sustainable product/service system. J. Clean. Prod. **140**(3), 1672–1685 (2017)

Song, W., Wu, Z., Li, X., Xu, Z.: Modularizing product extension services: an approach based on modified service blueprint and fuzzy graph. Comput. Ind. Eng. **85**, 186–195 (2015)

Sun, J., Zhang, Y.F., Nee, A.Y.C.: A distributed multi-agent environment for product design and manufacturing planning. Int. J. Prod. Res. **39**(4), 625–645 (2001)

Tsai, C.S., Chiu, M.C.: Design of personalized product service system utilizing multi-agent system. Transdiscipl. Eng.: A Parad. Shift, 845 (2017)

Tukker, A.: Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. Bus. Strategy Environ. **13**(4), 246–260 (2004)

Wang, P.P., Ming, X.G., Li, D., Kong, F.B., Wang, L., Wu, Z.Y.: Status review and research strategies on product-service systems. Int. J. Prod. Res. **49**(22), 6863–6883 (2011)

The Demand-Pull Approach to Business Model Innovation Through Product-Service Systems: A Case Study

Martha Orellano[1(✉)], Christine Lambey-Checchin[2], Khaled Medini[3], and Gilles Neubert[4]

[1] Ecole Nationale Supérieure des Mines de Saint-Etienne, CNRS, UMR 5600 EVS, 42023 Saint-Étienne, France
martha.orellano@emse.fr
[2] Université Clermont Auvergne, EA3849 CRCGM, 63008 Clermont-Ferrand, France
[3] Ecole Nationale Supérieure des Mines de Saint-Etienne, CNRS, UMR 6158, LIMOS, 42023 Saint-Étienne, France
[4] EMLYON Business School, CNRS, UMR 5600 EVS, 42009 Écully, France

Abstract. Industry is facing a deep transformation of the modes of production and consumption, resulting in a shift from product-centric practices towards sustainable and customer-oriented ones. In this context, Product-Service Systems (PSS) exhibit the potential for innovative and customer oriented value propositions. To take full advantage of PSS, it is essential to design suitable business models enabling an alignment of the processes, products and services to customer needs. Innovation Management is an important literature stream contributing to understand the business model transformation by differentiating between two main approaches of innovation: technology-push and demand-pull. Until now, little attention has been put in the demand-pull approach for business model innovation. The central question this paper addresses is: How does the demand-pull approach for the design of a PSS value proposition affects the whole business model of a company? To answer this question a literature review is a carried out, and then a research-intervention methodology is applied to a real case.

Keywords: Business models · Demand-pull innovation
Product-Service Systems · Case study

1 Introduction

Currently, manufacturing industry is shifting towards Product-Service Systems (PSS), considered as innovative value propositions, which are narrowly concerned with the customer integration and sustainability issues [1]. PSS are defined as the bundle of products and services capable to fulfill the customer needs along the time, improving profitability and competitiveness for the provider through services provision [1]. One of the main challenges for the adoption of PSS is the transformation of the whole business

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 201–210, 2018.
https://doi.org/10.1007/978-3-319-99704-9_25

model. Innovation Management is an important research stream contributing to understand the business model transformation and the effects inside and outside the company boundaries. Literature differentiates between two main approaches of innovation: technology-push and demand-pull, both influencing the business model design. Technology-push approach highlights the key role of science and technology as the trigger of innovation, while demand-pull approach argues that the innovation is the direct result of the customer demand. Even if in practice the demand-pull approach seems to be well understood, in literature little attention has been put in it [2, 3]. Taking into account such a lack on the literature, this paper focus on exploring the influence of the demand-pull approach in business models for innovative value propositions like PSS.

The central question this paper addresses is: *How does the pull-demand approach for the design of a PSS value proposition affect the whole business model of a company?* In particular, this paper aims at exploring how the organizational structure, the roles of actors and the value creation processes are transformed due to the adoption of a PSS value proposition triggered by the customer. To answer this question, a literature review is a carried out to understand the demand-based innovation of business models. Then a research-intervention methodology is applied in order to explore the influence of demand-pull innovation on the organizational structure, actors' roles, and PSS value creation process.

The structure of the paper is as follows: Sect. 2 explains briefly the state of the art and presents a conceptual framework of the PSS business model, with an emphasis on the demand-pull innovation. Section 3 presents the design of the research and Sect. 4 develops a single case study in a large-sized company carrying out a PSS project. Finally, conclusions and research perspectives are drawn in Sect. 5.

2 The Demand-Pull Approach to Business Models Innovation

2.1 The Demand-Pull Approach to Innovation

Innovation is traditionally defined as the set of technical, industrial and commercial operations that enable organizations to perform efficiently their economic activities [4]. Recent literature considers innovation as the iterative process of learning, which needs intensive collaboration between a broader set of actors to improve any process [5]. Given how extensive this concept is, innovation has been studied from two principal approaches: Technology-push and Demand-pull (also called Marked-pull) [4] (Fig. 1).

Technology-push approach highlights the key role of science and technology as the triggers of innovation, originated and developed from the provider capabilities [3]. Demand-pull approach, in contrast, argues that the innovation is the result of the market demand, which directly triggers the development of innovations and the principal actors are those involved in customer-provider relationships [4, 7]. In a technology-push innovation, the provider decides what to innovate in products, services and processes regarding its capabilities, taking the risk of developing an unsaleable offer. In this logic, the provider needs high investment in technology and internal learning, while the customer has mainly a secondary role during the whole development process

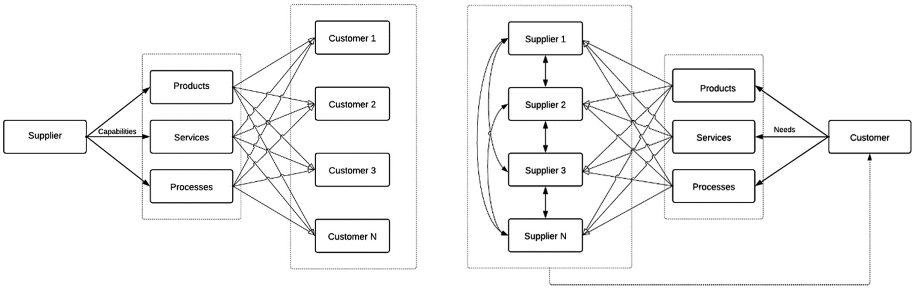


Fig. 1. Technology-push (left) and Demand-pull (right) approaches to innovation.

[2]. In a demand-pull innovation, the customer defines its needs in terms of products, services and processes and looks for providers capable to develop it while collaborating with a set of actors. In this logic, the provider must be reactive and manage the integration of the customer into the whole process, the risk is shared between the set of actors and the customer has a main role of coordinator. With the evolution of markets, technologies, human behavior and policies, the approaches to innovation have evolved towards more systemic models, adopting elements from both technology-push and demand-pull perspectives [5, 6]. Both approaches to innovation seems to be interdependent, where technology is a key resource and demand is the key driver guiding towards the right direction of economic growth [3]. However, the impacts of these innovation triggers on the business model are different [2], even if, in both cases, providers and customers must adapt their business models to the development of the innovative offers.

2.2 Business Model Innovation

Chesbrough [7] defines the business model as the heuristic logic of a company that connects the technical potential with the creation of value. They consider that innovation is not just about technology, but spans over the entire business model, which must be strictly aligned with the market [7]. Over the last decade, the research on business model has been associated to innovation in many ways, for instance, innovative revenue models (e.g. free business models, shared economy, low-cost offerings), the transformation of the value creation mindset (e.g. Service-Dominant Logic) and collaborating with external knowledge partners (open innovation) [7–9]. Several authors agree that the main challenge to innovate in business models is the conflict with the already established model, which means the resources, activities, actors, and the set of conventional practices [7, 8, 10]. Recent literature proposes the innovation in business model through the transformation of the value creation mindset, adopting a multi-actor and multidimensional approach [11]. One of the literature streams influencing the change of the value creation mindset is the SDL [9]. SDL states that the value is co-created by the provider and the customer, highlighting the primacy of value creation during the use phase, in which the value beneficiary is exclusively the customer. Beside customer-centric approach of SDL, recent authors consider that a business model encompasses environmental, social and economic values, co-created by and for a broader set of actors in a business ecosystem. For instance, Tukker et al. [12] associate business model innovation to disruptive innovative value propositions that seeks to respond to sustainability issues with a customer orientation. These authors argue that the radical innovation in business models is the most efficient way for achieving sustainability while improving competitiveness [10, 12]. In this sense, Bocken et al. [13] propose some sustainable business model archetypes, which are able to create value while respecting the environment and society. PSS is one of the considered business models archetypes, and it is typically defined as the bundle of products and services capable to fulfill customer needs along the time, improving profitability and competitiveness while seeking at reducing environmental and social impacts [1].

2.3 Conceptual Framework for PSS Business Models Innovation

This section reports on a conceptual framework for PSS business models, which takes into account the lifecycle perspective intrinsic into PSS offerings (Fig. 2). This conceptual framework aims at explaining the business model as a central element of the economic activities, which must be linked to the environmental and social spheres during the whole lifecycle of a given offer [10, 11, 14]. The business model shapes the interaction between socio-economic and politic actors, involving customers, stakeholders, partners, competitors, public institutions and government, which could be enablers of innovation initiatives [8, 11, 14].

	Beginning of life (BOL)				Middle of life (MOL)		End of life (EOL)	
Sub-process Business model element	Conception	Testing	Production	Distribution	Use	Maintenance	Tacking back	Disposal
Value structure	Actors (resources, activities, relationships)				Actors (resources, activities, relationships)		Actors (resources, activities, relationships)	
Value proposition	Product oriented PSS				Service or result oriented PSS		Service or result oriented PSS	
Value performance	Dimensions: Environmental, social, relational and economics.				Dimensions: Environmental, social, relational and economics.		Dimensions: Environmental, social, relational and economics.	
	Methods to evaluate value performance: LCC (Lifecycle Costing), LCA (Lifecycle Assessment), SLCA (Social Lifecycle Assessment), Relational metrics: PEAK Collaborative index							

Fig. 2. Conceptual framework of business models for Product-Service Systems (PSS) [16].

The elements of the proposed framework are defined as follows: *Value proposition* relates to the offer that is developed to fulfill a specific need of the customer, approached by a PSS type [15]. *Value structure* refers to the set of actors involved in the required processes and the relationships between them. *Value performance* refers to the evaluation of the value created from the business activity in each stage of the lifecycle. These elements of the business model are impacted by the ideas of innovation engendered from the customer side [8]. Next section illustrates this impact through a case study.

3 Research Design

3.1 Case Study Description

For this research, the case study method is used to generate in-depth insights about the effects of the demand-pull approach to innovation on the business model of a selected company. Using a case study contributes to addressing the lack of empirical data about business model innovation from a demand-pull approach, specifically, addressing PSS contexts [8]. The case study is conducted within a large-sized company, which we will call C1, for confidentiality reasons. C1 business activity is the production and distribution of energy. One of the most important support activities of the company is the provision of safety clothing for all its employees. Currently, the safety clothes belong to the employees who are fully responsible for their usage, maintenance and end of life. This process introduces a lack of control by C1 of some phases of the safety clothes lifecycle. To address this problem, C1 launched an innovation project to redefine the offer in collaboration with its key suppliers. The objective of the project is to move from a product purchasing-based offer towards a PSS-based offer considering a life-cycle perspective. For the new offer, C1 wants to have available safety clothes all the time for the employees, while guarantying the traceability during the entire lifecycle with the lowest possible environmental and social impacts. This project represents a clear demand-pull innovation, where the customer (C1) introduces the innovation and coordinates all the actors to achieve the objectives.

3.2 Research-Intervention Methodology

The collaboration with C1 takes place in a 2 years project, which started in October 2017. The project is structured in three main phases: (i) Diagnostic of the current business model, (ii) Proposal of the future business model and (iii) Transformation of the purchasing strategy. By the time this paper is written, the project is at an early development stage (phase i), whose objective is to give some insights about the current business model and the key elements for the transformation. The methodology during the diagnostic phase is as follows:

a. **Research preparation:** Literature review to define the business model elements and the PSS characteristics. Based on literature elements, we structured the interview guides, one model for the internal actors (inside C1) and another one for the external actors (outside C1).
b. **Intervention with internal actors:** We tested and validated the interview guides with the employees from the purchasing department. Then, a workshop was conducted with the employees from the following departments: Human Resources, Purchasing, Prescription, Research & Development and Sustainable Development. 12 semi-directive interviews were conducted with these employees, which include directors, managers and operative employees.
c. **Intervention with external actors:** A workshop was conducted with the contractors and potential providers, from confection, transportation, maintenance

(washing) and end of life treatment. 7 semi-directive interviews were conducted with the providers, which include commercial managers and CEOs.

d. **Diagnostic construction:** We made a lexical analysis of the interviews using the software ALCESTE to exploit the data.

4 Results

Based on the insights from the literature, C1 is clearly positioned in a demand-pull innovation scenario, where the customer is both the trigger of innovation and the main coordinator of the business model transformation (regarding internal and the external value chains). In the following, the case is described through the detailed framework of the PSS business model (Fig. 2). Each element of the business model is instantiated in the current model and in the prospective model as explained by the set of internal and external actors interviewed. Table 1 describes in detail the current C1 business model and Table 2 illustrates the different transformations observed from the demand-pull innovation induced with the PSS value proposition.

Table 1. Current business model of company C1.

Business model elements	Beginning of life (BOL)		Middle of life (MOL)	End of life (EOL)
Value proposition	Annual dotation of safety clothes following high security and image standards, short lead- time and at the lowest possible cost		N/A	N/A
Value structure (actors, resources, activities)	Internal value chain:	- Central role of the prescriber as the internal customer - Organization by "silos" - Purchaser dependent on the prescriber and providers - High privacy of internal data	- High level of responsibility of the users about the clothes use and maintenance	- High level of responsibility of the users about the clothes disposal
	External value chain:	- Transactional customer-provider relationships	- Productive partnership relationships - High privacy of own data	N/A

(*continued*)

Table 1. (*continued*)

Business model elements	Beginning of life (BOL)		Middle of life (MOL)	End of life (EOL)
		- High privacy of own data - Internalization of economic risks - Risk of market monopolization		
Value performance	- High economic expenses linked to the annual dotation - High water and energy consumption in the production and safety clothes (linked to use of cotton fiber)		- Uncontrolled water and energy consumption in the washing process of the safety clothes	- Uncontrolled Waste generation - Degradation of the company's image

Table 2. Effects of the demand-pull innovation on the business model of company C1.

Business model elements	Beginning of life (BOL)		Middle of life (MOL)	End of life (EOL)
Value proposition	Permanently availability of safety clothes, which incorporates high security standards		Washing and maintenance processes with the lowest possible environmental and social impacts	Management of remanufacturing/reusing/recycling processes with the lowest possible environmental and social impacts
Value structure (actors, resources, activities)	Internal value chain:	- Collaborative organization - Empowerment of the purchaser as the key coordinator between internal actors and providers - Information sharing	- Responsibility of employees about the correct use of safety clothes - Information sharing	- Intensive information sharing - Strategic perception of the waste

(*continued*)

Table 2. (*continued*)

Business model elements	Beginning of life (BOL)		Middle of life (MOL)	End of life (EOL)
		- Collaboration with the trade unions		
	External value chain:	- Collaboration with other purchaser companies to rich high demand levels - Collaboration with other actors of the value chain to achieve the set of criteria in the value proposition - Long-term partnerships - High responsibility on the entire lifecycle of the offer - Possibility to new providers to enter to the market - Risk of high customization and limited marketability of the offer	- Intensive information sharing - Possibility to new providers to enter to the market - High responsibility on the entire lifecycle of the offer	- Intensive information sharing - Possibility to new providers to enter to the market - High responsibility on the entire lifecycle of the offer
Value performance	- Economic savings linked to the reduction of the material consumption (purchasing availability and not physical products) - Economic risk sharing - Reduction of water and energy consumption linked to the use of eco-friendly fibers		- Economic risk sharing - Reduction of water and energy consumption linked to the control of the washing process - Guarantee of employees security and comfort	- Remanufacturing, reusing and recycling in the end of life - Contracting with local companies and charity organizations

The analyzed sample of internal and external actors is diverse regarding their profiles, for instance, operative employees, managers and CEOs from different departments of the implied organizations. The study reveals interesting points of evolution, relating particularly to the collaboration and the integration of sustainability issues into the PSS value proposition. Furthermore, some specific roles within the internal value chain of C1 are radically transformed, for instance, the prescriber and the purchaser changed their roles in front of the offer definition. Moreover, there is a need concerning the organization of transversal work teams in C1 to redesign the offer of safety clothing, and new alliances must be considered in the external value chain in order to fulfill the criteria of the innovative value proposition of a PSS.

5 Conclusions

Innovating in business models depends highly on the firm context and the objectives to be achieved through the innovation initiatives. Both technology-push and demand-pull approaches interact in an interdependent way to trigger successful transformations within the business model. Furthermore, the demand-pull approach seems to be crucial to achieve a successful business model transformation, as it enables to consider a complex set of needs coming from customers, partners, public sector and society in a global sense. The case study shows that, in PSS context, the demand-pull approach leads to radical transformations of the entire business model, involving the internal value chain and the external value chain. Additionally, the case study reveals that the actors' needs go beyond economic interests and integrate sustainability aspects like the minimization of the water consumption and the improvement of the work conditions. This paper investigates the general impacts of demand-pull approach on business models innovation in one single case study. Certainly, more research is needed in different company contexts, taking into account aspects as culture, size, and domain of activity and maturity in the market. Conducting broader empirical research in this emerging topic contributes to have a complete vision about the impact of the demand-pull innovation approach in the business model transformation in B2B, regarding both customers' business models as well as providers' business models.

Acknowledgments. Auvergne Rhone-Alpes Region (France) supports this research through a doctoral thesis allocation, and the sponsors of this research conducted within the framework of the PEAK Cluster: THESAME, Funds F2I/UIMM, French Plan d'Investissement d'Avenir and its financial operator Caisse des Dépôts, the ACE project of PFA.

References

1. Vezzoli, C., Ceschin, F., Diehl, J.C., Kohtala, C.: New design challenges to widely implement "sustainable product-service systems". J. Clean. Prod. **97**, 1–12 (2015)
2. Chau, P.Y.K., Tam, K.Y.: Organizational adoption of open systems: a "technology-push, need-pull" perspective. Inf. Manag. **37**, 229–239 (2000)

3. Di Stefano, G., Gambardella, A., Verona, G.: Technology push and demand pull perspectives in innovation studies: current findings and future research directions. Res. Policy **41**, 1283–1295 (2012)
4. Rothwell, R.: Developments towards the fifth generation model of innovation. Technol. Anal. Strateg. Manag. **4**, 73–75 (1992)
5. Van Lancker, J., Mondelaers, K., Wauters, E., Van Huylenbroeck, G.: The organizational innovation system: a systemic framework for radical innovation at the organizational level. Technovation **52–53**, 40–50 (2016)
6. Tohidi, H., Jabbari, M.M.: Different stages of innovation process. Procedia Technol. **1**, 574–578 (2012)
7. Chesbrough, H.: Business model innovation: opportunities and barriers. Long Range Plann. **43**, 354–363 (2010)
8. Lüdeke- Freund, F.: Towards a conceptual framework of business models for sustainability. In: Knowledge Collaboration and Learning for Sustainable Innovation ERSCP-EMSU Conference, Delft, The Netherlands, pp. 1–28 (2010)
9. Vargo, S.L., Maglio, P.P., Archpru, M., Akaka, M.A.: On value and value co-creation: a service systems and service logic perspective. Eur. Manag. J. **26**, 145–152 (2008)
10. Antikainen, M., Valkokari, K.: A framework for sustainable circular business model innovation. Technol. Innov. Manag. Rev. **6**, 5–12 (2016)
11. Boons, F., Lüdeke-Freund, F.: Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. J. Clean. Prod. **45**, 9–19 (2013)
12. Tukker, A., et al.: Fostering change to sustainable consumption and production: an evidence based view. J. Clean. Prod. **16**, 1218–1225 (2008)
13. Bocken, N.M.P., Short, S.W., Rana, P., Evans, S.: A literature and practice review to develop sustainable business model archetypes. J. Clean. Prod. **65**, 42–56 (2014)
14. Rennings, K.: Redefining innovation – eco-innovation research and the contribution from ecological economics. Ecol. Econ. **32**, 319–332 (2000)
15. Tukker, A.: Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. Bus. Strateg. Environ. **13**, 246–260 (2004)
16. Orellano, M., Lambey-checchin, C., Medini, K., Neubert, G.: Towards an integration of lifecycle thinking into PSS business models. In: 10th CIRP International Conference in IPS2 on PROCEDIA CIRP, Linköping, Sweden, pp. 29–31 (2018)

Collaborative Networks

Scenarios for the Development of Platform-Based Networks for Additive Spare Part Production

Jana Frank(✉), Philipp Jussen, Lennard Holst, and Timo Lütke Meyring

Research Institute for Industrial Management (FIR) at RWTH Aachen, Campus-Boulevard 55, 52074 Aachen, Germany
Jana.Frank@fir.rwth-aachen.de

Abstract. The additive manufacturing technique “Selective Laser Melting” (SLM) provides the basis that is required for a fundamental paradigm shift in industrial spare part manufacturing, which affects both technological and organizational company practices. To harness the full potential of the SLM-technology with regard to agility and customizability, decentralized additive production networks need to be established. According to the principles of just in time, just in place and just enough, a global online platform that distributes construction orders to local manufacturing hubs could empower the market participants to utilize production capacities at optimal costs and minimal efforts. This work evaluates relevant fields of action by developing three future scenarios, which point out different future developments of key factors within the subject area. These scenarios enable market participants to react better and more agilely to unexpected market developments and, by doing so, make it easier for them to use the full potential of plat-form-based additive spare part production.

Keywords: Selective laser manufacturing · Additive manufacturing
Spare part production · Manufacturing networks · Supply-Chain-Management

1 Introduction

Since introduction of additive manufacturing techniques (AM) in the 1980s, the market has been growing every year. According to recent studies, revenue in the field of 3D printing will increase from 3 billion U.S. dollars in 2013 to 10.8 billion U.S. dollars by 2021 [1]. Apart from polymer-based techniques, the process of SLM, which consists of laser-melting layers of powder material into three-dimensional elements, has become the most commonly used AM-method for manufacturing of metal components.

An interesting field of application for SLM-manufacturing is the production of industrial spare parts. According to PwC Strategy&, more than 85% of spare part suppliers will have introduced AM to their businesses by 2020 [2]. Given this fundamental market shift, suppliers and customers face different challenges concerning technical maturity, copyright and market positioning. Moreover, aspects of collaboration and customization are critical for the success of an additive spare part production [2]. Current spare part production systems are predominantly organized in centralized

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 213–221, 2018.
https://doi.org/10.1007/978-3-319-99704-9_26

supply chains, entailing high costs for transport activities, insufficient communication of customer needs and long delivery periods. Raising the spatial and personal proximity between production sites and the point of sale by producing in local additive manufacturing hubs would not only reduce logistical effort, but also result in an increased customizability. SLM-technology facilitates this process, because additive manufacturing processes enable mass customization and pave the way for an agile production planning in intelligent manufacturing systems.

The approach of decentralizing additive spare part production systems enables market participants to harness the full potential of SLM-technology. Construction orders can be distributed more cost- and time-efficiently with the help of an online platform, just in time and just in place. The research project Add2Log, subsidized by the Federal Ministry of Economics and Technology, aims to develop such a platform for decentralizing additive manufacturing, which is schematically illustrated in Fig. 1. To analyze potential benefits and challenges of the platform implementation, it is necessary to begin with the determination of influential parameters. So-called key factors refer to critical areas of activity, which address the challenges mentioned above and determine the success of additive manufacturing. Once key factors are selected, they can be used to create future scenarios for the development of SLM-based spare part manufacturing. These enable market participants to react with greater flexibility to certain market developments. It also makes it easier for them to create a basis for developing a corporate governance strategy.

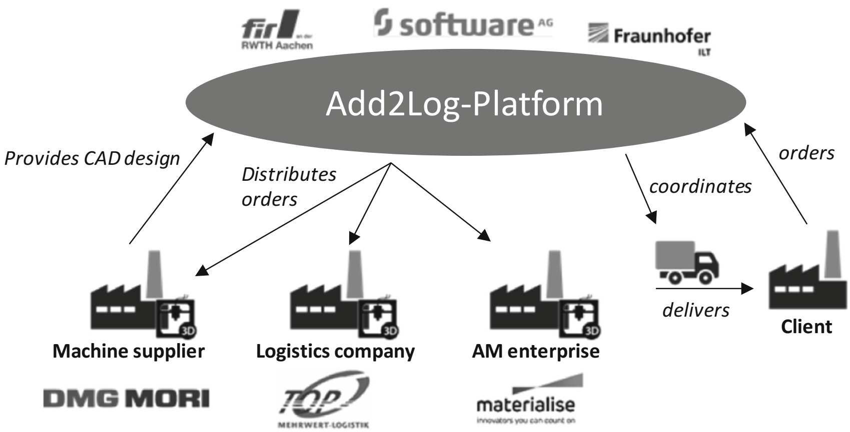


Fig. 1. Schematic illustration of the Add2Log platform for additive spare part manufacturing

2 State of Research

In this section, some of the scenarios currently available in scientific literature will be outlined to reveal research gaps regarding SLM-manufacturing, smart logistics and spare part production. Scenario A describes a large amount of small enterprises that use the full potential of new, inexpensive 3D printing techniques and machines to manufacture components on-demand, directly at the point of sale [3]. While distributors are being skipped in this scenario A, they play a key role in scenario B, according to which manufacturers partner with logistics companies to offer additional services. Services like this can be all kinds of different customization options. They are offered by the logistics company to shorten delivery times [4]. Scenario C subsequently proposes that manufacturers only provide the digital construction data, while manufacturing is outsourced to the customer. This business model focusses on data files as valuable and tradable goods, reshaping present manufacturing supply chains and branding strategies [5]. The results of this literature analysis disclose a research gap in the creation of SLM-specific scenarios for spare parts in digital networks, which is to be addressed in this work. Aspects such as material costs should be weighted differently when considering only metal-based AM-techniques. Furthermore, a focus on spare part production calls for a reconsideration of business models and quality management.

3 Methodology

The methodology used is called scenario analysis (see Fig. 2). Ute von Reibnitz describes this procedure, which is commonly used in many research fields, in great detail [6]. In this paper, the company-specific steps proposed by Reibnitz will not be taken into account, since the planned scenario analysis follows a rather holistic approach.

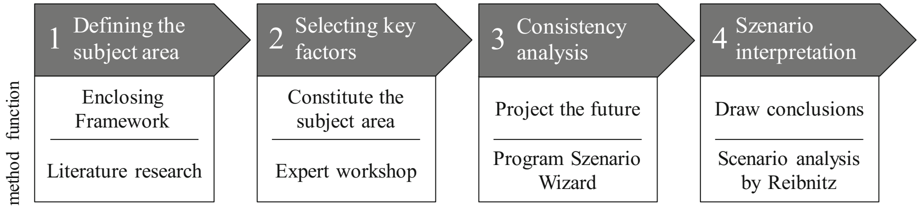


Fig. 2. Applied methodological steps from the scenario analysis [6]

In a first step, the subject area, which the key factors and scenarios will refer to, is defined and demarcated thematically, temporally, and territorially. Secondly, an impact analysis is conducted to determine potential key factors, which influence the subject area significantly. The factors are evaluated during a workshop with experts from the fields of logistics and additive manufacturing. Furthermore, the results of a comprehensive literature analysis are taken into consideration. The key factors serve as parameters to characterize the situation and determine the development of the subject area by dynamically interacting with each other. Thirdly, potential development trends of the selected key factors are specified. Three development trends are specified for each factor: An optimistic, a neutral and a pessimistic one, based on literature research. This is done in order to cover every possible future development of the respective aspect. To develop consistent scenarios, the results of the trend development serve as a basis for the creation of a two-dimensional cross-impact matrix. The matrix shows the mutual influences between all the determined development trends. The program ScenarioWizard is used to calculate consistent combinations of the key factors' development trends, based on certain preconditions [7]. In a fourth step, the resulting scenarios are interpreted and used to analyze implications for a network-based additive spare part manufacturing.

4 Results

4.1 Defining the Subject Area

The focus of this work is on the areas of intersection of the economic systems "additive manufacturing", "spare part manufacturing" and "logistics". More specifically, the key factor development focuses on the subsystem of logistics within SLM-manufacturing, considering critical fields of activity in platform-based production networks. The key factors are developed to be valid on a global scale. The time horizon for the scenario development is 10 years, as this represents a realistic time frame for the development and implementation of innovations in the field of additive manufacturing.

4.2 Selecting Key Factors

The subject area of SLM-based spare part production can be divided into a global environment, involving all external influences on the market, and a local environment that market participants have direct access to, as illustrated in Fig. 3.

Regarding the literature analysis, two theoretical models should be highlighted in particular: First, the PESTEL-analysis, which is used to map the global environment of SLM-based spare part production. This generally accepted model for macroeconomic analysis includes political, economic, social, technological, ecological and legal aspects [8]. Second, Ehrlenspiel list of requirements for cost-efficient product designing and is used as a starting point for modelling the challenges of product development within the local environment of SLM production. The list considers technological, human and environmental factors, including costs, time, personnel and resources [9].

During an expert workshop, the literature-based factors were analyzed further and completed with additional influencing factors. As SLM technology has a relatively short history among additive manufacturing techniques while meeting distinctively high quality requirements, aspects regarding the structural basis of SLM-production, such as quality management, were considered particularly relevant [10]. Subsequently, 14 key factors were selected from a range of influencing factor, as shown in Fig. 3.

In the following, the identified key factors will be outlined and put into context. Figure 3 shows that transport logistics and warehousing play a more passive role within the subject area, which is why they will not be elucidated explicitly.

Key Factor A – CAD-Design and Software Interfaces: Challenges for the development of CAD-software are the integration of AM-specific design opportunities into

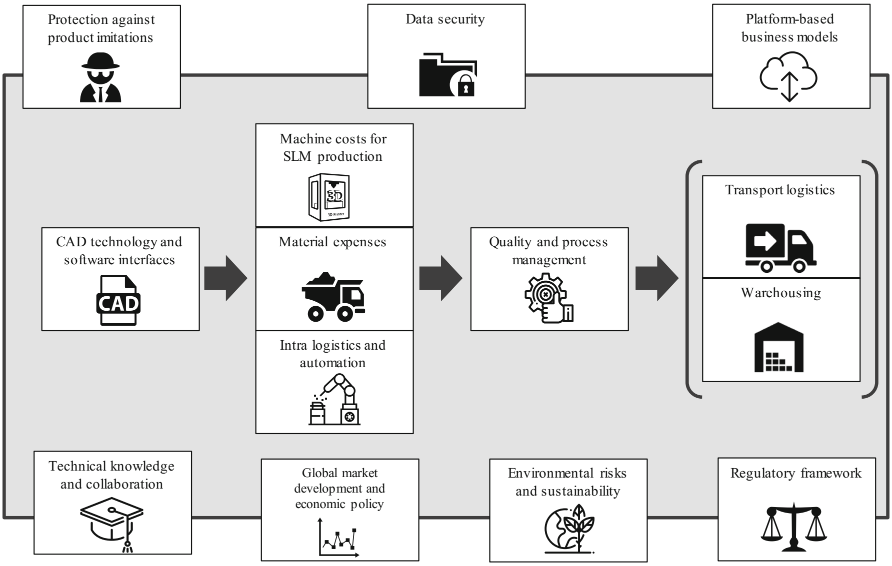


Fig. 3. Key factors for additive spare part manufacturing

datatypes and user interfaces and the required amount of necessary technical expertise, considering the short history of SLM technology [10].

Key Factor B – Machine Costs for SLM Production: A large proportion of manufacturing costs relates to the acquisition and maintenance of the SLM-machinery. This key factor refers to the economic efficiency of additive manufacturing processes, interpreted as the ratio between financial and temporal costs and product quantity.

Key Factor C – Material Expenses: Material costs have a major impact on manufacturing costs for SLM-components, as they must meet particularly high quality requirements. The costs are determined by size and shape, rheological properties and the degree of purity of the metallic particles [11].

Key Factor D – Intra Logistics and Automatization: The term intra logistics describes the organization, control and performance of the internal flow of material, flow of information and cargo handling within an industrial enterprise. Intra logistics can be comprehended as a cross-sectional task, covering the areas of materials handling, storage technology, information technology and process planning.

Key Factor E – Quality and Process Management: The qualification process for SLM components is based on the task areas of material, process, component and company qualification. Material qualification, the subsequent surface and heat treatment can be considered particularly crucial. Depending on the present loads, standards regarding component quality need to be established to enable product reproducibility.

Key Factor F – Platform-Based Business Models: Platforms usually form a virtual interface and are used to connect suppliers and buyers. In the given context, service providers, logistics companies and customers are integrated into a digital ecosystem, characterized by efficient trading and a reciprocal knowledge transfer. Fraunhofer IWU classifies five major types of business models for additive manufacturing. The platform-based approach, as used by Add2Log, covers three of these types: Product individualization, manufacturing at optimal costs and minimalizing delivery times [12].

Key Factor G – Data Security: Additive manufacturing currently is at risk of outpacing security infrastructure. As decentralizing additive spare part manufacturing leads to a change from physical to information logistics, data security increasingly grows in significance. This is especially true for SLM technology, which is particularly suitable for complex and highly specialized components for motorsports, aerospace or medicine industries [9].

Key Factor H – Global Market Development and Economic Policy: Considering the international market development, influencing the availability and pricing of metal powder materials or manufacturing machinery is crucial to determine the long-term development of additive manufacturing networks.

Key Factor I – Protection Against Product Imitations: Because CAD files are usually sufficient for imitating a SLM-component, decentralization would make the market for SLM-based spare parts particularly vulnerable for product imitations.

Key Factor J – Regulatory Framework: Many fields of technology currently experience a transformation of business models and contractual relationships. Licensing of usage rights as well as the contractual specification of required component properties and product liability must be considered.

Key Factor K – Environmental Risks and Sustainability: Additive manufacturing of metallic components is often associated with significant safety-related and environmental risks, especially in the case of new metallic alloys. Reactive metal powders can easily ignite or explode. With regard to CO_2 emissions, a decentralization of SLM-manufacturing could shorten delivery distances and reduce logistics-related emissions.

Key Factor L – Technical Knowledge and Collaboration: Due to the short history of SLM technology [9], the willingness to collaborate and share data, resources and methodological know-how with others can play a key role for technological progress.

4.3 Developing Consistent Future Scenarios, Based on Development Trends

For each key factor, three future predictions are used to develop consistent future scenarios, beginning with its current state. An optimistic, a neutral and a pessimistic trend scenario mark the margins for possible future developments.

For the development of consistent scenarios on this basis, it is necessary to consider mutual influences between the development trends of all key factors. If, for example, intra logistics and automation develop according to the optimistic future trend, this will most probably have a positive effect on the development of quality and process management. To map these one-directional influences, a two-dimensional cross-impact matrix was created. This matrix serves as input for the ScenarioWizard software, which calculates all consistent combinations of development trends, following certain criteria for logical coherence. The occurrence of a non-consistent scenario is considered impossible if the chosen prerequisites, given by the cross-impact matrix, are correct. If a positive development of one key factor A is projected, which would lead to a positive development of another factor B, choosing the negative development trend for factor B would be inconsistent, as the external influences work towards a positive development of factor B. This is true as long as factor B is influenced by just one other key factor.

The consistency analysis, as conducted by the program ScenarioWizard, results in three scenarios with a particularly high consistency. These imply a primary positive, neutral and negative development of the subject area. However, the key factor "Protection against product imitations" shows a contrasting development compared to the remaining factors, as an intensified data transfer within a manufacturing network and a decentralized product development expectantly leads to a higher risk of imitations.

4.4 Scenario Interpretation

To illustrate the development trends implied by the consistent scenarios and to validate their coherence intuitively, a scenario interpretation is conducted. The respective development trends are described from a future perspective.

The first scenario will be called "New distribution of roles in the SLM value chain" and can be considered a very optimistic and therefore extreme scenario. In this scenario, SLM manufacturing takes place close to the point of sale, supported by high investments in research and development, a high degree of standardization of processes and product quality and comprehensive legal protection. Instead of specialized manufacturing enterprises, products are directly produced by logistics service providers, resulting in decentralized manufacturing clusters. These developments benefit delivery periods as well as warehousing efforts and allow spare part manufacturing at minimal time.

The second scenario "SLM technology for high wage countries" is a rather ambivalent scenario, with every key factor following the neutral development trend. Products with high quality demands are predominantly manufactured in regional production sites, which specialize in aerospace, automotive engineering or medical technology.

The third scenario "Individualization instead of mass production" implies a pessimistic development of the subject area. In this scenario, barely any agreements on software and data transfer standards can be reached and CAD software offers hardly any options regarding SLM-specific component design. Other barriers that hinder the development include rising costs of machinery and powder materials, partially resulting from international trade barriers and economic protectionism. In some cases, insufficient component quality leads to an increasing failure rate of safety-relevant products, shattering confidence in SLM-technology.

The scenario interpretation makes it clear that the factors "Platform-based business models" and "Quality and process management" are most critical when establishing a coordinating software platform. Firstly, innovative business models, such as "SLM as a service" enable a decentralized production in local manufacturing hubs, allowing an online platform to exploit the full potential of SLM technology. Secondly, sufficient quality standards and process management practices form the basis for component reproducibility and for a relationship of trust between SLM-manufacturers, as spare parts immanently have to withstand critical loads and wearing processes. Both the optimistic scenario “New role allocation in SLM value creation” and the trend scenario “SLM technology for high-wage countries” characterize an environment in which the platform, developed in the project Add2Log, has the potential to increase efficiency through an intelligent distribution of responsibilities and knowledge.

5 Conclusion and Outlook

This work evaluated and selected key factors and creates future scenarios for the development of platform-based networks for SLM-based spare part production. For this purpose, the selected key factors have been analyzed with regard to future developments, resulting in three future scenarios. The scenarios further enable market participants to react more agilely to unexpected market developments. In a next step, the project Add2Log develops new business models for all market participants in the scenario “SLM technology for high wage countries”. On this basis, the Add2Log-platform can implement and thereby foster a decentralized, SLM-based spare part production throughout the manufacturing industry.

Acknowledgements. The research and development project that forms the basis for this report is funded within the scope of the “PAiCE Digitale Technologien für die Wirtschaft” technology program run by the Federal Ministry for Economic Affairs and Energy and is managed by the DLR project management agency at the German Aerospace Center in Cologne. The authors are responsible for the content of this publication.

References

1. Thiesse, F., et al.: Economic implications of additive manufacturing and the contribution of MIS. Bus. Inf. Syst. Eng. **57**, 139–148 (2015). https://doi.org/10.1007/s12599-015-0374-4
2. Geissbauer, R., Wunderlin, J., Lehr, J.: The future of spare parts is 3D. A look at the challenges and opportunities of 3D printing (2017). https://www.strategyand.pwc.com/media/file/The-future-of-spare-parts-is-3D.pdf. Accessed 31 Mar 2018
3. Thomas, O., Kammler, F., Zobel, B., Sossna, D., Zarvic, N.: Supply chain 4.0: revolution in der logistik durch 3D-druck. IM + io **1**, 58–63 (2016)
4. Kuckelhaus, M., Mei Yee, P.: 3D Printing and the future of supply chains (2016). http://www.dhl.com/content/dam/downloads/g0/about_us/logistics_insights/dhl_trendreport_3dprinting.pdf. Accessed 31 Mar 2018
5. Jiang, R., Kleer, R., Piller, F.T.: Predicting the future of additive manufacturing: a Delphi study on economic and societal implications of 3D printing for 2030. Technol. Forecast. Soc. Chang. **117**, 84–97 (2017). https://doi.org/10.1016/j.techfore.2017.01.006
6. Reibnitz, U.: Szenario-Technik. Instrumente für die unternehmerische und persönliche Erfolgsplanung, 2nd edn. Gabler Verlag, Wiesbaden (1992)
7. Weimer-Jehle, W.: ScenarioWizard 4.3. Constructing Consistent Scenarios Using Cross-Impact Balance Analysis. ZIRIUS, University of Stuttgart (2018). http://www.cross-impact.de/Ressourcen/ScenarioWizardManual_en.pdf. Accessed 31 Mar 2018

8. Yüksel, I.: Developing a multi-criteria decision making model for PESTEL analysis. IJBM **7**, 52 (2012). https://doi.org/10.5539/ijbm.v7n24p52
9. Ehrlenspiel, K., Hundal, M.S., Kiewert, A., Lindemann, U. (eds.): Cost-Efficient Design. Springer, Berlin (2007). https://doi.org/10.1007/978-3-540-34648-7
10. SLM Solutions Group AG, Rosswag GmbH (eds.): Metal-based additive manufacturing technology for professional applications. In: 3D fab + print(3), pp. 10–13 (2017)
11. Bilz, M.: Selective Laser Melting (2015). https://www.ipk.fraunhofer.de/fileadmin/user_upload/IPK_FHG/publikationen/themenblaetter/ps_ft_selective_laser_melting_en.pdf. Accessed 4 Apr 2018
12. Lutter-Günther, M., Seidel, C., Reinhart, G., Baader, A.: Geschäftsmodelle für den Einsatz der additiven Fertigung in der industriellen Praxis (2015)

Embedding Memorable Experience to Customer Journey

Duangthida Hussadintorn Na Ayutthaya and Pisut Koomsap(✉)

Asian Institute of Technology, Klong Luang, Pathumthani 12120, Thailand
pisut@ait.asia

Abstract. Customer journey mapping (CJM) is a well-known customer-oriented technique used to document and understand a customer's emotional responses (dissatisfaction-satisfaction) to a product or service on an individual journey for improving the overall experience. Despite the widespread use of CJM, the intention has been centered on providing a good and failure-free customer journey but may not guarantee success in today's competitive market wherein the aim is towards creating customer loyalty. Type and characteristic of experiences that create memorable experience have not yet been intentionally considered in this technique. Meanwhile, the 4Es model describing four distinct types of experience has been pervasively used, especially in the tourism industry, for providing the richest customer experience. Researchers found that the 4Es model has a positive effect on customer memories and loyalty. Therefore, presented in this paper is an approach to embedding memorable experience to customer journey by incorporating the 4Es model in CJM. A kick-off meeting program of a curriculum development project was used to illustrate the implementation of the proposed approach. The results show that the approach can be practically applied and appropriate for continuous improvement.

Keywords: Memorable experience · Customer journey · Experience design

1 Introduction

Customer journey mapping (CJM) is a well-known customer-oriented technique originated in the 1960s. CJM assists in documenting and understanding a customer's emotional responses, whether they are satisfied or dissatisfied, to products and services in a journey that a person may undertake for a company to improve the overall customer experience [1]. Customer pain points are subject to improvement.

The concept of the CJM, "walk in the customer's shoes" [2], and its applications have been seen in various fields of research [3]. For example, in the UK's National Health Service, CJM aided healthcare providers to visualize patients' journey map and to understand what to do and where their focus should be paid to improve the patients' experience [1]. At Birmingham City University Library and Learning Resources, CJM was used to improve students' experience and satisfaction [4]. CJM was also incorporated with service assembly concept to redesign a service in exhibition and tourism industries for dynamic improvement of the customer experience [5]. In this research, the emotional range [6] was applied to evaluate the experience of a group of customers.

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 222–229, 2018.
https://doi.org/10.1007/978-3-319-99704-9_27

With CJM, companies normally focus on a good and failure-free customer journey to satisfy their customers. However, the interesting question is, will it guarantee success in today's competitive market where many have been intending to create customer loyalty? Pine and Gilmore [7] stated that customers obtain the richest experience when they experience the four different types of experiences (4Es: entertainment, educational, esthetic, and escapist). The 4Es model has been pervasively applied in tourism industry [8], especially in wine tourist industry. A study shows that wine tourist activities, which collected from 30 publications, have already covered the 4Es [9]. Additionally, the 4Es has been reported to have a positive effect on customer memories and loyalty [10].

Therefore, this paper proposes an approach to embedding memorable experience to a customer journey by incorporating the 4Es model in CJM. The next section presents the definitions of the 4Es and examples. Sections 3 and 4 present a proposed approach and its illustration on a real case study followed by the conclusions and future research in the last section.

2 The 4Es Model

As aforementioned, the 4Es model composes of entertainment, educational, esthetic, and escapist. The four types of experience are according to two dimensions: (1) how a customer participates in the experience (passive-active), and (2) how a customer connects to the experience (absorb-immerse). The entertainment (passive absorption) is to sense, such as watching shows and attending concerts where customers do not affect the outcomes of the events. The educational (active absorption) is to learn. Customers gain this experience by taking, for instance, a cooking class where they do affect the outcomes of the event. The esthetic (passive immersion) is to be in the environment. The customers put themselves in a surrounding for pleasure such as sightseeing trips. The escapist (active immersion) is to do something new. The customers experienced something they do not do or have on a daily basis such as performing on a stage. When customers gain all the four types of experience, the richest experience (sweet spot) is stimulated [7, 11].

3 Embedding Memorable Experience to Customer Journey

Presented in this section is a proposed approach for embedding memorable experience to a customer journey. It composes of six steps. The first two steps are similar to the conventional CJM where a company prepares a good and failure-free customer journey. The remaining four steps are for embedding experience to make the journey memorable.

1. Create a customer journey. This step begins with acquiring the inventory of activities that the customers will go through. According to the obtained list of the activities, a customer journey is then created from the beginning to the end. It can be

the journey that the customers have undertaken or that the company would like the customers to take.

2. Make a pain point-free customer journey. This step requires the company to identify potential pain points for each activity along the journey and to try to find solutions to alleviate or remove them. The possible solutions are generated and selected.
3. Establish experience theme(s). The focus of this step is on establishing theme(s) to make the journey memorable. The theme(s) provides a specific context that assists in designing format of the activities to deliver particular types of 4Es.
4. Match the settings of the activities with the theme(s). With their typical settings, each activity is checked for their feasibility and compatibility with the theme(s). Adjustment of the settings may be required for the activity to support the themes(s).
5. Assess the 4Es of the current customer journey under the theme(s). The type of 4Es (E1: Entertainment, E2: Educational, E3: Esthetic, E4: Escapist) is identified for each activity. How each activity is set for the customers to connect with and how actively the customers will participate are two criteria for assessing the type of 4Es. The overall experience is assessed next from the presence of each of the 4Es in the journey. A memorable customer journey (MCJ) is ideal when the customers experience all the 4Es through a set of activities in a designed MCJ.
6. Enhance the experience in the customer journey. Additional activities, if necessary, may be introduced to enhance the experience in the customer journey. In case that the current set of activities offers limited experience, the company should consider introducing additional activities to increase experience as much as possible but should also manage potential pain points that may arise from the additional activities.

4 Customer Journey Implementation and Evaluation

A well-designed journey may not create a memorable experience for customers if activities are executed poorly. Therefore, the company must also pay attention to both preparation and execution during the implementation. It is important that a right set of physical settings and actions to execute each activity along the MCJ is predefined to avoid problems, issues, difficulties or inconveniences leading to customer dissatisfaction during participation in the MCJ. The plan assures that the customers will gain the designed types of 4Es.

Evaluation is also needed to improve the next offer. It intends to cross-check with customer feedbacks made on the designed MCJ in the following aspects: (1) whether unexpected pain points exist, and (2) how satisfied customers are with the activities. Accordingly, a query contains two sections. The first section focuses on identifying remaining pain points during participation in the journey caused by impromptu preparation. The second section focuses on customer satisfaction after completing the journey. The customers rate their satisfaction for each activity based on the experiential value [12] as (−3) intolerable, (−2) unacceptable, (−1) acceptable, (0) neutral, (+1) ordinary, (+2) extraordinary, (+3) priceless. The average values obtained from the survey results are illustrated and analyzed through a proposed memorable customer journey map. It is reasonable to conclude that the activity receiving either extraordinary or priceless rating and the majority agree on priceless is their memorable experience. Suggestions for further improvement are made when:

- Unexpected pain points are reported by the customers. The 2nd step must be revisited to obtain appropriate solutions.
- Some activities cannot satisfy a significant number of the customers. The activities are not well designed, and embedded type of experience might not be appropriate. Therefore, these activities should be redesigned in the 4^{th} step.
- Some activities can satisfy the majority; nonetheless, someone still dissatisfies. The activities are not well implemented. The preparation plan and execution have to be investigated for improvement.

5 Designing Memorable Customer Experience Journey for MSIE4.0 Kick-Off Meeting Program

This section illustrates the implementation of the proposed approach through an MSIE4.0 Kick-off Meeting. Since many participants travel a long distance, an organizing team, therefore, would like to create a memorable experience for them.

MSIE4.0 is a Curriculum Development of Master's Degree Program in Industrial Engineering for Thailand Sustainable Smart Industry project, which is co-funded by the Erasmus+ Program of the European Union (EU). The project has nine partners: six Thai universities and three European universities. The project kick-off meeting was held on February 12–16, 2018, in Thailand. The meeting aimed to provide a unique understanding of the objectives, rules, regulations, requirements, achievement, and space to exchange ideas to develop the project work plans. Besides, it was also intended to nurture partnership among all the partners. The meeting program was mainly organized by Asian Institute of Technology (AIT), the host, in collaboration with Prince of Songkla University (PSU) and Thammasat University (TU). Thirty-five representatives from all nine universities, including ten from the three European partners, and a few representatives from industry partners participated in the meeting. The main activities on the first two days at AIT were for all participants, and the rest of the program at PSU and TU was for the participants from EU to learn more about Thai education, industry and culture.

The meeting was for the first time that the representative of all partners met. The organizing team did not have much information about the participants and organized this type of a meeting for the first time. Therefore, they used their previous experiences in attending several meetings and international conferences to create a customer journey map containing ten key activities: 1. Project Executive Committee (PEC) meeting, 2. Work Package meetings, 3. General meeting, 4. Public seminars, 5. Group photo sessions, 6. Program registrations, 7. Coffee breaks and meals, 8. Local transportation, 9. Hotel reservations, and 10. Domestic flight booking.

Each activity was studied. The team did brainstorming to identify possible pain points as well as to find possible effective solutions. The possible pain points identified for meeting activities, for example, were improper room layouts, non-functional facilities and equipment, and participants getting thirsty and sleepy. As such, the given solutions were to re-arrange the rooms' layout, to prepare and check facilities and equipment, and to provide water as well as candies.

After preparing for pain points removal, the team designed the memorable customer journey. They decided to use two themes. One was "Industrial Engineering for Thailand 4.0", an academic theme for providing a knowledge base of the project and insights of current needs and viewpoints of the industry towards Thailand 4.0. Another one was "Authentic Thai Experiences", a cultural theme for creating personal ties and nurturing partnership through social activities.

For the academic theme, the meeting activities typically bring participants into ambiances where the knowledge is brought to them. Their roles during the meeting will shape their individual experiences. If they are active, discussing and/or presenting, they gain the educational experience (E2). If they are passive like being audiences, they gain the entertainment experience (E1). Since the current academic activities would offer only entertainment and educational experiences, the organizing team decided to add lab visits at AIT and TU, as well as plant visits, for the participants to immerse into the theme. These additional activities would stimulate esthetic experience (E3) to them.

The main channel to embed Thai experience to the current customer journey was the coffee breaks and meals. The team decided to serve Thai sweet snacks during the coffee breaks and to arrange Thai foods for some meals for the participant to absorb the theme. By having and tasting Thai cuisines and Thai sweet snacks in a cozy/romantic/beautiful place would stimulate the entertainment experience (E1). For a gala dinner, the team decided to provide the esthetic experience (E3) with Thai cuisines served in Thai Benjarong ceramic sets in Thai house to immerse the participants into the theme. Additional activities were brought into the journey to provide the participants more experience on this theme. The organizing team decided to arrange trips to visit attractive places and to arrange a time for the participants to experience a festival celebrated during the week. Visiting the historic city of Ayutthaya composed of several sub-activities. The participants would gain the esthetic experience during an elephant riding in the old city as well as during a visit to historic temples, and gain the entertainment experience during visiting and cruising in the Ayutthaya floating market (an imitative place according to the theme) and watching fencing show.

The designed MCJ for the five-day kick-off meeting program had nineteen key activities offering three types of experience. Only the escapist experience (E4) was omitted in this journey.

The set of embedded experience activities were the focus in the implementation stage. Each activity was prepared for proper execution. For example, the team to deliver the key activity no.5 (Dinner @Ayutthaya Retreat) surveyed the place; tasted foods; reserved dining room; designed the room layout; selected menus; set dining time and duration; set serving time and order; arranged the transportation. The identified potential pain point for this activity was a dietary restriction. Therefore, the team checked with the participants for their dietary preferences before the menu selection and arranged the meal accordingly.

Most of the activities were successfully executed and illustrated in Fig. 1 is the ambiances of the key activities captured during the five-day program. Please be noted that the key activity no.2 (ISE Lab Tour) was designed aside from the main journey for a group of participants who are not PEC members.

Fig. 1. Key activities in memorable customer journey for MSIE4.0 kick-off meeting program

After the meeting, the ten EU participants, one of them did not partake the program on the 3rd and 4th days, were asked to evaluate their experiences gained from the program via online survey because they were the group that participated in the entire program. Photos taken during the program were also provided on the running questions to remind them about the activities.

Figure 2 presents the memorable customer experience journey map for MSIE4.0 kick-off meeting program, obtained from the survey. The participants agreed that 'ISE Lab Tour' and 'Visiting Historic City of Ayutthaya' were their memorable experiences. Majority of the participants rated priceless for these two activities, and the rest rated them extraordinary. The main suggestions are for a group of activities that obtained the neutral and negative ratings, specifically, activity numbers 8, 9, 12, 14. There is a need to investigate and improve the preparation plan and execution of these activities, especially activity no.8 because one participant rated his satisfaction at the intolerable level.

Additionally, the survey asked the participants to provide comments for the overall program. The majority expressed that the program was well-organized. However, some comments for improvement were stated, such as "it was great but maybe with too many

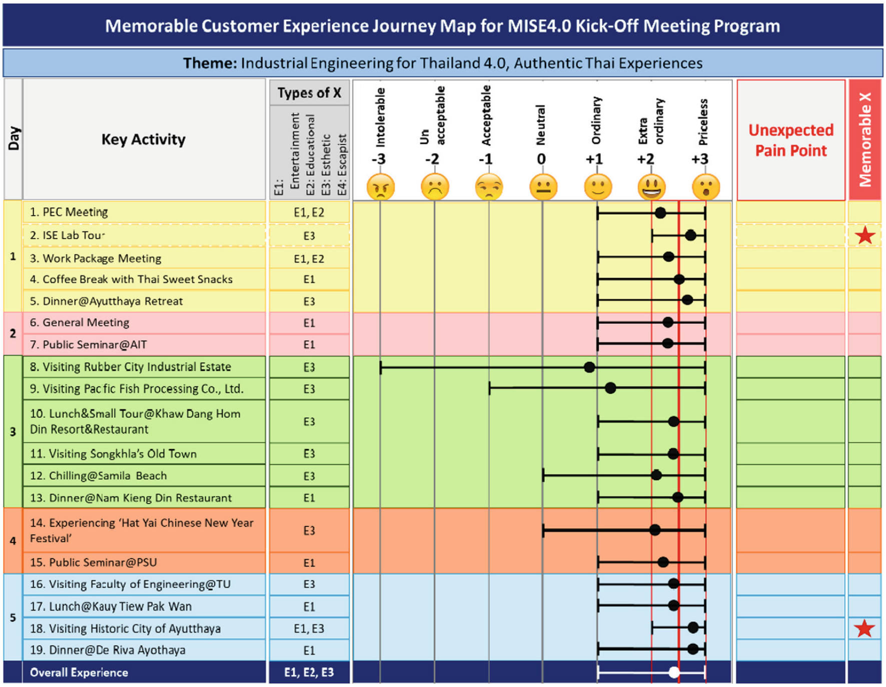


Fig. 2. Memorable customer experience journey map for MSIE4.0 kick-off meeting program

activities", "far too many attractions and resulting overload of the program", and "too many parallel sessions for the Work Package Meetings". The team discussed the issues and found that the activities were rearranged to accommodate the schedule of the EU participants and to avoid the conflict with the activity for the festival on that week.

6 Conclusions and Future Research

The 4Es model has been introduced to embed memorable experience to a customer journey. The proposed approach can not only help a company remove pain points but also help embed memorable experience to the customer journey. The approach is practical also for an on-going case and continuous improvement. As illustrated in the case study, the identified activities are ordinary activities being offered in a typical meeting program. The pain points would be removed if the typical CJM was applied, but the activities would remain ordinary ones. The proposed approach transformed most of these ordinary activities to be extraordinary and left the participants with a memorable experience. However, it is still important that the delivery must be well executed to avoid dissatisfaction occurred to a couple activities. Besides, there are still opportunities for enhancement. It is found from the results that one participant rated his satisfaction at the ordinary level to all dining activities while the others scored them as extraordinary or priceless activities. That may be because he concentrated on main activities (e.g., meetings and industry visits). Therefore, investigating customer preferences and interests would be beneficial in designing a proper MCJ for all customers.

Acknowledgement. This project has been funded with support from the European Commission. This publication paper reflects the views only of the authors, and the Commission cannot be held responsible for any use, which may be made of the information contained therein. The authors would like to thank Dr. Thanate Ratanawilai, Dr. Supapan Chaiprapat, Dr. Suriya Jirasatitsin, and Dr. Apiwat Muttamara for their support.

References

1. Crosier, A., Handford, A.: Customer journey mapping as an advocacy tool for disabled people: a case study. Soc. Mark. Q. **18**(1), 67–76 (2012)
2. Holmlid, S., Evenson, S.: Bringing service design to service sciences, management and engineering. In: Hefley, B., Murphy, W. (eds.) Service Science, Management and Engineering Education for the 21st Century. SSRI, pp. 341–345. Springer, Boston (2008). https://doi.org/10.1007/978-0-387-76578-5_50
3. Følstad, A., Kvale, K., Halvorsrud, R.: Customer journey measures-State of the art research and best practices. SINTEF Rapport A24488 (2013)
4. Andrews, J., Eade, E.: Listening to students: customer journey mapping at Birmingham City university library and learning resources. New Rev. Acad. Librariansh. **19**(2), 161–177 (2013)
5. Li, Q.Y., Lee, C.H., Chen, C.H., Lee, Y.C., Li, F.: Dynamic enhancement for customer experience by incorporating customer experience journey map and service assembly concept. In: Chen, C., Trappey, A., Peruzzini, M., Stjepandie, J., Wognum, N. (eds.) Proceedings of the 24th ISPE Inc. International Conference on Transdisciplinary Engineering: A Paradigm Shift, vol. 5, pp. 860–867. IOS Press BV, Netherlands (2015)
6. Mayer, J.D., DiPaolo, M., Salovey, P.: Perceiving affective content in ambiguous visual stimuli: a component of emotional intelligence. J. Pers. Assess. **54**(3–4), 772–781 (1990)
7. Pine, B.J., Gilmore, J.H.: Welcome to the experience economy. Harv. Bus. Rev. **76**, 97–105 (1998)
8. Hosany, S., Witham, M.: Dimensions of cruisers' experiences, satisfaction, and intention to recommend. J. Travel Res. **49**(3), 351–364 (2010)
9. Quadri-Felitti, D., Fiore, A.M.: Experience economy constructs as a framework for understanding wine tourism. J. Vacat. Mark. **18**(1), 3–15 (2012)
10. Ali, F., Hussain, K., Ragavan, N.A.: Memorable customer experience: examining the effects of customers experience on memories and loyalty in Malaysian resort hotels. Procedia-Soc. Behav. Sci. **144**, 273–279 (2014)
11. Pine, B.J., Gilmore, J.H.: The Experience Economy: Work is Theatre & Every Business a Stage. Harvard Business Press, Brighton (1999)
12. LaSalle, D., Britton, T.A.: Priceless: turning ordinary products into extraordinary experience. Harvard Business School Press, Boston, Massachusetts (2002)

Overcoming Barriers Against Interaction on Innovation Capabilities Within and Between SMEs

Sara Hajikazemi(✉), Anandasivakumar Ekambaram(✉), Carl Christian Røstad(✉), and Bjørnar Henriksen(✉)

SINTEF Technology and Society, Trondheim, Norway
{Sara.Hajikazemi,Siva,Carl.C.Rostad,
Bjornar.Henriksen}@sintef.no

Abstract. Handling metadata and module-based capabilities are enablers for radical new ways of interaction within and between small and medium-sized enterprises (SMEs) in terms of innovation. A challenge in this often complex actor and interaction picture is that there can be organizational, process-related, financial and practical barriers which tend to reduce innovativeness. There is thus a need for methods which can provide dynamic and company-based innovation networks. This study investigates the main barriers for effective interaction and sharing of innovation capabilities within SMEs. The factors identified are individual, technological and organizational factors. The success of SMEs lies in overcoming all these barriers in order to ensure effective interaction and sharing of innovation capabilities through their networks. This study suggests the main conditions and elements which can contribute to overcoming the barriers against effective interaction on innovative capabilities among SMEs.

Keywords: Innovation capability · SMEs · Barriers

1 Introduction

Norwegian industry, and specifically its land-based industry, is in an ever more demanding situation where competition is becoming fiercer and more complex. This is of course not just the case for Norway, but is typical for all land-based industries in the global market-place. In order for the companies to succeed, they are dependent on their innovativeness combined with a quality-focus and the ability to cooperate smarter. Therefore, the companies need to develop capabilities (resource and knowledge) and find effective approaches in order to adopt these capabilities for developing and producing the right products and services. Interaction on innovation capabilities among SMEs result in increased access to resources and knowledge, more effective innovation processes and thus better products. Interaction among capabilities (shared capabilities) will also provide better return on investment in for example test facilities, equipment, competence and motivation of further initiatives. This study is based on two ongoing four-year long Norwegian R&D projects, Live Innovation Performance and Innovative

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 230–237, 2018.
https://doi.org/10.1007/978-3-319-99704-9_28

Kraft (Power). These projects are financed by the Norwegian Research Council and the participating companies focusing among other things on collaboration and the shared use of companies' test facilities and the belonging competences of companies in order to find concrete solutions and mechanisms for integration of innovation processes. Outsourcing, supply chain integration, production network are some examples of how industrial businesses adjust and have adjusted to new conditions. A challenge in this often complex actor and interaction picture is that there can be organizational, process related, financial and practical barriers which tend to reduce the innovation power. There is thus a need for methods which can provide dynamic and firm-based innovation networks. This study will address the main barriers for effective interaction and sharing of innovation capabilities among SMEs and develop a model for overcoming these barriers in practice.

2 Background

This section includes a literature review on a number of relevant concepts which can contribute to better understanding the required capabilities within SMEs in order to compete within an ever more demanding situation in the market where competition is becoming more difficult and more complex. The main focus will be on (1) the interaction of firms with their innovation capabilities in order to gain increased access to resources and knowledge and (2) the barriers for effective interaction and sharing of innovation capabilities. These theoretical frameworks will be used as a platform for answering the main research question mentioned above.

2.1 Critical Success Factors in SMEs; The Innovation Power

Resource-constraint SMEs need to focus on critical success factors to stay competitive amidst the challenges from globalization and liberalization [1]. Business literature presents a wide range of success factors through a number of conceptual frameworks that seek to capture aspects of SMEs success. However, their importance appears to be relative and varies with the business environment, that is the industry and country SMEs operate in. I.e. one success factor may be of great importance in one industry or country, it may not necessarily be of equal importance in another [2].

Ho and Yang [3], categorize the main success factors in four main groups including knowledge conditions, political and regulatory, Industry/product life cycles and industry structure. A number of factors under the knowledge conditions category include: diffusion of knowledge, knowledge innovation and knowledge sharing. In general organizations are becoming ever more knowledge intensive and the need for applying knowledge is increasing. Thus knowledge is becoming one of the critical driving forces of success for businesses and organizations need to be aware of the success factors of effective knowledge management [4].

Anantatmula and Kanungo [5] also state that the main driving factors in building a successful knowledge management effort, within SMEs, are top management involvement, knowledge management leadership, and the culture of the organization. This calls for a positive attitude and motivation towards knowledge sharing behavior, values that are adhered in the SME owners, as well as behavior which is acceptable to all parties. The knowledge sharing behavior will contribute to formation of innovation capability within SMEs [6].

2.2 Enablers for Sharing Innovation Capabilities Among SMEs

For innovation to take place, the organization must possess innovation capability and operate in an environment (internal and external) with appropriate enablers which work sufficiently under a sound innovation management system [7]. As earlier mentioned, in SMEs, the success of knowledge sharing stimulates knowledge creation and encourages individuals to think more creatively and critically. It has been proved that the responsiveness of SMEs is likely to improve if they strongly develop capabilities in external knowledge acquisition and intra-firm knowledge distribution [8]. This results in being decisive for aligning them with external environments [9].

Love and Roper [10] indicate three main channels through which firms may obtain external knowledge which may contribute to their innovation and exporting activity:

1. "Being there" in which firms benefit from un-priced, and perhaps unanticipated, flows of local knowledge or information mediated through social contacts or labor market linkages.
2. "Openness" partnering in which firms engage in purposeful relationships with other organizations in order to gather either technical knowledge or market understanding.
3. "Learning by exporting" in which firms gain market – and also potentially innovation-related – knowledge through their exporting activities.

Lage and Alturas [11] in their study investigate on possible enablers for sharing knowledge and information among SME. The existence of a "Power" asymmetry between the giver of knowledge (upper position) and the receiver is also very common; the rate of acquisition of knowledge by the recipient is a key factor to change the relationship of dependency.

Another important factor is the "Trust in the network's leadership". Cooperation among SMEs highly depends on their level of trust in their network's relationship. Therefore, trust in the network's coordination may also be an important factor for the information sharing process to happen.

The role of "Information and communication technology" is also quite important in sharing of knowledge and technology. ICT is basically the main channel for sharing information within the network. The relevance of ICT is probably higher when the members are geographically dispersed throughout the country and the network has a more vertical coordination, which demands the exchange of more operational information.

Ngah and Jusoff [12] point out the importance of strength on motivation, a good working network, unique skills and short informal communication as enablers for effective information sharing in SMEs. The success of knowledge sharing among SMEs encourages the creation of knowledge, the increase of continuous innovation capabilities and stimulating employees to think more critically and creatively [13].

Despite the fact that knowledge sharing within and among SMEs is a source of competitive advantage for these firms, not all firms and SME clusters succeed in effectively sharing their knowledge and information either internally or externally among the business cluster that they are part of. These barriers will be discussed further in the following section.

3 Barriers for Effective Interaction and Sharing of Innovation Capabilities Among SMEs

According to Bremmersa and Sabidussib [14], working in cooperation to innovate has become an imperative in an economy where firms' links are increasing in number and in relevance. To innovate, individual efforts alone are not sufficient and the use of partnerships has developed remarkably in the last years.

One of the key ingredients for innovation in a cooperative environment is sharing knowledge. However, there are always barriers against effective knowledge sharing within SMEs and among SME networks.

In general, barrier factors influencing knowledge sharing within an organization are categorized into three main categories: individual factors, technological factors and organizational factors [15].

Individual factors are related to elements such as beliefs and perceptions of each individual. For example employees may not want to share due to the sense of losing control and authority over knowledge. Some might want to take ownership of it to receive accreditation from the other members. The lack of understanding of the knowledge they hold or of the benefits coming from sharing represent other reasons of resistance [16]. Employees may be reluctant also simply because they are not able or do not have the time to integrate knowledge sharing activities into their everyday duties [17]. Another aspect is the trust between the knowledge provider and the knowledge seeker [18]. The sharing of information happens when the knowledge provider is confident that the knowledge seeker has the capability (attitudes and professional capability, etc.) to make use of the shared knowledge. In fact, the level of capability of the knowledge seeker can act as a barrier for sharing of knowledge.

Technological factors include the unavailability of the required technological resources such as software and hardware to assist in implementation of knowledge management activities. ICT systems enable rapid search, gathering and retrieval of information, apart from providing support for communication and collaboration among employees through intranet, groupware, online databases, and virtual communities. Small-medium enterprises are increasingly adopting ICT tools, including e-commerce, but they are still limited by scarce financial investments [19].

Organizational factors include the influence of the organizational culture, lack of proper integration between knowledge management activities and long-term goals as well as objectives of the company, lack of proper leadership, and lack of appropriate rewards in the organization [17]. Research has shown that small firms tend to lack a strategic approach in knowledge management, being more concerned about the day-to-day viability [20]. Another organizational aspect that hinders knowledge transfer is the "not-invented-here-syndrome", which represents an attitude of not willing to make use of solutions/knowledge created by others. The not-invented-here syndrome does not allow organizational members to look for existing relevant solutions, depending on the premises behind the knowledge as well as contextual considerations.

Avdimiotis et al. [21] classified the factors contributing to lack of knowledge sharing into two categories; psychological factors, and organizational structural factors. The psychological factors included trust, willingness to communicate, and reliability of source. The organizational structural factors included motivation, structure, and organizational leadership. These two sets of factors correspond to our categorization, namely individual factors and organizational factors respectively.

However, there are significant barriers to knowledge acquisition for clustered SMEs, both social and cognitive, and these significantly constrain smaller firm's ability to accrue knowledge-based advantage from clusters [22]. The success of SMEs lies in overcoming these barriers in order to ensure effective interaction and sharing of innovation capabilities among their network.

4 A Model for Overcoming Barriers for Sharing Innovative Capabilities

This section will point out the main conditions and elements which can contribute to overcoming the barriers against effective interaction on innovative capabilities among SMEs. According to Mitchell et al. [23], the role of technical specialists is essential as knowledge gate keepers and facilitators of knowledge sharing to and between SMEs in clusters. This role is significant because it illustrates an effective knowledge brokering function in clusters that overcomes the constraints set by significant cognitive distance from the technological frontier.

Another important element which contributes to overcoming the knowledge sharing barriers is the role of social capital built up by the technical specialists which will be utilized to identify and assimilate knowledge in order to transfer their knowledge to recipient organizations [23].

The culture of knowledge sharing within organizations plays a significant role in the enhancement of innovation capabilities in SMEs. Increased partnership between entrepreneur in the cluster as well as other possible clusters within the same area [6]. The above mentioned elements call for the support of the SME senior management by building up effective strategic management of firm capabilities [24]. Development of an environment of trust where people feel free to create, share, and use information and knowledge, working together toward a common purpose, within and among SMEs is also one of the drivers for overcoming the organizational barriers which were mentioned in the previous section.

According to Vajjhala and Vucetic [25], SMEs need to focus on motivational issues and identification of non-monetary mechanisms to motivate employees to actively participate in knowledge sharing activities. The organizational leadership of SMEs should recognize the efforts of employees participating in knowledge sharing activities to foster the creation of an organizational culture which will promote the spirit of knowledge sharing in the firms.

The commitment of top management within SMEs is also an important factor which can positively contribute to effective knowledge sharing among SME networks. The top management commitment is positively related to the exchange of strategic information. Information and communication technologies are also essential for information sharing, ICT being the main channel used to share information within SME networks. Indeed, trust in partners and in network coordination is relevant for all networks as a basic condition for the sharing of information to happen [11].

Based on the above mentioned elements and the enablers for sharing innovation capabilities among SMEs discussed in Sect. 2.2, a model is proposed for overcoming the possible barriers against effective interaction and sharing of innovation capabilities among SMEs.

The suggested elements for overcoming the barriers against interaction on innovation capabilities is means to cover the whole cycle of knowledge management based on Dalkir's [26] knowledge management model. Dalkir's model presents three major parts: Capturing/creating knowledge, sharing knowledge, and applying knowledge. In the transition from knowledge capture/creation to knowledge sharing and dissemination, knowledge content is assessed. Knowledge is then contextualized in order to be understood ("acquisition") and used ("application"). This stage then feeds back into the first one in order to update the knowledge content (Figs. 1 and 2).

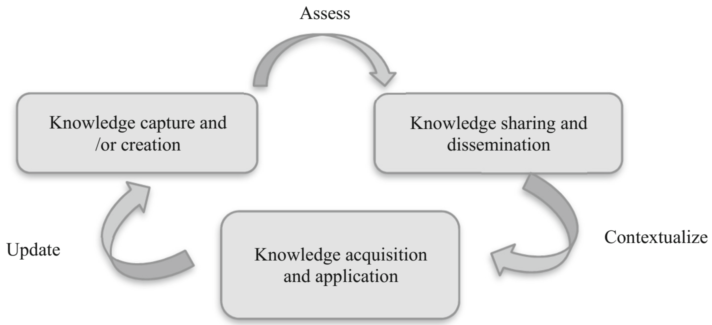


Fig. 1. An integrated knowledge management cycle ([26], p. 43)

As seen in the figure, there is large focus on approaches for overcoming organizational barriers against interaction on innovations and knowledge. This might be an indication that a top-down approach within organizations can foster actions which will eventually contribute to overcoming both individual and technological barriers as well.

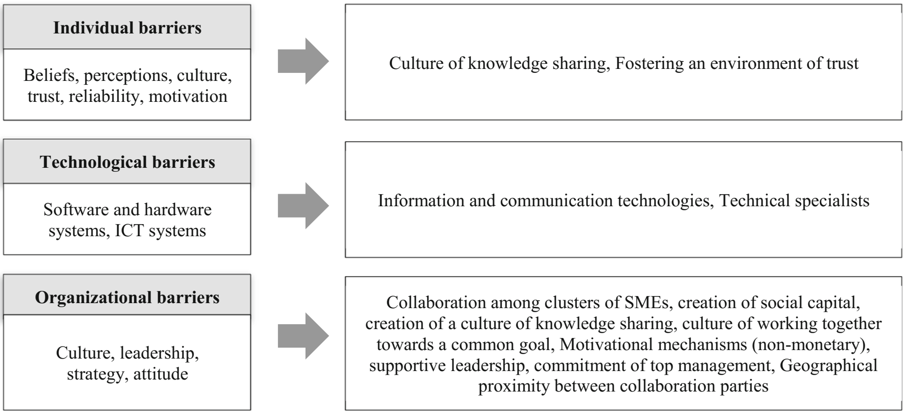


Fig. 2. Model for overcoming barriers against interaction on innovation capabilities – based on [15]

5 Conclusions

The main barriers for effective interaction and sharing of innovation capabilities among SMEs have been elucidated in this study alongside the possible approaches for overcoming these barriers. The main barriers identified through this study include: Individual barriers, technological barriers and organizational barriers. A number of approaches have been suggested for overcoming these barriers. The commitment of top management within SMEs is an important factors which can positively contribute to effective knowledge sharing among SME networks. Further research can be done on how each of these barriers and the solutions for overcoming them are different in different industries and contexts.

References

1. Ramukumba, T.: Overcoming SMEs challenges through critical success factors: a case of SMEs in the Western Cape Province, South Africa. Econ. Bus. Rev. **16**(1), 19–38 (2014)
2. Lampadarios, E.: Critical success factors for SMEs: an empirical study in the UK chemical distribution industry. Int. J. Bus. Manag. **11**(7), 67–82 (2016)
3. Ho, C., Yang, Y.: The key success factors of small business innovation and research of taiwan automotive electronics industry. Int. J. Bus. Manag. Technol. **3**(5), 521–524 (2012)
4. Dalotă, M., Grigore, S.: Successful implementation of knowledge management in small and medium enterprises. Manag. Chall. Contemp. Soc. **6**(1), 46–49 (2010)
5. Anantatmula, V., Kanungo, S.: Modeling enablers for successful KM implementation. J. Knowl. Manag. **14**(1), 100–113 (2010)
6. Sulistyani, R., Harwiki, W.: How SMEs build innovation capability based on knowledge sharing behaviour? Phenomenological approach. Procedia Soc. Behav. Sci. **219**, 741–747 (2016)
7. Gor, K., Mummassabba, J., Muturi, S.: Evidencing enablers of innovation capabilities and their effects on organizational performance. Strateg. J. Bus. Change manag. **2**(2), 2183–2196 (2015)

8. Matusik, S.F., Heeley, M.B.: Absorptive capacity in the software industry: identifying dimensions that affect knowledge and knowledge creation activities. J. Manag. **31**(4), 549–572 (2005)
9. Liao, S.H., Fei, W.C., Shen, C.C.: Knowledge sharing, absorptive capacity and innovation capability: an empirical case study on Taiwan's knowledge intensive industries. J. Inf. Sci. **33**(3), 340–359 (2007)
10. Love, J.H., Roper, S.: SME innovation, exporting and growth: a review of existing evidence. ERC White Paper No.5 published by the Independent Enterprise Research Centre, UK (2013)
11. Lage, E., Alturas, B.: Factors influencing information sharing in four SME networks in Portugal: a coordination perspective. In: KMIS 2012 - Proceedings of the International Conference on Knowledge Management and Information Sharing, pp. 178–183. SCITE-PRESS, Portugal (2012)
12. Ngah, R., Justoff, K.: Tacit knowledge and SME's organizational performance. Int. J. Econ. Finance **1**(1), 216–220 (2009)
13. Kang, Y.J., Kim, S.E., Chang, G.W.: The impact of knowledge sharing on work performance: an empirical analysis of the public employees' perception in South Korea. Int. J. Pub. Adm. **31**, 1548–1568 (2009)
14. Bremmersa, H., Sabidussib, A.: Co-innovation: what are the success factors? Appl. Stud. Agribus. Commer. - APSTRACT **3**, 29–35 (2009)
15. Zawawi, A.A., Zakaria, Z., Kamarunzaman, N.Z., Noordin, N., Sawal, M.Z.H.M., Ju-nos, N. M., Najid, N.S.A.: The study of barrier factors in knowledge sharing: a case study in public university. Manag. Sci. Eng. **5**(1), 59–70 (2011)
16. Bagnaia, S.: The role of knowledge sharing in SMEs' innovation and internationalization process, a case study. Monnalisa Spa, M.Sc. thesis in Department of Business and Management, Libera Università Internazionale degli Studi Sociali - Guido Carli, Rome, Italy (2013)
17. Cabrera, A., Cabrera, E.F.: Knowledge-sharing dilemmas. Org. Stud. **23**(5), 687–710 (2002)
18. Ekambaram, A.: The role of knowledge transfer in reducing reinvention of the wheel in project organizations. Doctoral thesis, Department of Industrial Economics and Technology Management, Norwegian University of Science and Technology (NTNU) (2008)
19. Beijerse, R.P.: Knowledge management in small and medium-sized companies: knowledge management for entrepreneurs. J. Knowl. Manag. **4**(2), 162–179 (2000)
20. Riege, A.: Three-dozen knowledge-sharing barriers managers must consider. J. Knowl. Manag. **9**(3), 18–35 (2005)
21. Avdimiotis, S., Kokkinis, G., Kamenidou, E.: Sharing knowledge between the peers of a winery network: the case of wine routes in Northern Greece. China-USA Bus. Rev. **11**(1), 38–51 (2012)
22. Morrison, A., Rabellotti, R.: Knowledge and information networks in an Italian wine cluster. Eur. Plan. Stud. **17**(7), 983–1006 (2009)
23. Mitchell, R., Boyle, B., Burgess, J., McNeil, K.: You can't make a good wine without a few beers: gatekeepers and knowledge flow in industrial districts. J. Bus. Res. **67**, 2198–2206 (2014)
24. Munir, A., Lim, M.K., Knight, L.: Sustaining competitive advantage in SMEs. Procedia – Soc. Behav. Sci. **25**, 408–412 (2011)
25. Vajjhala, N.R., Vucetic, J.: Key barriers to knowledge sharing in medium-sized enterprises in transition economies. Int. J. Bus. Soc. Sci. **4**(13), 90–98 (2013)
26. Dalkir, K.: Knowledge management in theory and practice. Elsevier Inc., Canada (2005)

Controllable Production Rate and Quality Improvement in a Two-Echelon Supply Chain Model

Mitali Sarkar[1] and Byung Do Chung[2(✉)]

[1] Department of Industrial and Management Engineering, Hanyang University, Ansan, Gyeonggi-do 15588, South Korea

[2] Department of Industrial Engineering, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul, South Korea

bd.chung@yonsei.ac.kr

Abstract. The flexible production plays the key role within any production system. An optimization model is developed for a production system with flexible production rate within a fixed limit, defined by the management, with quality improvement in a supply chain management. The aim of the model is to obtain the best optimum production rate with the global minimum cost. It is assumed that the lead time demand follows a normal distribution and a lead time crashing cost is used to reduce the lead time. A classical optimization technique is used to solve the supply chain model. A theorem is established to obtain the global minimum total cost. A numerical example is given to illustrate the model. Numerical studies prove that this model converges over the existing literature at the global minimum cost.

Keywords: Flexible production rate · Supply chain management
Quality improvement · Controllable lead time

1 Introduction

Supply chain management (SCM) is introduced by Goyal [1], where he thought about the basic combination of buyer and vendor. There was no especial policy except the adding the basic cost of two players. After a decade, another researcher Banerjee [2] incorporated a new strategy lot-for-lot (LFL) within SCM model, where it is found that LFL policy is convergent over basic model of Goyal [1]. Just after 2 years of Banerjee's [2] model, Goyal [3] wrote a short note over a major concept as single-setup-multi-delivery (SSMD) policy. The policy is valid when the buyer's holding cost is less than vender's holding cost. But there is a trade-off between holding cost and transportation cost of buyer. Sarkar et al. [4] extended SSMD policy to single-setup-multi-unequal-delivery (SSMUD) policy, where they proved that SSMUD is always convergent over SSMD policy. Even though SSMUD is the best strategy for transportation policy till now, but the trade-off between two different costs exist till now. The whole invention is within the grip of domestic deterministic modelling, where the

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 238–245, 2018.
https://doi.org/10.1007/978-3-319-99704-9_29

basic aim of proposed model is to consider a probabilistic modelling with some real extensions.

The basic inventory model for SCM with continuous controllable lead time is considered by Ben-Daya and Rauf [5]. The controllable lead time crashing cost with discrete lead time crashing is initially utilized by Ouyang et al. [6], whereas that model is modified by Moon and Choi [7]. The concepts of quality improvement and setup cost reduction were introduced by Ouyang et al. [8]. This model of Ouyang et al. [8] was extended by Sarkar and Moon [9] by controllable lead time dependent backorder rate but with continuous investment for setup cost reduction. Sarkar et al. [4] extended the concept of quality improvement with backorder price discounts. Kim and Sarkar [10] extended the same field with multi-stage production system Majumder et al. [11] developed a SCM model with similar direction for quality improvement. There are several extensions in this direction, but no one considered variable production rate with SSMUD policy in supply chain management (SCM). Nowadays, it is found that constant production rate (Glock, [12]) may not support always for different types of rapid production. Glock [13] proved that production rate may be variable or controllable but not constant for all production systems. The production rate should be controllable as if machine moves to out-of-control state, it may produce defective products. Thus, to control defective products or imperfect quality items, production rate should be reduced or due to urgent production, production rate may increase to a certain limit for rapid production. Therefore, production rate is always constant, it is not always valid for all production system. The proposed model considers a SCM model with SSMUD policy under variable production rate, which is the initial stage to make a sustainable supply chain management through sustainable manufacturing which follows a normal distribution. The total cost is minimized through a classical optimization technique.

The rest of the paper is organized as follows: Sect. 2 explains mathematical model of the research problem. Section 3 contains the numerical results of the model. Finally, conclusions and future extensions are discussed in Sect. 4.

2 Mathematical Model

A basic two-echelon supply chain management is considered for single type of products within single-manufacturer and single-buyer. The Production rate P is variable and it is considered as $f(P) = aP + \frac{b}{p}$; a and b are scaling parameters and P is the production rate with production setup cost S per setup. The unit production cost is production dependent (see for reference Sarkar et al. [14]) and the quality improvement with continuous investment is considered here (see for reference Kim and Sarkar [10]). If the buyer orders Q items, manufacturer produces zQ items and transports them into z times of shipments to buyer. The reorder point R of each buyer is allowed when the inventory touches the reorder point $R = DL + k\sigma\sqrt{L}$, where D is the demand of products during unit time, L is average lead time, DL is the expected demand during lead time, $k\sigma\sqrt{L}$ is safety stock, and k is safety factor. Safety factor is considered as a decision variable instead of reorder point. Let us suppose $L_0 \equiv \sum_{j=1}^{n} v_j$ and L_i be the length of lead time with components *1, 2,....,i* crashed to their minimum duration. Thus, L_i can be expressed as $L_i \equiv \sum_{j=1}^{i} (v_j - u_j), i = 1, 2\ldots., n$; where u_j and v_j are the minimum duration and normal duration to crash the lead time. The lead time crashing cost per cycle *C(L)* is expressed as $C(L) = c_i(L_{i-1} - L) + \sum_{j=1}^{i-1} c_j(v_j - u_j)$, $L \in [L_i, L_{i-1}]$, where c_i is the crashing cost per unit time. Due to controllable lead time shortages are allowed and fully backlogged.

The average total cost of manufacturer is

$$\begin{aligned} \mathrm{TC_M(z,Q,P,\gamma)} &= \frac{\mathrm{SD}}{\mathrm{zQ}} + \mathrm{h_m}\frac{\mathrm{zQ}}{2}\left[\mathrm{z}\left(1 - \frac{\mathrm{D}}{\mathrm{f(P)}}\right) - 1 + \frac{2\mathrm{D}}{\mathrm{f(P)}}\right] + \frac{\mathrm{yDzQ\gamma}}{2} \\ &+ \left(\mathrm{C_m} + \frac{\mathrm{C_d}}{\mathrm{f(P)}} + \alpha\mathrm{f(P)}\right)\mathrm{D} + \mathrm{B}\ \ln\left(\frac{\gamma_0}{\gamma}\right) \\ &+ \frac{\mathrm{F_1D}}{\mathrm{Q}}. \end{aligned} \tag{1}$$

For the manufacturer, the average total cost is combination of setup cost, holding cost, investment for imperfect products, variable production cost, quality improvement cost, and transportation cost, respectively. Here h_m is the holding cost of the manufacturer per unit product per unit time, y is the investment for quality improvement, C_m and C_d are material cost and development cost, α is the tool/dye cost, γ is the probability for shifting *"in-control"* state to *"out-of-control"* state of the manufacturing process, γ_0 is the initial probability to go *"out-of-control"* state, B is the scaling parameter related with the quality of product, and F_1 is the transportation cost of the manufacturer.

The average total cost of buyer is

$$TC_B(Q,k,L) = \left[\frac{AD}{Q} + \frac{DC(L)}{Q} + h_b\left[\frac{Q}{2} + R - DL\right] + \frac{\pi D}{Q}E(X-R)^+\right], \tag{2}$$

which is the summation of ordering cost, lead time crashing cost, holding cost, and shortage cost. Here A is the ordering cost per order and h_b is the holding cost of the buyer per unit time, and π is shortage cost per unit shortage.

The expected shortage at the end of the cycle can be written as

$$\begin{aligned} E(X-R)^+ &= \int_R^{\infty} (x-R)dF(x) \\ &= \sigma\sqrt{L}\psi(K), \end{aligned} \tag{3}$$

where $\psi(k) = \phi(k) - k[1 - \Phi(k)]$, ϕ stands for the standard normal probability density function and Φ stands for the cumulative distribution function of normal distribution.

Total supply chain cost can be found as the summation of total cost of two players. Therefore,

$$TC_S(z,Q,P,\gamma,k,L) = \frac{SD}{zQ} + h_m\frac{zQ}{2}\left[z\left(1-\frac{D}{f(P)}\right)-1+\frac{2D}{f(P)}\right] + \frac{yDzQ\gamma}{2} + \left(C_m + \frac{C_d}{f(P)} + \alpha f(P)\right)D + B\ \ln\left(\frac{\gamma_0}{\gamma}\right) + \frac{F_1 D}{Q} + \left[\frac{AD}{Q} + \frac{DC(L)}{Q} + h_b\left[\frac{Q}{2}+R-DL\right] + \frac{\pi D}{Q}E(X-R)^+\right] \tag{4}$$

Taking partial differentiation with respect to Q, and after simplification, one can be obtained

$$Q = \sqrt{\frac{AD + F_1 D + DC(L) + \pi D\sigma\sqrt{L}\psi(K) + \frac{SD}{z}}{\frac{h_m z}{2}\left[z\left(1-\frac{D}{f(P)}\right)-1+\frac{2D}{f(P)}\right] + \frac{yDz\gamma}{2} + \frac{h_b}{2}}} \tag{5}$$

Partially differentiating Eq. (4), with respect to P and after simplifying, one can find

$$P = \frac{\sqrt{\frac{1}{\alpha}\left[C_d - \frac{h_m zQ(z-2)}{2}\right]} + \sqrt{\frac{1}{\alpha}\left[C_d - \frac{h_m zQ(z-2)}{2}\right] - 4ab}}{2a} \tag{6}$$

For obtaining the optimum value of k, one can take the partial differentiation of the total supply chain cost with respect to k and after simplification, one can have

$$h_b\sigma\sqrt{L} + \frac{\pi D\sigma\sqrt{L}}{Q}(\Phi(k)-1) = 0. \tag{7}$$

Solving the equation, it can be found

$$\Phi(k) = 1 - \frac{h_b Q}{D\pi}. \tag{8}$$

Differentiating partially twice with respect to L of the total cost function, it can be obtained

$$\frac{\partial^2 TC_S}{\partial L^2} = -\frac{1}{4}\left[\frac{h_b k\sigma}{L^{3/2}} + \frac{\pi D\sigma\psi(K)}{QL^{3/2}}\right] \tag{9}$$

The total cost function TC_S is concave with respect to L as second order derivative with respect to L is less than zero. For optimum value of γ, differentiating the total cost function and simplifying, one can obtain,

$$\gamma = \frac{2B}{YDzQ}. \tag{10}$$

These values of the decision variables are optimum values as the principal minors are positive definite always.

3 Numerical Experiment

This section consists of experiment's result and analysis from the results.

3.1 Numerical Example

To test the model, an illustrative numerical experiment is conducted. The experiment is considered with a tool as MATLAB 17B. For the experiment, the input parameters' value are taken from Majumder et al. [11] and given below:

The demand of products is considered here 600 unit/cycle. The ordering cost of the retailer is \$200/order. Shortages are allowed in this model and it is considered as \$10/unit shortage. Safety σ has the fixed value of 7. Setup cost is assumed as \$200/setup. γ_0 is the initial probability to shift "out-of-control" state 0.0002; F_1 = \$.1/shipment; The investment for quality improvement is \$175. The holding cost of the manufacturer is considered as \$0.13/unit/unit time and buyer as \$0.18/unit/unit time. Material cost, development cost and tool/dye cost are assumed as \$3/setup, \$10/setup, and \$0.001/cycle, respectively. Scaling parameters' values are $a = 0.05$ and $b = 500$, and $B = 400$. Lead time crashing cost is \$22.4.

The numerical experiment has been done with the given values of the parameters. The model obtains the global optimal solution using classical optimization technique in MATLAB coding. The optimum values of Eqs. (5)–(10) are used to obtain the optimum results. The optimal results are obtained as follows: the optimum supply chain cost TC_S = \$5929.88; the optimal lot size (Q^*) = 28.26 unit; the optimal probability of shifting to *"out-of-control"* state from *"in-control"* state $\gamma^* = 0.00009$; the optimal production rate $(P^*) = 3.33$ units; $k^* = 1.37$ the number of shipments $(z) = 3$; lead time $(L) = 4$. It is found that optimum production rate is more than the demand, which indicates that there should not be any shortages any time and the model is validated with the theoretical perspective based on the taken assumptions. Based on the probability value of shifting to *"out-of-control"* state from *"in-control"* state, it can be concluded that the quality of products is improved as the probability is reduced, and finally the shipment number indicates that the model follows single-setup-multi-delivery policy.

If we compare this research model with Majumder et al. [11], then the cost of their model is \$6393.17 under same assumptions whereas the proposed model gives the cost \$5929.88. Therefore, the savings from the existing literature is 7.18%.

3.2 Sensitivity Analysis

A sensitivity analysis is performed here to estimate the variation of total cost of supply chain with change of key parameters of the model. The optimal value of total cost is changed (−10%, −5%, +5%, +10%) with the change of different parameters are given below in Table 1.

Table 1. Sensitivity analysis table

Parameters	Changes (in %)	TC_s^*(in %)	Parameters	Changes (in %)	TC_s^*(in %)
A	−10	−0.05	π	−10	−0.004
	−5	−0.03		−5	−0.001
	+5	+0.02		+5	−0.0001
	+10	+0.05		+10	+0:001
S	−10	−0.02	σ	−10	+0.03
	−5	−0.01		−5	+0.01
	+5	+0.01		+5	−0.01
	+10	+0.02		+10	−0.03
γ_0	−10	−0.007	F_1	−10	−0.00003
	−5	−0.003		−5	−0.00001
	+5	+0.003		+5	+0.00001
	+10	+0.006		+10	+0.00003
Y	−10	−0.007	α	−10	−0.002
	−5	−0.003		−5	−0.001
	+5	+0.003		+5	+0.001
	+10	+0.006		+10	+0.002
h_m	−10	−0.01	h_b	−10	−0.03
	−5	−0.006		−5	−0.01
	+5	+0.005		+5	+0.01
	+10	+0.01		+10	+0.03
C_m	−10	−0.03	C_d	−10	+0.001
	−5	−0.02		−5	+0.0005
	+5	+0.02		+5	−0.0003
	+10	+0.03		+10	−0.0005
a	−10	+0.002	b	−10	−0.002
	−5	+0.0008		−5	−0.0008
	+5	−0.0007		+5	+0.0008
	+10	−0.001		+10	+0.002
B	−10	−0.02			
	−5	−0.008			
	+5	+0.008			
	+10	+0.01			

From Table 1, one can say that ordering cost, setup cost, material cost, backlogging cost, and transportation cost are changing as they are directly proportional to the total cost of the supply chain. Scaling parameters (a, b) of flexible production rate are inversely and directly proportional, respectively to the total cost. For the controllable production rate development cost is inversely proportional to total cost of the supply chain.

4 Conclusions

Two-echelon supply chain model was considered where single-setup-multiple-delivery was applied. Production rate was variable and controllable. Manufacturing system always maintained quality of products. Buyer faced some shortages, but it was fully backlogged. To continue the business supply chain players had to follow some strategies. The model had been solved analytically and numerically. Analytically quasi-closed form solutions were obtained and from numerical study optimal total cost were gained.

This model can be easily applied in any production system, where the production system is flexible and producing single-type of products. The model can be used where the production system is passing through a long-run production system and there is a probability for the production system moves from *"in-control"* state to *"out-of–control"* state; the policy from this model can be employed to improve the quality of products. This model can be extended with the setup time and transportation time-dependent lead time demand, which may be considered as controllable. One can invest some investments to reduce the setup time or transportation time or both. It may be considered that second setup is dependent on first setup and hence the lead time is dependent only setup time, which may be controllable also.

Acknowledgement. This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (NRF-2017R1C1B1008106).

References

1. Goyal, S.K.: An integrated inventory model for a single supplier-single customer problem. Int. J. Prod. Res. **15**(1), 107–111 (1976)
2. Banerjee, A.: A joint economic-lot-size model for purchaser and vendor. Decis. Sci. **17**(3), 292–311 (1986)
3. Goyal, S.K.: A joint economic-lot-size model for purchaser and vendor: a comment. Decis. Sci. **19**(1), 236–241 (1988)
4. Sarkar, B., Saren, S., Sinha, D. Hur, S.: Effect of unequal lot sizes, variable setup cost, and carbon emission cost in a supply chain model. Math. Probl. Eng. 1–13 (2015)
5. Ben-Daya, M., Raouf, A.: Inventory models involving lead time as a decision variable. J. Oper. Res. Soc. **45**(5), 579–582 (1994)
6. Ouyang, L.Y., Yeh, N.C., Wu, K.S.: Mixture inventory model with backorders and lost sales for variable lead time. J. Oper. Res. Soc. **47**(6), 829–832 (1996)
7. Moon, I., Choi, S.: Technical note: a note on lead time and distributional assumptions in continuous review inventory models. Comput. Oper. Res. **25**(11), 1007–1012 (1998)
8. Ouyang, L.Y., Chen, C.K., Chang, H.C.: Quality improvement, setup cost and lead-time reductions in lot size reorder point models with an imperfect production process. Comput. Oper. Res. **29**(12), 1701–1717 (2002)
9. Sarkar, B., Moon, I.: Improved quality, setup cost reduction, and variable backorder costs in an imperfect production process. Int. J. Prod. Econ. **155**, 204–213 (2014)
10. Kim, M., Sarkar, B.: Multi-stage cleaner production process with quality improvement and lead time dependent ordering cost. J. Clean. Prod. **144**, 572–590 (2017)

11. Majumder, A., Guchhait, R., Sarkar, B.: Manufacturing quality improvement and setup cost reduction in an integrated vendor-buyer supply chain model. Eur. J. Ind. Eng. **11**(5), 588–612 (2017)
12. Glock, C.H.: A comment: integrated single vendor-single buyer model with stochastic demand and variable lead time. Int. J. Prod. Econ. **122**(2), 790–792 (2009)
13. Glock, C.H.: The joint economic lot size problem: a review. Int. J. Prod. Econ. **135**(2), 671–686 (2012)
14. Sarkar, B., Sana, S.S., Chaudhuri, K.S.: An imperfect production process for time varying demand with inflation and time value of money – An EMQ model. Expert Syst. Appl. **38**, 13543–13548 (2011)

Reduction of Decision Complexity as an Enabler for Continuous Production Network Design

Günther Schuh, Jan-Philipp Prote, Bastian Fränken, Stefan Dany, and Andreas Gützlaff(✉)

Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen University, 52074 Aachen, Germany
a.guetzlaff@wzl.rwth-aachen.de

Abstract. Today, the continuous design of production networks is challenging due to their high complexity and diverging interests of individual sites. In order to increase the efficiency and agility of global producing companies, this paper presents a method that shifts the often-present focus on locations towards a market and production process oriented design approach of production networks. By subdividing the product range into product families, the complexity of decision-making processes is reduced. Subsequently, target conflicts between product families are resolved systematically from an overall corporate view by deriving the smallest possible holistic decision scope. The method was applied to a machine tool manufacturer.

Keywords: Production networks · Complexity management · Decision making

1 Introduction

1.1 Challanges of Production Network Design

While companies are already continuously developing and optimizing their individual production sites by the use of lean management approaches, production networks are mainly designed in individual projects [1]. Manufacturing companies lack a continuous process for systematical network design [2] to face the continuing trend towards globalized value creation [3]. As a result, companies face the constant risk that their production network will quickly lose competitiveness due to poor internal decisions, such as a suboptimal allocation of new products [4].

One of the main reasons for this problem is that production networks are one of the most complex and dynamic man-made systems [5]. The continuing trend towards product diversification increases this complexity [6].

Thus, suitable management approaches are needed which, on the one hand, are capable of simplifying complexity in decision-making processes and, on the other hand, are able to make optimal decisions for the entire company [4]. In the past, many approaches for designing production networks focused on the configuration of the network, which frequently emphasize the site and location design and often do not put enough emphasis on the market and production processes [7].

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 246–253, 2018.
https://doi.org/10.1007/978-3-319-99704-9_30

1.2 Exemplary Case Study

The considered company is a global producer of machine tools. It has introduced a uniform production system at all its sites to ensure continuous value stream optimization from "ramp to ramp". The sites are focused on optimizing their own balance sheet. They make independent investment decisions and use individual internal cost allocation methods, which makes it difficult to compare manufacturing costs at the network level. Site roles were defined and parts of the production program were strategically assigned by allocating core competencies to main production facilities. The site managers are incited to allocate as much of the remaining products as possible to their site to distribute overhead costs. Despite numerous acquisitions of new sites, there has not been an optimization from a network perspective for years, and the site roles have not led to the desired optimization of the production network.

Initial analyses suggest high productivity potential through network consolidation. For the continuous development of the network, a stronger focus on the value stream of the products and the target markets shall be achieved.

1.3 Aims of This Paper

The aim of this paper is to reduce decision complexity in production network configuration and to shift the design process from a site oriented view towards a stronger focus on the product- and market perspective. In order to achieve this, the paper presents an approach which utilizes the well-established method of value stream mapping [8] on a production network level. The result is a paradigm shift from a site-oriented to a product- and market-oriented configuration of production networks. The approach contributes to enabling a continuous design process for production networks and to the control of complexity in the management of global production networks. The specific challenge stems from industry projects and is summarized in the case study in Sect. 1.2. Case study based research was recently recommended by Ferdows in order to gain a practical management approach for decision-making in the context of global production networks [3].

2 State of the Art

2.1 Evaluation Criteria

Continuous network design is a key to long-term competitiveness of producing companies [2]. To enable continuous network design, a method is needed which meets the following requirements to meet the challenges stated in Sect. 1.1:

- Production network design decisions must always be taken from a company perspective rather than from a location perspective
- Decision complexity must be reduced systematically to a manageable level in order to enable continuous network optimization
- The method has to be applicable to large, complex production networks

2.2 Discussion of Excisting Approaches

Cheng et al. [7] and Saenz et al. [9] present numerous approaches for production network design. Most of the approaches focus on finding solutions for singular network design optimization problems. The most promising are discussed regarding the requirements defined above.

Ferdows describes an approach to reduce the complexity of production networks by delayering them into a set of subnetworks based on complexity and proprietary design of the products they produce and complexity and proprietary design of the processes they use to produce them [4]. This approach is not sufficient since it ignores the production process chain in the delayering process.

Schilling provides an approach for the continuous development of production networks with a focus on fast moving consumer goods [10]. However, due to the specific characteristics of the branch focus, complex supply relationships between sites as well as high product and process complexity, as found for example in mechanical and plant engineering, are neglected.

Lanza and Moser present a dynamic multi-objective optimization model for global manufacturing networks, which evaluates the impact of changes of influencing factors and optimizes the global design of the manufacturing network [11]. The model includes objectives like delivery time, quality, flexibility and coordination effort into consideration. Yet it does not describe a management approach to continuously optimize production networks.

"Making the Right Things in the Right Places" is an approach for continuous production network design presented by Christodoulou et al. [12]. Several methods for global footprint design are presented and embedded as part of cyclic business planning that should be fully owned by all levels of management. The presented framework is proposed as a definitive basis for all manufacturing footprint decision-making. Friedli recognizes it as one of the most relevant approaches to date [13]. Nonetheless the method does not consider complexity reduction as a mayor challenge for continuous production network design.

Schuh et al. present a reference process for the continuous design of production networks [2]. The reference process divides the network design process in a strategic, a tactical and an operational sub process with cyclical interaction. The approach does not provide a detailed proceeding, but is used as a framework for the method described in this paper.

Other approaches like Gölzer et al. aim to make complexity in global production networks manageable through big data analyses instead of complexity reduction [14]. A review of recent big data approaches for supply chain management is given by Tiwari et al. [15].

2.3 Deficits of Existing Approaches

In summary, existing management approaches partly address the problem of enabling continuous production network design, but they are not directly applicable in practice, since they do not include an approach for complexity reduction or ignore main complexity drivers such as process chains. Big data approaches try to enable complexity management but do not consider qualitative, strategic decision factors in decision-making. Furthermore, Olhager et al. support the need of an integrated view of product structure and production process in the network by pointing out that more research is needed to obtain fuller understanding of the mutual impacts of product architecture and supply chain design [16].

3 Approach

The aim of this approach is to reduce the complexity of decision-making processes for production network design to a level that enables continuous production network design. At the same time, it should be ensured that optimal decisions are made from an entrepreneurial point of view.

As shown in Fig. 1, the presented method is divided into five steps, which are arranged according to the reference process by Schuh et al. [2] into a strategic and a short cyclical, tactical process, which are interrelated. At a strategic level, the company's product program is divided into product families. At the tactical level, optimization potentials per product family are identified. Afterwards, target conflicts between product families are derived and the smallest possible decision scope per optimization case is identified in order to subsequently optimize from a company perspective.

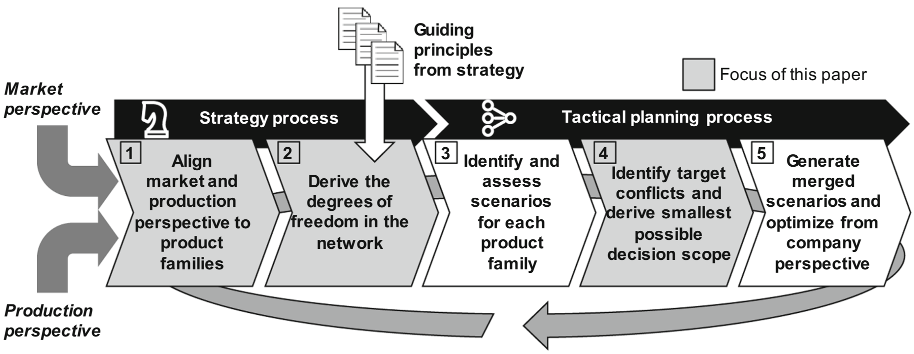


Fig. 1. Integrated approach for complexity reduced, continuous decision-making processes based on product families

Step 1: The first step is a re-orientation of the network structure from site- to product- and production perspective. For this purpose, proven structures from lean production and product development are adopted and transferred to a network view. Rother and Shook describe product families as "a group of products that pass through similar processing steps and over common equipment in your downstream processes" [8]. In the design process of modular systems, modules are formed by means of an external market analysis and an internal production process analysis [17].

Transferred to network design, product families are initially formed from a market perspective as shown in Fig. 2. The product families are categorized according to the sales markets and the product features that are perceived by customers. The assignment is company-specific, since it depends heavily on the product program. For example, a manufacturer of products with a low value density will likely take geographical aspects in focus when forming product families due to the proportionately high transport costs. A manufacturer of equipment used in the medical or food industry may focus on product requirements.

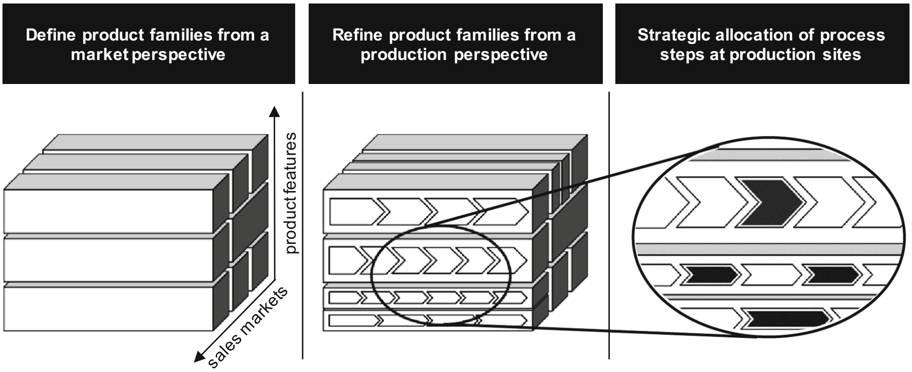


Fig. 2. Market and production specific product family segmentation and match with guiding principles from the production strategy

Subsequently, the product families are detailed from a production perspective. The product families are further subdivided according to the similarity of their value chains. Here, the comparability of the process steps is crucial. The current assignment of process steps to locations is not taken into account in this process step.

Step 2: The degrees of freedom in the network are derived by comparing strategic specifications and the current distribution of the value added. This can be, for example, the linking of production and development for a product at a specific site. Aim is the reduction of network design complexity by not constantly challenging previously defined core competencies at specific sites on a tactical level. Core competencies can be reworked within the strategy process.

Step 3: In the next step, the optimization potential is identified and evaluated for each product family. Methods for identifying optimization potential are not the focus of this paper. Hence, an exemplary reference for an existing approach regarding this topic is given by Shi et al. [18].

Step 4: Afterwards, the design projects of the individual product families resulting from step 3 are set in an overall entrepreneurial context. In order to keep complexity as low as possible, the aim is to find the smallest possible decision-making scope that allows an overall entrepreneurial decision. This is done by analyzing the resources concerned. Resources can be defined company-specifically as individual production and assembly areas within a location or, in more detail, as individual machines or production lines.

The procedure shall be explained by using the example shown in Fig. 3: The value added of product family 1 at location 1 is to be relocated to location 3. This has an impact on all four product families: Product family 2 is closely linked because resources are shared. The removal of product family 1 in plant 1 could also make the relocation of product family 2 from plant 1 beneficial. At the same time, product family 3 uses a resource at site 3 to which the relocation is intended. This results in the new scenario scope, which must take into account product family 1 and parts of the product families 2 and 3. The relocation from location 1 to location 3 increases the contribution margins per unit for product family 4, which reduces the profitability of production, but cannot be shifted for the time being due to strategic specifications. However, the investment calculation must also take product family 4 into account.

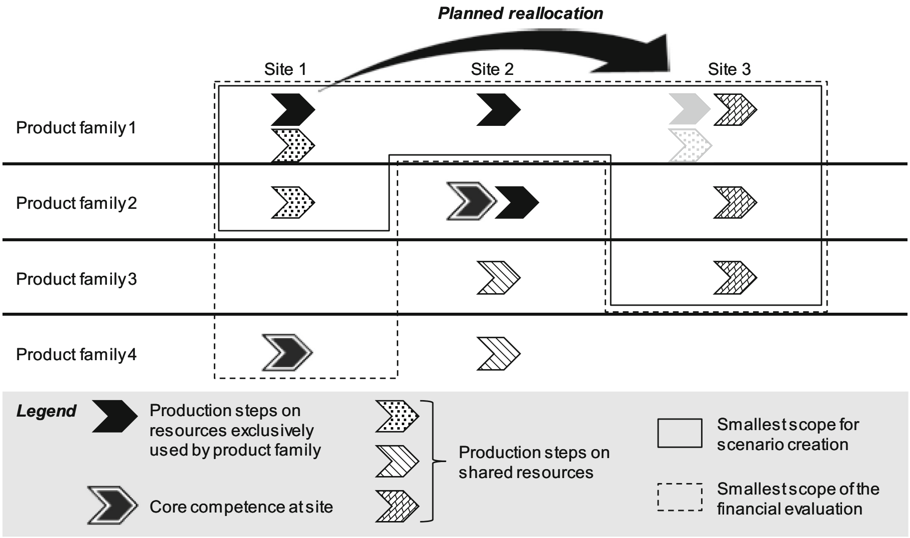


Fig. 3. Derivation of the smallest possible decision scope using the example a the relocation of value added for a product family

Step 5: Finally, the combined scenarios are evaluated. Schuh et al. [19] for example provide a method for holistic scenario evaluation from an overall company perspective. In addition, a financial evaluation of strategic decisions is possible. If, for example, the business case for the example shown in Fig. 3 is positive without taking product family 4 into account, but negative with product family 4, this results in a negative assessment of the relocation from an overall company perspective. The difference to the relocation scenario without consideration of product family 4 are the costs for a strategic decision to be questioned. This must be reflected in the strategy process and the core competence at that site should be questioned.

4 Discussion and Future Research

The strategic process steps 1 and 2 of presented approach have been applied to the company described in the case study in Sect. 1.3. Main driver for the product family separation has been the final assembly of the products. In total, eight product families have been derived.

In order to implement the entire approach in a sustainable way, it is necessary to create the appropriate organizational structures. Therefore, the assignment of decision-making competencies to a value stream manager per product family managers is required and committees have to be defined that solve target conflicts from an overall network perspective. In addition, the method leads to an increased number of evaluation processes in the network, therefore methods are required that are able to evaluate these situation-specific scenarios with an adequate effort.

Furthermore, testing with companies from other industries is necessary to examine the general validity of the procedure. However, the following advantages are expected from the presented approach:

- By dividing the product range into product families, the network design focus is directed towards the value-added process instead of conflicts of interest between production sites
- The derivation of optimization projects per product family enables a complexity reduction for the identification of optimization potentials
- Target conflicts between product families create a value-added oriented discussion within the company and are resolved from an overall entrepreneurial perspective.

Acknowledgment. The authors would like to thank the German Research Foundation DFG for the kind support within the Cluster of Excellence “Integrative Production Technology for High-Wage Countries”.

References

1. Ferdows, K.: Managing the evolving global production network. In: Markides, C., Murray, J.A., Galavan, R. (eds.) Strategy, Innovation, and Change. Challenges for Management. Oxford University Press, Oxford (2008)
2. Schuh, G., Prote, J.-P., Dany, S.: Reference process for the continuous design of production networks. In: 2017 International Conference on Industrial Engineering and Engineering Management (IEEM) (2017)
3. Ferdows, K.: Keeping up with growing complexity of managing global operations. Int. J. Oper. Prod. Manag. **14**(1), 73 (2018)
4. Ferdows, K., Vereecke, A., Meyer, A.: Delayering the global production network into congruent subnetworks. J. Oper. Manag. **41**, 63–74 (2016)
5. Váncza, J.: Production networks. In: Chatti, S., Laperrière, L., Reinhart, G., Tolio, T. (eds.) CIRP Encyclopedia of Production Engineering, pp. 1–8. Springer, Heidelberg (2016). https://doi.org/10.1007/978-3-642-35950-7

6. Mourtzis, D., Doukas, M.: The evolution of manufacturing systems. In: Handbook of Research on Design and Management of Lean Production Systems, pp. 1–29. IGI Global, Hershey, Pennsylvania (2014)
7. Cheng, Y., Farooq, S., Johansen, J.: International manufacturing network: past, present, and future. Int. J. Oper. Prod. Manag. **35**(3), 392–429 (2015)
8. Rother, M., Shook, J.: Learning to See: Value-Stream Mapping to Create Value and Eliminate Muda. Version 1.4 ed. Lean Enterprise Institute, Cambridge (2009)
9. Maria Jesus Saenz, P., Koufteros, X., Olhager, J., Pashaei, S., Sternberg, H.: Design of global production and distribution networks. Int. J. Phys. Distrib. Logist. Manag. **45**(1/2), pp. 138–158 (2015)
10. Schilling, R.: Manufacturing network development in fast-moving consumer goods industries. Kovač, Hamburg (2012)
11. Lanza, G., Moser, R.: Multi-objective optimization of global manufacturing networks taking into account multi-dimensional uncertainty. CIRP Ann. **63**(1), 397–400 (2014)
12. Christodoulou, P., Fleet, D., Hanson, P., Phaal, R., Probert, D., Shi, Y.: Making the right things in the right places: a structured approach to developing and exploiting 'manufacturing footprint' strategy. University of Cambridge Institute for Manufacturing, Cambridge (2007)
13. Friedli, T., Mundt, A., Thomas, S.: Strategic Management of Global Manufacturing Networks: Aligning Strategy, Configuration, and Coordination. Springer, Berlin (2014). https://doi.org/10.1007/978-3-642-34185-4
14. Gölzer, P., Simon, L., Cato, P., Amberg, M.: Designing global manufacturing networks using big data. Procedia CIRP **33**, 191–196 (2015)
15. Tiwari, S., Wee, H.M., Daryanto, Y.: Big data analytics in supply chain management between 2010 and 2016: insights to industries. Comput. Ind. Eng. **115**, 319–330 (2018)
16. Pashaei, S., Olhager, J.: Product architecture and supply chain design: a systematic review and research agenda. Supply Chain Manag. **20**(1), 98–112 (2015)
17. Schuh, G. (ed.): Leitfaden zur Baukastengestaltung: Ergebnisse des Forschungsprojekts Gestaltung innovativer Baukasten- und Wertschöpfungsstrukturen (GiBWert), VDMA Verl., Stuttgart (2015)
18. Shi, Y., Gregory, M., Naylor, M.: International manufacturing configuration map: a self-assessment tool of international manufacturing capabilities. Integr. Manf. Syst. **8**(5), 273–282 (1997)
19. Schuh, G., Prote, J.-P., Fränken, B., Gützlaff, A.: Assessment of production network scenarios based on economic value added. In: 24th International Conference on Production Research (ICPR 2017), pp. 116–121. DEStech Publications Inc., Lancaster (2017)

Collaborative and Sustainable Network Design in Courier Services

Ki Ho Chung[1], Seung Yoon Ko[2], and Chang Seong Ko[3](✉)

[1] Department of Business Administration, Kyungsung University, 309 Suyeong-ro, Nam-gu, Busan 48434, South Korea
khchung@ks.ac.kr

[2] Department of Industrial and Management Engineering, Korea University, 145 Anam-ro, Seongbuk-gu, Seoul 02841, South Korea
rhtmddbs@korea.ac.kr

[3] Department of Industrial and Management Engineering, Kyungsung University, 309 Suyeong-ro, Nam-gu, Busan 48434, South Korea
csko@ks.ac.kr

Abstract. While the courier service demand has been continuously increasing over the last decade, the unit price has been dropping due to the more severe competition among the courier services. The courier service companies with low market share are making several types of efforts to survive in competitive market. Collaboration via the economy of sharing can allow the courier service companies to extend their service network and increase the market share. This study suggests a collaboration model to increase the competitiveness of every participating company. In addition, a nucleolus-based profit allocation method is applied for fair allocation of the profits to each participating company based on a cooperative game theory. An illustrative example problem demonstrates the applicability and efficiency of the proposed model.

Keywords: Courier service · Economy of sharing · Collaborative Sustainable · Nucleolus

1 Introduction

In recent years, the concept for economy of sharing has been applied in various industry areas to meet the needs for utilizing the physical assets more efficiently. It could generate innovation-based community, and foster changes in business relationships up to the ecosystem. The consumer-driven sharing economy based on trust and experience such as Airbnb and Uber, etc. is gradually transferring to the emphasis on B2B (business-to-business) shared economic support for preventing duplicate asset loss. Compared with other industries transportation and logistics sector are leading the sharing economy. In particular, it has been active in the aviation and maritime transport and extended to several sectors of land transport. Nowadays, rapid increase in B2C (business-to-customer) is accelerating a steep surge of courier service market. The courier amount in Korean courier market has continuously been growing year by year. On the other hand, the unit price has been dropping due to the more severe competition

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 254–261, 2018.
https://doi.org/10.1007/978-3-319-99704-9_31

among the courier service providers. In the end, the courier companies with low market share are not likely to survive in competitive market and cannot help avoiding collaboration for increasing their market shares company [1, 2].

The objective of this study is to apply the sharing economy to the courier service for developing win-win business model and suggest an equitable allocation method of alliance profits based on co-operative game theory. A study for the courier service network design reflecting collaboration was first performed by Chung *et al.* [4]. Then some decision making models appeared considering several types of collaborations following it [5–10]. Also, Ko *et al.* carried out a collaboration-based reconfiguration problem with cut-off time adjustments in courier service network [13]. Ferdinand *et al.* took account of collaborative pick-up and courier routing problem of line-haul vehicles for maximizing the profits of participating companies [11]. Recently, Chung *et al.* [3] proposed a sustainable collaboration model with monopoly of service centers using Shapley value allocation. Their study was also extended to the problem of sharing consolidation terminals of each company [2]. A multi-objective non-linear integer programming model was developed for reflecting two types of collaboration problems such as survival of service centers and terminal sharing simultaneously.

2 Model Design

Suppose that there are m express courier companies, and that the locations of terminals and service centers operated by each company are known in advance. And it is assumed that there are n merging regions where companies have a relatively small delivery amount. In addition, suppose that the daily delivery amount of every company in each region and the processing capacity of terminals per day are given beforehand.

In order to develop the mathematical formulation for this problem some notations are introduced.

I: Set of express courier companies, $I = \{1, 2, \ldots, m\}$

J: Set of service regions in which service centers are to be merged, $J = \{1, 2, \ldots, n\}$

T_i: Set of consolidation terminals for company i, $i \in I$

J_{ik}: Set of merging regions allocated to company i's terminal $k, i \in I, k \in T_i$

d_{ij}: Daily delivery amount of company i within the merging region $j, i \in I, j \in J$

D_j: Sum of daily delivery amount of all the service centers within the merging region $j, j \in J$

r_{ij}: Revenue that company i obtains by delivering one unit within the merging region $j, i \in I, j \in J$

c^1_{ij}: Unit delivery cost when company i's service center exists in the merging region $j, i \in I, j \in J$

c^2_{ij}: Unit delivery cost when company i's service center does not exist in the merging region $j, i \in I, j \in J$

a_{ij}: Indicator constant such that $a_{ij} = 1$, if company i's service center exists in the merging region j before alliance, $a_{ij} = 0$, otherwise, $i \in I, j \in J$

Q_{ik}: Delivery process capacity remaining at terminal k of company $i, j \in J, k \in T_j$

f_{ij}: Daily fixed cost for operating the service center when company i's service center exists in the merging region $j, i \in I, j \in J$

x_{ij}: Binary variable such that $x_{ij} = 1$, if company i's service center in the region i is still open after alliance, $x_{ij} = 0$ otherwise, $i \in I, j \in J$.

The problem can be formulated as the following multi-objective integer programming model (P) with m objective functions:

(P)

$$\begin{aligned} Max\, Z_1 &= \sum_{j \in J} \left(r_{1j} - c^1_{1j} \right) a_{1j} \left(D_j x_{1j} - d_{1j} \right) \\ &\quad + \sum_{j \in J} f_{1j} a_{1j} \left(1 - x_{1j} \right) + \sum_{j \in J} \left(c^2_{1j} - r_{1j} \right) d_{1j} \left(1 - a_{1j} \right) \\ &\quad \vdots \\ Max\, Z_m &= \sum_{j \in J} \left(r_{mj} - c^1_{mj} \right) a_{mj} \left(D_j x_{mj} - d_{mj} \right) \\ &\quad + \sum_{j \in J} f_{mj} a_{mj} \left(1 - x_{mj} \right) + \sum_{j \in J} \left(c^2_{mj} - r_{mj} \right) d_{mj} \left(1 - a_{mj} \right) \end{aligned} \tag{1}$$

Subject to

$$\sum_{i \in I} x_{ij} = 1, \qquad j \in J \tag{2}$$

$$x_{ij} \le a_{ij}, \quad i \in I, j \in J \tag{3}$$

$$\sum_{j \in J_{ik}} \left(D_j x_{ij} - d_{ij} \right) \le Q_{ik}, \quad i \in I,\ k \in T_i \tag{4}$$

$$x_{ij} \in \{0, 1\}, \quad i \in I, j \in J \tag{5}$$

The objective function (1) consists of m conflicting objectives corresponding to m companies. Each objective function represents the sum of net profit increases obtained through alliance. Constraint (2) assures that only one service centers can be open in each merging region and all the others should be closed. Constraint (3) implies that open service center is chosen among the existing service centers in the merging region. Constraint (4) means that the sum of daily delivery amount of merging regions allocated to a terminal cannot exceed more than process capacity remaining at the terminal. Constraints (5) represents 0-1 integer variable.

3 Nucleolus-Based Profit Allocation Procedure

To sustain long-term collaboration, a fair allocation of coalition profit is very important. In cooperative game theory there exists a core for any coalition if completeness, rationality and marginality conditions are satisfied. Necessity of coalition is more emphasized by means of existence of the core. Since no core or too many cores for some coalitions may exist, Shapley value and Nucleolus-based allocations are suggested as a single solution procedure [12, 15]. Shapley value is well known as the most equitable profit sharing method in cooperative game theory, which reflects a concept to distribute synergies obtained through the coalition according to the marginal contribution of participants [14]. However, its weakness is that it may not satisfy core conditions. On the contrary, nucleolus-based allocation is proposed to overcome the problem of Shapley value. It tries to maximize excess vector under the core conditions. To find a nucleolus-based allocation for combinations of three companies' coalitions the linear programming is developed as follows:

$$\textit{Maximize } t \tag{6}$$

Subject to

$$R_1 \geq C_1 + t \tag{7}$$

$$R_2 \geq C_2 + t \tag{8}$$

$$R_3 \geq C_3 + t \tag{9}$$

$$R_1 + R_2 \geq C_{12} + t \tag{10}$$

$$R_1 + R_3 \geq C_{13} + t \tag{11}$$

$$R_2 + R_3 \geq C_{23} + t \tag{12}$$

$$R_1 + R_2 + R_3 = C_{123} \tag{13}$$

$$R_1, R_2, R_3, \mathrm{t} \geq 0 \tag{14}$$

where t is excess vector, R_i is profit allocation for company i, C_i, C_{ij}, C_{ijk} means coalition profit for only company i, companies i and j, companies i, j and k, respectively.

The objective function (6) means maximum of excess vector. Constraints (7)–(12) assure satisfaction of rationality and marginality conditions of the core. Constraint (13) means core's completeness. Constraint (14) represents non-negativity.

Table 1. Data for company A, B, and C

Regions of service centers	Delivery amount			Allocated terminal			Daily fixed cost ($)		
	A	B	C	A	B	C	A	B	C
1	29	45	37	1	1	2	77	91	89
2	22	17	29	1	2	2	97	79	79
3	46	30	40	1	2	2	89	67	83
4	10	26	27	2	2	2	81	86	61
5	48	42	19	2	1	1	66	54	–
6	47	42	35	1	2	1	64	62	–
7	29	14	37	2	2	2	67	–	94
8	25	18	23	1	1	2	82	–	63
9	20	36	29	2	1	1	–	77	90
10	23	50	42	2	2	1	–	80	52

Table 2. Data for each company's remaining processing capacity

Q^1_{A1}	Q^1_{A2}	Q^1_{B1}	Q^1_{B2}	Q^1_{C1}	Q^1_{C2}
145	137	112	162	129	106

Table 3. Optimal solution for maxmin criterion

	1	2	3	4	5	6	7	8	9	10
x_{Aj}	1	1	0	0	1	0	1	0	0	0
x_{Bj}	0	0	1	0	0	1	0	0	1	0
x_{Cj}	0	0	0	1	0	0	0	1	0	1

Table 4. Optimal solution for maxsum criterion

	1	2	3	4	5	6	7	8	9	10
x_{Aj}	1	0	0	0	0	0	1	0	0	0
x_{Bj}	0	1	1	0	1	1	0	0	1	0
x_{Cj}	0	0	0	1	0	0	0	1	0	1

Table 5. Nucleolus-based and Shapley value allocation

Subgroup		Subgroup output	Marginal contribution		
			A	B	C
No collaboration	A	0	0		
	B	0		0	
	C	0			0
	Column average (①)		0	0	0
Collaboration between two companies	A, B	606	606	606	
	B, C	638		638	638
	A, C	678	678		678
	Column average (②)		642	622	658
Full collaboration	A, B, C (③)	1,365	727	687	759
Shapley value			456.3	436.3	472.3
Nucleolus			457.3	417.3	489.8

4 Numerical Example

An illustrative example is provided to explain the appropriateness of the collaboration model and to evaluate the nucleolus-based allocation. It is assumed that there are three companies with two consolidation terminals and ten merging regions. Table 1 shows delivery amount, allocated terminal, and capital recovery from fixed assets according to service center closedown for each company A, B and C. Current remaining processing capacities of terminal for each companies are generated as shown in Table 2.

The optimal solution for maxmin criterion can be obtained using Excel Solver in Table 3. The total profit obtained from strategic alliance by consolidating the service centers is $1,345. On the other hand, the optimal solution acquired by the maxsum criterion is shown in Table 4, and the total profit that is shown in this table is $1,365, which is greater than the total profit by the maxmin criterion. Table 5 also shows the Shapley value results by applying maxsum criterion and an allocation method by fairly allocating to each company based on its marginal contribution. According to Tarashev *et al.* [16] the marginal contribution of a company to a subgroup is calculated as the output of the subgroup minus the output of the same subgroup excluding the individual participant. Then the Shapley value of each company is the average of its marginal contributions across all differently sized subgroups. On the contrary, the linear programming was solved with the parameter values; $C_1 = 0$, $C_2 = 0$, $C_3 = 0$, $C_{12} = 606$, $C_{13} = 678$, $C_{23} = 638$ and $C_{123} = 1{,}365$ to find the nucleolus-based allocation for three companies. By seeking benefits based on the maxmin criterion, all participating companies will feel fair and impartial. However, applying the maxsum criterion increases the total benefit through coalition compared to the maxmin criterion. Therefore, it is better to apply the maxsum criterion from the perspective of total benefit. But, there exists still a problem of how to distribute coalition profits to affiliates. Using Shapley value or nucleolus concept can be a good alternative because it can be rationally distributed.

5 Conclusions

Most small and medium-sized courier service companies in Korea are in trouble due to severe competition in the market. Coalition is emerging as a unique survival strategy to obtain a higher market share with limited resources in industry fields. In addition, one of the difficult parts of applying collaboration is determining how to allocate costs or profits to each participating company. This study proposed a decision making model for alliance in courier services. A nucleolus-based allocation as a systematic allocation methodology was also proposed for fair allocation to each company. This study can accelerate the collaboration in several industry sectors by providing technology for coalition and fair allocation for its sustainability. Furthermore, in further research, various types of collaboration models related to the overall network design in express delivery services will also be included.

Acknowledgments. This research was supported by Basic Science Research Program though the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (NRF-2015R1D1A3A01019761).

References

1. Bae, M.S.: Korean delivery service market. National Logistics Information Center Bulletin, Seoul (2017)
2. Chung, K.H., Ko, S.Y., Ko, C.S.: A cooperative game-theoretic network design for collaborative operation of service centers and consolidation terminals in express delivery services. Int. J. Ind. Eng. **25**(1), 18–28 (2018)
3. Chung, K.H., Ko, S.Y., Lee, C.U., Ko, C.S.: Sustainable collaboration model with monopoly of service centers in express delivery services based on shapley value allocation. Int. J. Ind. Eng. **23**(3), 166–173 (2016)
4. Chung, K.H., Rho, J.J., Ko, C.S.: Strategic alliance model with regional monopoly of service centers in express courier services. Int. J. Serv. Oper. Manag. **5**(6), 774–786 (2009)
5. Chung, K.H., Ko, C.S., Hwang, Y.M., Rho, J.J.: Network design for strategic alliance in express courier services: a fuzzy set approach. Int. J. Innov. Comput. Inf. Control **6**(1), 349–359 (2010)
6. Chung, K.H., Ko, H.J., Ferdinand, F.N., Ko, C.S.: A fuzzy set-theoretic approach to the weak strategic alliance for the survival of multiple service centers in express courier services. ICIC Express Lett.: Int. J. Res. Surv. **5**(2), 385–389 (2011)
7. Ferdinand, F.N., Chung, K.H., Ko, H.J., Ko, C.S.: Genetic algorithm-based approach to multi objective decision making model for strategic alliances in express courier services. ICIC Express Lett.: Int. J. Res. Surv. **6**(4), 929–934 (2012)
8. Ferdinand, F.N., Chung, K.H., Ko, H.J., Ko, C.S.: A compromised decision making model for implementing a strategic alliance in express courier services. Inf.: Int. Interdiscip. J. **15** (12c), 6173–6188 (2012)
9. Ferdinand, F.N., Moon, I.K., Chung, K.H., Ko, C.S.: A decision making model for strategic alliance-based network design in express delivery services. ICIC Express Lett.: Int. J. Res. Surv. **7**(6), 1813–1818 (2013)

10. Ferdinand, F.N., Chung, K.H., Lee, E.G., Ko, C.S.: Collaborative system design in express delivery services: formulation and solution heuristic. ICIC Express Lett. Part B: Appl. **5**(1), 2185–2766 (2014)
11. Ferdinand, F.N., Kim, Y.J., Lee, H.K., Ko, C.S.: A study on collaborative pick-up and delivery routing problem of line-haul vehicles in express delivery services. Int. J. Ind. Eng. **21**(6), 376–383 (2014)
12. Kimms, A., Cetiner, D.: Approximate nucleolus-based revenue sharing in airline alliances. Eur. J. Oper. Res. **220**(2), 510–521 (2012)
13. Ko, C.S., Chung, K.H., Ferdinand, F.N., Ko, H.J.: Collaboration based reconfiguration of a package service network with multiple consolidation terminal. Int. J. Ind. Eng. **20**(1–2), 72–83 (2013)
14. Shapley, L.: A value for n-person games. Ann. Math. Stud. **28**, 307–317 (1953)
15. Schmeidler, D.: The nucleolus of a characteristic function game. SIAM J. Appl. Math. **17**(6), 1163–1170 (1969)
16. Tarashev, N., Borio, C., Tsatsaronis, K.: The systemic importance of financial institutions. BIS Q. Rev. 75–87, September 2009

Measuring Throughput Times in Wood Component Production: A Case Study

Sven-Vegard Buer(✉), Oladipupo Olaitan, and Jan Ola Strandhagen

Department of Mechanical and Industrial Engineering, NTNU, Norwegian University of Science and Technology, Trondheim, Norway
sven.v.buer@ntnu.no

Abstract. An increasing number of manufacturing companies acknowledge the importance of flow efficiency. As an important key performance indicator in lean implementation processes, being able to measure the throughput time of products is important to assess the current situation. This paper presents a stepwise method for measuring the throughput time in manufacturing environments with no unique identification of products, products made up of several levels of subcomponents, as well as varying batch sizes throughout the process. With relatively few data points, the method calculates the average throughput time of products for a chosen time period. The method is applied to a case company who manufactures wood components.

Keywords: Throughput time · Performance measurement
Production planning and control

1 Introduction

Lean manufacturing highlights the importance of flow efficiency rather than resource efficiency, which traditionally has been the focus for manufacturing companies. While resource efficiency emphasizes local optimization, flow efficiency rather focuses on minimizing the throughput time for a product through the system.

To support lean improvement projects, it is important to have accurate and responsive key performance indicators (KPIs). Lean improvement projects typically aim to improve operations in one or more performance dimensions; therefore, establishing relevant KPIs is important to give decision makers feedback on the current state and the effect of the improvement initiatives. While some KPIs are easy to extract from the operations, for instance through existing IT systems, others require more effort from employees to gather the data and calculate the value.

An important KPI in lean manufacturing implementations is the throughput time of products [1]. This gives an accurate measure of the current performance of the company regarding their efforts to streamline the production and eliminate waste and waiting times along the value chain. While it is easy to measure throughput time in a situation where products are allocated unique IDs, for instance, a barcode or RFID chip, securing accurate throughput time measurements in a situation without individual

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 262–270, 2018.
https://doi.org/10.1007/978-3-319-99704-9_32

identification of components and varying batch sizes throughout the manufacturing process can be a challenge.

Despite the increased popularity of IT systems in manufacturing companies, through the adoption of Industry 4.0, many still only have basic transaction and IT systems. Motivated by the challenges of such companies, this paper presents a method for measuring throughput times in an environment without individual tracking of components and varying batch sizes. The rest of the paper is organized as follow: Sect. 2 provides a background of the case company and reviews the literature on methodologies for estimating throughput time, while Sect. 3 describes the calculation method that has been utilized in this study. Section 4 presents the results from the throughput time analysis in the case company. Findings from the results are then discussed in Sect. 5, followed by conclusions and recommendations for future work.

2 Theoretical Background and Overview of Case System

Flow is one of the five lean principles as described by Womack and Jones [2]. A central aspect of lean is to shift the focus from resource efficiency to flow efficiency [3]. Product flow efficiency concerns keeping the product moving through the production process [3], and this is mainly achieved through an eradication of all forms of production waste [2] and a tight synchronization between the upstream and downstream stages of a production system [4]. The obvious benefits of keeping continuous flow are that it shortens the system throughput time and increases the responsiveness of the system to the fulfillment of customer orders. However, it is generally difficult to quantify the improvements derived from the implementation of lean, particularly because lean encompasses various elements and involves company-wide changes. It is difficult to isolate and quantify the improvements that are due to individual elements. Ironically, the company-wide changes required by lean means that a preliminary quantification of the level of improvement to expect from its implementation is necessary to convince an organization to invest resources in it.

Lean's ability to achieve shorter throughput time is one of its most easily attributable benefits. Lean threats inventory as waste and aims to eradicate it [2], and, based on Little's law, lower inventory level should shorten the throughput time [5]. Even though the relationship between throughput time and other parameters of the system that are often targeted by a lean implementation is clear as expressed in Eq. (1), the approach to estimating those parameters for a system produces different results.

$$L = \lambda\mu \tag{1}$$

where:

L is the number of items in the system (i.e. inventory level)

λ is the average number of items arriving per unit time (i.e. arrival rate)

μ is the average waiting time in the system for an item (i.e. throughput time)

While the original equation defines λ as the arrival (or input) rate into the system under consideration, a subsequent study has represented it as the departure (output) rate from the system [6]. In a system with a steady flow, the use of either definition should produce similar estimates of throughput time [7]; however, this would not be the case if there were conditions that significantly impact the steady flow of items through the system. Little and Graves [7] highlight two conditions that need to be valid in order to use output rate instead of input rate for calculating throughput time. First, there needs to be conservation of flow (steady state). Second, all jobs that enter must also be completed and exit the shop. Other factors that could result in discrepancy between the use of input and output rates are fluctuations in system inventory, variability in system capacity, the presence of assembly or batching operations in the system, highly variable product routing and the application of prioritization rules or order release mechanisms that significantly alter the flow of items within the system.

This study uses input and output rates to estimate the throughput time for a case company, which specializes in the manufacture of internal and external (visible) wood components. The company operates with modern machinery for processes such as wood planing, gluing, cutting, sanding, machining and lacquering. In addition, they operate manual assembly stations and an automated robot assembly cell. They operate on an order-driven basis and, therefore, do not have a finished goods inventory. Instead, the customer order decoupling point (CODP) is located at a supermarket (i.e. a buffer for holding semi-finished parts) close to the end of the manufacturing process. Whenever there is an incoming order, parts are picked from here and lacquered (only for visible wood) and assembled before being shipped directly to the customer. In order to map the current state of the case company regarding material and information flows, the control model methodology by Alfnes and Strandhagen [8] was used. This AS-IS mapping of the company provided valuable insights into the current situation and helped to identify which data points were available for use. Figure 1 illustrates a simplified control model for the case company, focusing on the process investigated in this study.

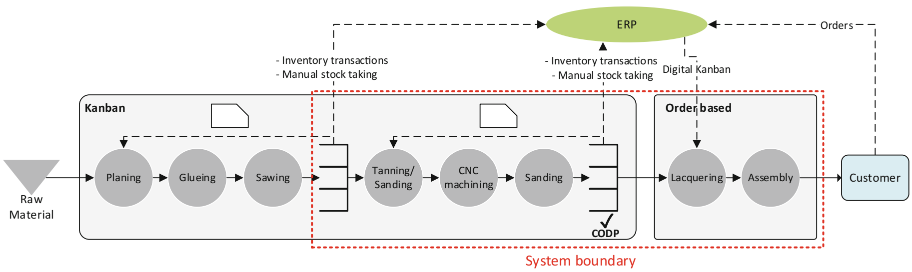


Fig. 1. Simplified control model of the process for product family Z

The application of input and output rates to estimate throughput time for this case company should give insights into the extent to which the factors earlier described would influence the reliability of using either approach. In the following section, both methods are described, followed by their application to the case company. The section also gives insights into the process of translating raw data into the KPIs that are needed to evaluate the progress made when undertaking system improvement programmes.

3 Throughput Time Measurement Method

This section will give a step-wise introduction to the applied throughput time measurement method that is suggested and used in the presented case. To use this method, the required data inputs are: (i) the amount of work-in-process (WIP) for each product family (including sub-components), (ii) the output (sales) and/or input for each product family in a chosen time period, and (iii) number of working days in the chosen time period.

Step 1: Define the System Boundaries
The first step in calculating the throughput time is to decide on the boundaries of the system in which the throughput time should be measured. This means to look at specific parts of the value stream and/or specific products [9]. In a general case, it would be beneficial to have a holistic view and look at the whole manufacturing system, but in special cases, there might be reasons for looking at specific parts of the manufacturing process. This could, for instance, be in cases where there have been improvement projects in a specific department, but the throughput time through this department is so small compared to the total throughput time that the improvements can be difficult to observe. The selection of the system boundary will also depend on the available data points. In order to use the method, data is needed about input or output rate and the level of WIP. For instance, in a situation where only the WIP is known for parts of the process, it would be necessary to alter the system boundary to only consider this part.

Step 2: Use the Bill of Materials to Calculate the "Longest" Value Stream
If a product consists of assembled components, it is essential to adjust its contribution to the WIP, based on the individual contributions of its components. Therefore, based on the bill of materials (BOM), which specifies the relationship between the end product and the components, the WIP for each component should be converted into a corresponding number of end products. Following this, the "longest" value stream should be calculated by adding up the number of end products and the component which have the largest WIP in "end product" units. This approach is similar to the calculations of Manufacturing Critical-path Time, known from Quick Response Manufacturing [9].

Step 3: Calculate Average Throughput Time for a Chosen Time Period
Some general notations are outlined below:

$TT_{i,p}$: Average throughput time for product, i, through the defined system boundaries in period, p
WIP_i: Current WIP of product, i, in the defined system boundaries (in number of products)
$O_{i,p}$: Output (sales) of product, i, in period, p
$OR_{i,p}$: Output rate for product, i, through the defined system boundaries in period, p (in number of products per time unit)
$I_{i,p}$: Input of product, i, into the production process in period, p

$IR_{i,p}$: Input rate for product, i, through the defined system boundaries in period, p (in number of products per time unit)
WD_p: Number of working days in period, p

Equation (2) calculates the output rate by dividing the output in the period by the number of working days in the same period.

$$OR_{i,p} = \frac{O_{i,p}}{WD_p} \tag{2}$$

Similarly, Eq. (3) can be used to calculate the input rate.

$$IR_{i,p} = \frac{I_{i,p}}{WD_p} \tag{3}$$

As explained in Sect. 2, Hopp and Spearman [6] argue for using the output rate of the system to calculate the throughput time of the selected product(s) within the selected system boundary. The method is shown in Eq. (4).

$$TT_{i,p}\,(OR) = \frac{WIP_i}{OR_{i,p}} \tag{4}$$

On the contrary, Little [5] argue for using the input rate, as shown in Eq. (5).

$$TT_{i,p}\,(IR) = \frac{WIP_i}{IR_{i,p}} \tag{5}$$

By combining Eqs. (2) and (4), or Eqs. (3) and (5) alternative versions of the formula are obtained as shown in Eqs. (6) and (7), respectively:

$$TT_{i,p}\,(OR) = \frac{WIP_i \times WD_p}{O_{i,p}} \tag{6}$$

$$TT_{i,p}\,(IR) = \frac{WIP_i \times WD_p}{I_{i,p}} \tag{7}$$

4 Applying the Method at the Case Company

This section describes how the proposed methodology was used in the case company to calculate the throughput times for a family of products. This section will follow the step-wise method described in the previous section. We focused the analysis on a specific product family, from here known as product family Z. The BOM for product family Z is presented in Fig. 2, while its sales in 2016 are presented in Table 1.

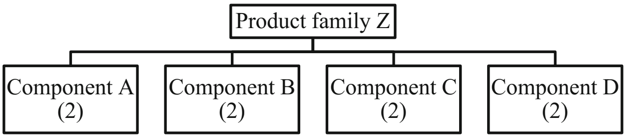


Fig. 2. The BOM for the investigated product family Z.

Table 1. Sales of product family Z in 2016

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
820	1036	714	792	656	653	153	588	735	493	1128	266

Step 1: Define the System Boundaries

The case company did not have any data available regarding the inventory level at the raw material inventory or the amount of WIP from the raw material inventory up until the first intermediate inventory (supermarket). Based on this constraint, it was therefore chosen to define the system boundary from the first supermarket up until products are delivered. In addition, up until the first supermarket, the material is not assigned to a specific product family, which complicates the process of assigning product family specific throughput times. The system boundary is illustrated in Fig. 1.

Step 2: Use the Bill of Materials to Calculate the "Longest" Value Stream

The case company does not continuously keep track of their WIP levels. Although they utilize a Kanban control system internally in production, which limits their maximum WIP, there will still be variations in WIP because of uneven demand, replenishments at different times and products being scrapped. Also, there is still a large discrepancy between the registered WIP and the actual WIP, even though material transactions are supposed to be registered in the ERP system. This is confirmed by quarterly stock-takings. Therefore, in this case, the WIP recorded from the stock takings shown in Table 2 were used as input data. However, if they are able to increase the compliance between the ERP system and the actual inventory levels, using the WIP data from the ERP would provide a more accurate and responsive solution than using the stock taking data.

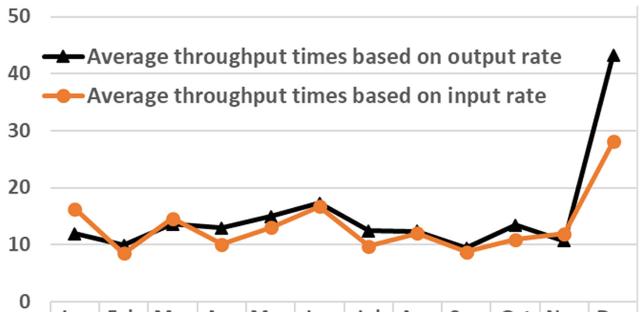
Table 2. The results of the stocktakings in 2016

	March	May	September	December
Product family Z	136	104	84	164
Component A	564	383	449	768
Component B	495	818	345	581
Component C	703	786	281	665
Component D	410	781	462	655
Total for the "longest" value stream*	487	513	315	548

**In number of end units*

By going through their historical data, and using the calculation method described in Sect. 3, it became clear that the component which created the "longest" value stream tended to change between each time. This is normal and related to the WIP variations in the Kanban system described above. If there was a trend that there was always a specific component causing the "longest" value stream, it would have been a sign that the Kanban bin size or the number of Kanban cards should be adjusted for this component.

Step 3: Calculate Average Throughput Time for a Chosen Time Period
By using the collected data, we calculated the average throughput time for each month for the investigated product family Z. As visible in Fig. 3, there is a huge spike in December. This was caused by a reorganization at the company's main customer, which led to a large decrease in demand that month. Since they operate on an order-driven basis, this naturally affected the output rate, which again led to an increase in the throughput time. The figure also shows that the calculated average throughput times are typically higher when using the output rates as the basis for the calculation. This is because, in most cases, the input is larger than the output of a process because of scrap during the production. However, one example of a situation where the input is smaller than output is in periods where the WIP is reduced.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average throughput times based on output rate	11.9	9.9	13.6	12.9	14.9	17.3	12.4	12.3	9.4	13.4	10.7	43.3
Average throughput times based on input rate	16.3	8.5	14.6	10.1	13.0	16.7	9.7	12.0	8.7	10.9	11.9	28.1

Fig. 3. Calculated average throughput times for product family Z in 2016 (in working days)

5 Findings, Conclusions, and Recommendations

The case company have carried out several initiatives to continuously lower the throughput time. However, they lacked a system for measuring the throughput time of products based on their current data gathering points. The method described in this paper is adapted to their needs and provides an updated KPI to measure the effect of their future improvements, both minor and major.

The method is not able to track the exact throughput time of specific products; however, its accuracy increases with the accuracy of the amount of WIP. For production systems that operate with a batch size larger than one, there is a natural variation in WIP and the specific throughput time will naturally vary between the first and the last part of the batch or lot. In such situations, it can be argued that the average time for the batch is of more interest than tracking individual orders.

This paper provides theoretical reflections as well as empirical data regarding the choice between input rate and output rate in throughput time calculations. For manufacturing environments that are similar to that studied here, we propose that using the output rate is the preferred choice. One reason is that output rate is more reflective of ongoing challenges in the system, which might result from issues such as blockage, scrap or reworks. For instance, as observed in Fig. 3, the throughput time estimated using the output rate was more reflective of the challenges the company faced during the December period. Because of reorganization by the customer downstream, the sales volume and, therefore, the output rate reduced, but the input rate did not reduce correspondingly. Another reason is that of simplicity; it is easier to measure the output rate of a single end item rather than the input rates of its many components.

This paper presents a method for measuring throughput time of products, illustrating its use through a case of a wood component producer. Although the method in itself is not novel, as it draws on well-known and established formulas, the paper presents a stepwise description of the calculation method. The contribution of the paper lays here, assisting practitioners in adapting the basics of Little's law to measure the throughput time of their production system, in addition to comparing the use of input and output rate. The basics of Little's law helps to highlight the fact that a reduction of cycle and setup time in most cases will not have a strong effect on the throughput time. This is because products usually spend most of their time in inventory. However, reducing the cycle and setup time will have an indirect effect since it increases the responsiveness of the manufacturing system, allowing for reducing the inventory levels without necessarily lowering the service levels.

Future research should investigate the effect of using a rolling horizon (e.g. last 30 days) instead of fixed intervals (e.g. months) on the quality of the results.

Acknowledgments. The authors would like to acknowledge the support from the ongoing research projects Manufacturing Network 4.0 and SØM 4.0 with its respective partners, for supporting the research presented in this paper. A special thanks to the anonymous case company for providing valuable input data for this study.

References

1. Duque, D.F.M., Cadavid, L.R.: Lean manufacturing measurement: the relationship between lean activities and lean metrics. Estud. Gerenciales **23**, 69–83 (2007)
2. Womack, J.P., Jones, D.T.: Lean Thinking: Banish Waste and Create Wealth in Your Corporation. Simon and Schuster, London (2003)
3. Modig, N., Åhlström, P.: This is Lean: Resolving the Efficiency Paradox. Rheologica, London (2012)

4. Ohno, T.: The origin of Toyota production system and Kanban system. In: International Conference on Productivity and Quality Improvement, pp. 3–8. Industrial Engineering and Management Press, Atlanta (1982)
5. Little, J.D.C.: A proof for the queuing formula: L = λW. Oper. Res. **9**, 383–387 (1961)
6. Hopp, W.J., Spearman, M.L.: Factory Physics: Foundations of Manufacturing Management. Irwin McGraw-Hill, Boston (2001)
7. Little, J.D.C., Graves, S.C.: Little's law. In: Chhajed, D., Lowe, T.J. (eds.) Building Intuition: Insights From Basic Operations Management Models and Principles, pp. 81–100. Springer, Boston (2008). https://doi.org/10.1007/978-0-387-73699-0_5
8. Alfnes, E., Strandhagen, J.O.: Enterprise design for mass customisation: the control model methodology. Int. J. Logist. Res. Appl. **3**, 111–125 (2000)
9. Suri, R.: It's About Time: The Competitive Advantage of Quick Response Manufacturing. Productivity Press, New York (2010)

Possibilities and Benefits of Intermediate Care Units in Healthcare Systems from a Logistics Perspective

Aili Biriita Bertnum(✉), Giuseppe Ismael Fragapane, Marco Semini, and Jan Ola Strandhagen

Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology, 7491 Trondheim, Norway
{aili.b.bertnum, giuseppe.fragapane, marco.semini, ola.strandhagen}@ntnu.no

Abstract. Intermediate care units have been established as a response to the emerging challenges of healthcare systems to maintain high quality and continuous care. While the term is well known in both literature and practice, it lacks a unified definition. There is no common consensus of how intermediate care units can be successfully implemented and properly utilized in healthcare systems. Large variations of services in intermediate care units can be found. This literature review has structured the existing research on intermediate care units, identifying the possibilities and benefits of intermediate care units in healthcare systems from a logistics perspective. The main findings discussed in this study concern the following topics: the effect of intermediate care units on healthcare system performance and patient outcomes, and potential users of and services provided by intermediate care units. This study presents the state-of-the-art research on intermediate care units and suggests topics for further research.

Keywords: Intermediate care units · Healthcare system · Logistics

1 Introduction

A high quality and well-performing healthcare system is essential for the health and welfare of the population. An ongoing trend is to shift from expensive inpatient treatments to more cost-efficient outpatient treatments. This is done by investing in primary care making it responsible for coordination of care, while reducing the number of hospital beds and length of hospital stays [1]. However, investments in primary care is not following the same pace as the scale-down of inpatient care, making coordination of healthcare services a challenge.

Poorly coordinated and fragmented care in interfaces of the healthcare system can result in unmet needs of complex health [1, 2]. Elderly are known to have complicated care pathways. Statistics show that 89% of people aged 85 and above have at least two chronic conditions [1]. In addition, the population of elderly is ever-increasing, from 9% in 1960 to 17% in 2015 on average for the population of OECD countries [2]. An

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 271–278, 2018.
https://doi.org/10.1007/978-3-319-99704-9_33

ageing population increases the demand for long-term care [2, 3] and respectively the pressure on the healthcare system. Expenditures for long-term care are also increasing more compared to other healthcare services [2].

Intermediate care units are established to support the healthcare systems in facing the challenges of coordination and long-term care and involves healthcare provided in the interfaces of the healthcare system [4, 5]. The term, intermediate care, is widely used in both literature and practice, but there is no unified definition of the term [4, 6, 7]. E.g., it is used both for a unit in a hospital and for a separate facility between primary and secondary care [8]. There are widespread effects of intermediate care units found in literature and few attempts of comparisons for generalization. Implying a need for comparing different intermediate care units [7].

There are opportunities within the field of logistics to support the challenges of the healthcare system. It can assist healthcare workers and act as the foundation for building healthcare operations [9]. This study will identify and structure the existing research on intermediate care units, with the aim of showing the possibilities and benefits of intermediate care units in healthcare systems. In addition, the study will suggest topics for further research.

2 Background

In most western countries, the healthcare system consists of two main sectors. The primary sector provides preventive healthcare, diagnostics and treatment, medical rehabilitation, nursing services and emergency care [2]. The general practitioner at the primary sector is often the first point of contact in the healthcare system [2, 10]. The primary sector aims at fulfilling the basic and emergent needs of the patients, and is thus a decentralized service provider closely located to the patients.

The patient is referred to the secondary sector by the general practitioner, but in some countries the patient can choose to approach secondary sector directly [2]. The secondary sector consists of hospitals and specialist healthcare institutions [11], and is responsible for operation of inpatient and outpatient clinics, and ambulance and laboratory services. The secondary sector is a centralized service provider aiming at providing specialized care. Due to comprising expensive and limited resources [12], cost- and resource-efficient operation of hospitals is desirable. After hospital discharge the general practitioner is responsible for the medical follow-up of the patient [11].

Logistics involves both internal and external healthcare operations [9]. Logistics can be defined as the strategic management of procurement, movement and storage of materials and inventory for maximized profitability through cost-effective order fulfilment [13]. Management of logistical activities relates to the planning and coordination of the activities required for providing the demanded service at the highest quality and lowest cost possible [13].

Being concerned with providing high-quality healthcare services to the needs of the patients, the healthcare system can be characterized as a service supply chain. The demand of healthcare services is expressed by patient flow [12]. A strategic fit between the supply chain strategy and the competitive strategy is achieved by having knowledge of both the uncertainties related to customers and the supply chain, and the capabilities of the supply chain [14]. Having strategic fit involves providing the desired level of responsiveness at the lowest possible cost [14].

The healthcare system should be designed like production systems, with the aim of minimizing waiting times between referral and service provision, synchronizing between utilization of healthcare resources and patient flow, and identifying and fixing bottlenecks in the healthcare system [10].

3 Research Design

The research was performed in two steps. First, an initial literature search was performed to increase the knowledge of intermediate care units. It identified keywords related to the most common terms, aims and outcomes of intermediate care units, as shown in Table 1. Second, a literature review was performed based on the keywords to get an overview of the existing research on intermediate care units. Literature reviews are often used to identify, evaluate and synthesize the existing body of knowledge [15].

Table 1. Keywords used in the literature review.

Terms		Aims		Outcomes
Intermediate care *OR* Community hospital *OR* Nursing home	*AND*	Coordination *OR* Cooperation *OR* Integration *OR* Continuity	*AND*	Admission *OR* Length of stay *OR* Readmission *OR* Discharge

Several databases (Web of Science, Scopus and Google Scholar) were selected to get a more reliable body of knowledge. The keywords and relevant synonyms were combined in the literature review. Table 1 illustrates the use of the common Booleans “AND” and “OR”. In addition, the Booleans “*” and “?” were used for including different endings and different spellings of the word.

The publications were chosen if the title and abstract indicated that the research topic would concern the definition, utilization or effect of intermediate care on healthcare systems. Based on the rest of the publication, it was excluded if the main objective was to discuss medical or mental illnesses instead of intermediate care. In addition, publications from references and relevant publications from the initial literature search were included. The literature review identified 19 publications as relevant for this study.

4 Results

The identified research in the literature review provided several results. The geographical distribution of publications is shown in Table 2. The publications are structured by publication year in Table 3. In Table 4 the suggested outcomes and potential utilization areas of intermediate care units are divided into effect on the overall healthcare system and on patients receiving treatment, potential users of intermediate care units, and potential services provided by intermediate care units.

Table 2. Geographical distribution of publications.

Country	Publications	References
United Kingdom	12	[5, 16–26]
Unites States	3	[27–29]
Netherlands	2	[6, 8]
Norway	1	[3]
Italia	1	[30]

Table 3. Number of publications by year.

Publication year	Publications	References
Before 2000	1	[26]
2001–2005	4	[5, 21–23]
2006–2010	5	[16, 25, 27–29]
2011–2015	7	[3, 6, 18–20, 24, 30]
2016–2017	2	[8, 17]

Table 4. Outcomes and utilizations of intermediate care units.

Effect on patient and healthcare system	Publications	References
Reduction of unnecessary hospital admissions	9	[3, 6, 18, 20–24, 27]
Reduction of prolonged hospital stays and delayed discharges from hospitals	9	[3, 5, 6, 16, 20–24]
Support independent living	3	[3, 23, 28]
Reduction of long-term admissions	2	[6, 23]
Continuity of care	2	[3, 17]
Reduction of travel distance	2	[18, 23]
Identified patient types		
Elderly	8	[3, 5, 21, 24, 25, 28–30]
Patients with chronic diseases	2	[26, 29]
Surgical patients	1	[8]
Disabled patients	1	[30]
Identified healthcare services		
Rehabilitation and therapeutic care	5	[17, 21, 22, 26, 30]
Hospice care	3	[27, 29, 30]
Geriatric care	2	[5, 24]
Social care	2	[16, 24]
Acute care	2	[24, 26]
Palliative care	2	[26, 29]

5 Discussion

Intermediate care is receiving more attention than before. Table 3 illustrates an increasing number of publications from 1993 to 2017 indicating that it is a topic of current and increasing interest. Research on intermediate care units is mostly happening in Europe, being the origin of 85% of publications in the literature review, as shown in Table 2. United Kingdom seems to be the foremost driver of research on and establishment of intermediate care with nearly 2/3 of the publications. In addition, 86% of localities in England are approaching the integration of or have integrated intermediate care units [16]. United States is the second largest contributor to research on intermediate care, as shown in Table 2. The literature review implies that intermediate care is not a highly researched topic in eastern countries as publications only originate from Europe and the United States.

Intermediate care units are centered on the needs of the patient and can improve the overall quality of healthcare system performance. Patients generally have positive perceptions of intermediate care [19]. Research also shows that intermediate care can result in improved outcomes for all patient types [17, 18]. E.g., providing hospice services in intermediate care units has shown to be beneficial for both hospice and non-hospice patients [27].

The literature review implies that elderly are considered the main user of intermediate care, as shown in Table 4. Elderly constitute an ever-increasing part of the population, and increase the pressure on the healthcare system requiring a larger amount of customized services compared to the rest of the population. With the pressures on cost- and resource-efficiency in healthcare systems [12], it is natural to focus on the most resource-needing patient type. However, it does not demonstrate that elderly are the only patient type suitable for intermediate care. It can imply that the knowledge and experience required to treat complex patient needs provides flexibility to treat many different patient types.

Large variations are found in which services that are or should be provided in intermediate care units [6, 7, 16, 19]. The literature review shows similar findings, as summarized in Table 4. There are concerns that intermediate care unit is a top-down solution that is poorly suited to real-life situations [31], which is strengthened with the fact that intermediate care units do not seem to have a standardized structure. Instead of accommodating to an ideal-model or choose between a set of predefined models, intermediate care units are implemented with the healthcare services that fit the local healthcare system and patient needs [22].

The customization of intermediate care units to local needs can be both an advantage and a disadvantage. Without a standardized structure, or at least some predefined guidelines, it is difficult to measure performance and success of implementation. In worst case, the diversity of intermediate care units can imply a poor adherence to existing models resulting in poor clinical outcomes and inefficiency [22]. However, by complying with local needs, intermediate care units are better equipped to handle the uncertainties and large variations in demand associated with the healthcare environment. Each patient is unique regarding the combination of age and health.

Intermediate care units show possibilities and benefits for both patients and the healthcare system. Intermediate care units can reduce waiting times by having the responsiveness to handle uncertain demand; can contribute to improved synchronization between healthcare resources and patient flow by having the flexibility to treat many types of patients; and can fix bottlenecks by adapting to local needs and provide customized services. It can be characterized as a collection of healthcare services complementing the existing healthcare system [22]. The integration with primary and secondary sector is of importance [17, 19, 24]. There is a need to map and characterize different healthcare environments to be able to match and successfully implement intermediate care units. It involves identifying and defining a set of intermediate care units, where each type is suitable for a specific healthcare system. It will require greater availability of comparable data on cost, service intensity and quality of care [27].

6 Conclusion

This study has identified and structured the existing research on intermediate care units. A current and increasing research interest of intermediate care units in Europe and the United States has been highlighted. In addition, the study has identified possibilities and benefits for healthcare systems with intermediate care units and for patients receiving treatment at intermediate care units.

The effects of intermediate care units on healthcare systems and patient flow are the following. Intermediate care units can reduce waiting times through responsiveness to handle uncertain demand; can improve synchronization between healthcare resources and patient flow through flexibility to treat many types of patients; and can reduce bottlenecks through providing customized services to local healthcare needs. There is still a need to identify and define a set of intermediate care units suitable for different healthcare systems.

The limitations of this study are related to the difficulties of identifying the full body of knowledge, as there is no common understanding of intermediate care units. The literature review of 19 papers is able to show research trends, but not the full picture of the current situation.

Future research should focus on mapping different healthcare systems and identify the proper utilization and service provision of intermediate care units in each case, in terms of identifying the desired level of responsiveness at the lowest possible cost. In addition, investigating the emergence of intermediate care units in eastern countries can also be a topic of interest, as it was not represented in this study.

Acknowledgement. This research received funding from the strategic research area NTNU Health in 2018 at NTNU, Norwegian University of Science and Technology. The authors also want to gratefully acknowledge the structured literature review performed by Nathalie Bruntveit Madsen and Ida Borgen Vaule, master students at NTNU, which provided the initial structure of this study.

References

1. Berchet, C., Forde, I.: Caring for quality in health: lessons learnt from 15 reviews of health care quality. OECD Publishing (2017)
2. OECD: Health at a glance 2017: OECD indicators. OECD Publishing, Paris (2017)
3. Dahl, U., Steinsbekk, A., Jenssen, S., Johnsen, R.: Hospital discharge of elderly patients to primary health care, with and without an intermediate care hospital–a qualitative study of health professionals' experiences. Int. J. Integr. Care **14**(2), 1–11 (2014)
4. Melis, R.J.F., Rikkert, M.G.M.O., Parker, S.G., van Eijken, M.I.J.: What is intermediate care? An international consensus on what constitutes intermediate care is needed. BMJ **329** (7462), 360–361 (2004)
5. Steiner, A.: Intermediate care - a good thing? Age Ageing **30**, 33–39 (2001)
6. Millar, A.N., Hughes, C.M., Passmore, A.P., Ryan, C.: Intermediate care: the role of medicines management. Drugs Aging **31**(1), 21–31 (2014)
7. Prin, M., Wunsch, H.: The role of stepdown beds in hospital care. Am. J. Respir. Crit. Care Med. **190**(11), 1210–1216 (2014)
8. Plate, J.D.J., Leenen, L.P.H., Houwert, M., Hietbrink, F.: Utilisation of intermediate care units: a systematic review. Crit. Care Res. Pract. **2017**, 1–10 (2017)
9. Kros, J.F., Brown, E.C.: Health Care Operations and Supply Chain Strategy, in Health Care Operations and Supply Chain Management: Strategy, Operations, Planning, and Control. Wiley, Somerset (2012)
10. Hall, R., Belson, D., Murali, P., Dessouky, M.: Modeling patient flows through the health care system. In: Hall, R. (ed.) Patient Flow: Reducing Delay in Healthcare Delivery, pp. 3–42. Springer, Boston (2013). https://doi.org/10.1007/978-1-4614-9512-3_1
11. Røsstad, T., Garåsen, H., Steinsbekk, A., Sletvold, O., Grimsmo, A.: Development of a patient-centred care pathway across healthcare providers: a qualitative study. BMC Health Serv. Res. **13**(1), 121 (2013)
12. Côté, M.J.: Understanding patient flow. Decis. Line **31**(2), 8–10 (2000)
13. Christopher, M.: Logistics & Supply Chain Management. Pearson Education, Edinburgh (2016)
14. Chopra, S., Meindl, P.: Supply Chain Management: Strategy, Planning, and Operation, 6th edn. Pearson Education Limited, Harlow (2016)
15. Okoli, C., Schabram, K.: A guide to conducting a systematic literature review of information systems research (2010)
16. Martin, G.P., Hewitt, G.J., Faulkner, T.A., Parker, H.: The organisation, form and function of intermediate care services and systems in England: results from a national survey. Health Soc. Care Commun. **15**(2), 146–154 (2007)
17. Cornes, M., et al.: Improving hospital discharge arrangement for people who are homeless: a realist synthesis of the intermediate care literature. Health Soc. Care Commun. **26**, e345–e359 (2017)
18. Pearson, M., Hunt, H., Cooper, C., Shepperd, S., Pawson, R., Anderson, R.: Providing effective and preferred care closer to home: a realist review of intermediate care. Health Soc. Care Commun. **23**(6), 577–593 (2015)
19. Young, J., Gladman, J.R.F., Forsyth, D.R., Holditch, C.: The second national audit of intermediate care. Age Ageing **44**, 182–184 (2015)
20. Szczepura, A.: Residential and nursing homes: how can they meet the challenge of an aging population? Aging Health **7**(6), 877–887 (2011)
21. Nancarrow, S.: Improving intermediate care: giving practitioners a voice. J. Integr. Care **12** (1), 33–41 (2004)

22. Martin, G.P., Peet, S.M., Hewitt, G.J., Parker, H.: Diversity in intermediate care. Health Soc. Care Commun. **12**(2), 150–154 (2004)
23. Roe, B., Beech, R.: Intermediate and Continuing Care: Policy and Practice. Blackwell Publishing Ltd, Oxford (2005)
24. Philp, I., Mills, K.A., Thanvi, B., Ghosh, K., Long, J.F.: Reducing hospital bed use by frail older people: results from a systematic review of the literature. Int. J. Integr. Care **13**, 1–19 (2013)
25. Young, J.: The development of intermediate care services in England. Arch. Gerontol. Geriatr. **49**(Suppl. 2), S21–S25 (2009)
26. McCormack, B.: The developing role of community hospitals: an essential part of a quality service. Qual. Health Care **2**(4), 253–258 (1993)
27. Stevenson, D.G., Bramson, J.S.: Hospice care in the nursing home setting: a review of the literature. J. Pain Symptom Manag. **38**(3), 440–451 (2009)
28. Murray, L.M., Laditka, S.B.: Care transition by older adults from nursing homes to hospitals: implications for long-term care practice, geriatrics education, and research. J. Am. Med. Dir. Assoc. **11**, 231–238 (2010)
29. Hanson, L.C., Ersek, M.: Meeting palliative care needs in post-acute care settings. J. Am. Med. Assoc. **295**(6), 681–686 (2006)
30. Longo, F., Salvatore, D., Tasselli, S.: The growth and composition of primary and community-based care services. Metrics and evidence from the Italian national health service. BMC Health Serv. Res. **12**(393), 1–13 (2012)
31. Evans, J.G., Tallis, R.C.: A new beginning for care for elderly people? Not if the psychopathology of this national service framework gets in the way. BMJ **322**(7290), 807–808 (2001)

Smart Production for Mass Customization

A New IT Architecture for the Supply Chain of Configurable Products

Ernst-August Stehr[1,2](✉), Jan Reschke[2], and Volker Stich[2]

[1] SIM-ERP GmbH, Ernst-Bauchstr. 4, 08280 Aue, Germany
[2] FIR e.V. an der RWTH Aachen, Campus Boulevard 55, Aachen, Germany
{ernst-august.stehr, jan.reschke, volker.stich}@fir.rwth-aachen.de
http://www.sim-erp.de

Abstract. Many ERP systems support configurable materials. Due to an ever increasing number of product variants the benefits of this approach are well understood. However, these implementations are not standardized. In this article we propose a new standard interface for the exchange of configuration data. This would lead to further benefits as systems as Advanced Planning systems could better use manufacturing flexibility while web shops as Amazon could easily integrate manufacturers of complex products with much reduced implementation effort.

Keywords: Interface definition · Configurable material
Flexible manufacturing system · Online retail

1 Introduction

Great progress has been made in the coupling of ERP systems via EDI to exchange order and invoicing data. Further progress has been made by companies as Amazon to include other companies as a shop-in-shop concept. This helps both parties to increase their attractiveness to customers. However, all these approaches rely on simple products, articles that can be clearly identified by an article number/supplier combination.

The emergence of industry 4.0 however suggests an increasing share of unique and mass-customized products. These products in turn can only be sensible manufactured with a sort of configuration. An example is the automotive industry. The Volkswagen Golf is available in more than a million variants which clearly cannot be maintained in separate article numbers. Complex articles like cars were historically sold via an expensive dealer network. Alternatively, online configurators are hosted and run by the manufacturing companies. However, for importers without such sales channels it might be interesting to use existing channels as Amazon or any other online retailer. This however requires a technical interface to ease the implementation on manufacturing as well as retailer side.

Besides the actual product configuration often the manufacturing can be done in different ways (e.g. different production plants, different routings and different bills of material). Therefore, one might speak of manufacturing options. However, current ERP/MRP logic dictates that the decision on the "correct" routing and bill-of-material

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 281–288, 2018.
https://doi.org/10.1007/978-3-319-99704-9_34

structure is made by a system that does not consider capacities and other advanced information as specialized planning systems do. The advanced planning systems in turn cannot change the plan derived earlier, thus resulting in a lack of flexibility and sub-optimal results. If it were possible to consider manufacturing options in the same way as product configuration, and furthermore there would be a standard interface for this, than the manufacturing planning could use the additional degrees of freedom for a better logistical performance.

2 Literature Survey

In this literature survey first the commercial importance of variant configuration is described. After that an overview of current IT architecture is given and lastly the link between configuration and manufacturing explained.

According to studies by Roland Berger approximately one third of the total sales price of a car is spent on sales and distribution [1]. Another study highlights that already 10% of cars are sold online and 21% of the customers would like to buy their cars at independent vendors [2]. These figures only consider a product which is quite expensive and emotionally charged; therefore, the results will look even more dramatic for other products.

A large number of works discusses the commercial impact of variants in the automotive industry [3], approaches to manage/reduce the complexity associated with variants [4] or to manage the manufacturing process [5].

Further patents and commercial products describe the implementation of configurable materials, however without talking about the integration of different systems.

Sabin and Weigel [6] as well as Trygegseth [7] describe production configuration languages. Further patents [8, 9] describe specific configurators. SAP describes in its help [10] the setup of configurable materials (KMAT), while Confirado describes its own online configurator [11]. The company Orisa produces a web configurator of which it claims to have a standard interface to one ERP system (SAP) [12].

Interviews with BMW, Confirando, myMuesli have confirmed the above finding that there is no industry standard to couple the web configurator to ERP systems. In many cases data was maintained redundantly in those systems, if an interface is used, it is individually programmed and certainly not "plug-and-play". In the case of BMW and Daimler one cannot even order via the web configurator, but has to print the configuration and ask a dealer for the entry in the order management system.

A number of papers highlight the importance and effect of especially routing flexibility in flexible manufacturing systems (FMS):

Zammori [13] proposes a method to measure routing flexibility. Nomden [14] simulates the effects and comes to the conclusion that a limited flexibility in routing can improve overall waiting time by up to 40%. Different works give approaches on the scheduling of FMS [15, 16]. However, none of these works considers the problem of getting the actual data from an ERP in the first place. Therefore, to the best of our knowledge, no literature exists on how to actually get the routing flexibility from ERP or configuration software in order to utilize it for some manufacturing optimization.

2.1 Summary of Literature

Many papers have been written about the benefits and application of product variants. Still, there exists no standard on the exchange of configuration data between manufacturers and retailers. Interviews confirmed the desire to include additional sales channels like Amazon without huge integration projects. On the other hand, literature shows that even a slight increase in routing flexibility can improve logistics performance drastically. There is however a distinct lack of literature on how the manufacturing alternatives are modelled. We propose to use the same interface and model manufacturing alternatives in the same way as the product specification and therefore solve two problems at once.

3 Interface Design

Before the interface of the product configuration is described the basic factors shall be explained and a simple reference implementation is given. Actual system implementations are encouraged to use a more sophisticated implementation, this just showcases one simple approach to the problem.

3.1 The Basic Model

On the manufacturing side, a product is specified by a number of options, which are either numeric (as e.g. the length of profiles or coils) or based on a list of options as e.g. the available engines for a car. Between those options, there might be restrictions that require or forbid certain combinations of options. The configured product then must be priced in terms of manufacturing cost as well as in the sales cost. Lastly there must be a short hand notation for a specific variant as shop floor systems rely on a unique ID for every (interchangeable) article.

ERP Master Data Structures

A typical ERP contains already tables for articles, routings and bills of material (BOM). A simple implementation adds the following tables for the configuration:

- Options with a unique ID, type (numerical or list) and description stored for each article. An example for an option is the engine of a car.
- OptionValues with a unique ID, description and list price stored for each record in the options table. Examples are the specific Diesel, Gasoline etc. engines of various displacement and power rating available for the car.
- OptionRestrictions which describes dependencies across multiple options.

By means of an example: There is an article “C-class car”. The options table contains a row “engine” while the option values table contains the different engines available for this car. The same applies to the transmission, air conditioning, navigation system and so on. Obviously one can choose only one value for every option. Sometimes there are restrictions across different options. In the optionsRestrictions table for each option value (e.g. a specific, powerful engine) forbidden other option values can be listed (e.g. insufficient gearboxes). Alternatively the same logic can be applied for required other options (no navigation system without corresponding steering wheel). By means of negation one notation can be transferred to the other.

The link to the manufacturing is twofold: First the routing and BOM tables contain an additional column for the ID of the specific option value. In this way one can select only those routing operations and BOM-positions which are required by the chosen options. Secondly, instead of numeric fields for the processing times and quantities formulas can be given like `ceil($optionID=10$/2.5)`. The numerical value of the option with ID number 10 is inserted at runtime and used to calculate the actual demand. In this case metal sheets of 2.5 m length are used, so the consumption can be calculated as the length that the customer wanted over 2.5 to get the total number of sheets. This number has to be rounded upwards. In the following parts we will describe the ERP services called by the web shop.

Service “getMaterialList”

This service lists all (sellable) articles with their description and a base price. This can be used by a retailer to offer the customer a first overview and is easily integrated into existing interfaces.

Service “getConfig”

When the end customer in a web shop clicks on an article, the shop queries this service with the articleID. This service in the ERP generates a JSON of all possible options and their potential values. This just reflects the master-detail relation of the corresponding database tables. The web shop itself can easily convert the JSON to a table of options with the corresponding drop-down fields.

There are two different approaches possible: (a) the restrictions are included in the JSON-objects of the specific values or (b) after every configuration step the service is called to calculate the possible selections. The first approach requires less communication. However, the second is much more flexible as it leaves the details of the restrictions to the ERP and allows a more sophisticated implementation. For this reason the latter possibility is pursued.

To make things clearer an example is given. The shop queries the manufacturers API and gets a JSON-file like the following

```
{
  articleID: “0815”,
  description: “Hatchback car”,
  listPrice: 25000€
  options: [
    {
      optionID: 7,
      optionName: “Engine”,
      optionType: “List”,
      optionvalues: [
        {
            valueID: 9,
            valueName: “Diesel 2.0 l 140KW”,
            status: ”possible”,
            priceSurcharge: 2500€
        },
        {
          valueID: 11,
          valueName: “Gasoline 1.6l 100KW”,
          status: “possible”,
          priceSurcharge: “0€”
        }
  ]
]}
```

What differs to existing approaches is that the retailer does not need any advance knowledge on the number or type of options. Once an option is selected, the selection is sent via HTTP(s) to the ERP which in turn generates a new JSON which can be displayed. Depending on dependencies some options might be greyed out (status forbidden). Furthermore the total price, delivery times etc. and even pictures of the car may be returned by the ERP. All this would be much more difficult to accomplish if all the possible data was transferred at the beginning of the session.

Once the configuration is complete and saved, the ERP generates a product specification string (PSS). This describes in a shorthand notation the variant. A simple way is a comma-separated list of key-value pairs. Each pair describes the IDs of the chosen option and its value, separated by an equal-sign. If this list is sorted by the optionID the same, interchangeable variant will always be represented by the same PSS.

Service “getOrderForConfig”

This web service in the ERP takes the above described combination of article number and PSS to generate the production order. From the PSS the system can directly see the IDs of the chosen option values. Therefore it can easily skip all operations and BOM-positions which are not selected by the customer. In case of numerical options the actual processing times and quantities can be calculated by the stored formulas as described above.

3.2 Possible Extensions

In the above chapter a system was described that allows retailers (web-shops) and manufacturers to be coupled without any advance knowledge of the exact structure of the configuration. A simple reference implementation was sketched; however, the actual systems are free to develop their own ideas as long as they keep to the described interface. This means specifically the way in which combinations of options are restricted and the generation of appealing product pictures.

Multi-Vendor-Comparison

The above solution generates for each vendor (and potentially article) a different form. It would be an improvement if multiple vendors could be searched for a single specification, e.g. a diesel-engined hatchback car costing no more than 30.000$. A company as “Check24” or “Autoscout” could search through new as well as used-car-pools without the need to specify and map each vendor separately.

This could be accomplished if the manufacturers (possibly by means of their associations) agreed on certain keywords. So the option “Motor” of one manufacturer and the option “engine” of another might both include the common keyword “engine”. The same applies for the option values which can be standardized e.g. with “gasoline”, “diesel”, “displacement” or “Power rating (kw)”. Therefore the option values would additionally contain a list of such key-value pairs, at least for the most common and relevant options. This is easily accomplished by additional tables which contain for each option value the corresponding standard keywords and their values.

In this way the web shop might offer a condensed form containing the typical options of the category “car” and a maximum list of all available option values. The same can be applied to numerical or textual options as e.g. the power rating or engine displacement. In these cases the customer enters a range and all configurations which fulfil the criteria can be found.

Alternative Branches

The examples in this paper were focused on the automotive industry. However, it can easily be extended to any other branch with configurable, but pre-engineered items as furniture, electronics and so on. Another example could also be the capacity market of contract manufacturers. After all machines can be described by the process, tolerances, maximum dimensions of the part and the materials to be processed. All these factors can be seen as configuration options. As companies normally know the geometric and material properties of their products, they can easily translate this to a request for corresponding machinery. This way a manufacturing company could automatically request quotations from hitherto unknown contract manufacturers for the specific product it needs.

Production Alternatives

The above described logic focused on options that describe the final outcome of the product. In the literature survey we have shown that (a) many production systems have different ways how to manufacture a product (b) that the usage of this flexibility can drastically improve logistical performance and (c) that these possibilities are not widely used for the lack of a standardized data structure of the alternatives.

However, the above described configuration logic can be used to provide exactly this data structure. Manufacturing alternatives as different routings or bills of material can be modelled in the same way as options and option values (e.g. “Plant” and “A” or “B”) and therefore use the same functionality of online configurators. These manufacturing options do not get part of the contract between supplier and customer, but can be chosen later in the manufacturing control department of the supplier.

In the easiest way the contract options are chosen by the customer, but before the actual order release the manufacturing control department finally selects a manufacturing option. Many modern advanced planning systems (APS) already know in advance the expected utilization of machines, staff and material shortages. They would communicate those bottlenecks ideally to the ERP in the form of artificial penalty costs per machine and material. An example might be a fixed price if the machine is overloaded. The ERP can easily sum up these penalties for all bill-of-material positions and routing operations per article and option value. Therefore the service “getConfig” can display the penalty costs of all given alternatives. In this way the production control can easily choose the best alternative to lighten the burden of already overloaded machines. This new balance is reflected in different penalty points so that for newly arrived orders again an optimal configuration can be chosen.

4 Conclusion and Outlook

In this paper we have specified an interface for the configuration of a product and the generation of the specific manufacturing order. Furthermore, we have given a very simple reference implementation that shows the potential of this standard interface:

- Manufacturers can sell their complex, configurable products via third-party webshops as Amazon
- Complex products of multiple vendors can be compared programmatically by means of a mapping provided by vendor associations
- Manufacturers can model their production alternatives as options and use the same logic to increase their flexibility and logistical performance

Future work should focus on building a demonstrator of the concept. Further conceptual work is needed to automate the negotiations between suppliers and customers by making different offers comparable. This is especially important when hitherto unknown relationships are found where no trust exists a priori. In this case letters of credit which guarantee the fulfillment of the contract might be a way forward.

Another line of work could integrate the CAD/CAM world in order to change the corresponding drawings and CNC-programs.

References

1. Schmitt-Lühmann, C.: Automotive sales champions (2007). http://www.handelsblatt.com/unternehmen/management/automobilindustrie-autos-chancen-liegen-im-vertrieb/2821410.html
2. Kleimann, P.G.: Online sales of new cars (2016)
3. Proff, H.: Komplexitätsmanagement in der Automobilindustrie. Deloitte (2016)
4. SCHUH: Produktkomplexität managen 3A. Carl Hanser Verlag GmbH, [S.l.] (2017)
5. Boysen, N.: Variantenfliessfertigung, 1st edn. Betriebswirtschaftliche Forschung zur Unternehmensführung, Bd. 49. Deutsche Universitäts-Verlag, Wiesbaden (2005)
6. Sabin, D., Weigel, R.: Product configuration frameworks-a survey. IEEE Intell. Syst. **13**, 42–49 (1998)
7. Tryggeseth, E., Gulla, B., Conradi, R.: Modelling systems with variability using the PROTEUS configuration language. In: Estublier, J. (ed.) SCM 1993/1995. LNCS, vol. 1005, pp. 216–240. Springer, Heidelberg (1995). https://doi.org/10.1007/3-540-60578-9_20
8. Cram, R., Liou, M.-T., Stauber, C.: Method and system for product configuration Patent US 5963953A (1998)
9. Cookson, A., Florey, D.C., Sublett, A.C., Kraus, J.J.: Generalized configurator software system Patent US 20040083239 A1 (2002)
10. SAP: Product configuration with the configuration engine in SAP CRM (2017). https://help.sap.com/saphelp_crmhana/helpdata/en/0c/f415e345194020a1bff65ad121c1ca/frameset.htm
11. Confirado: Confirado (2017). https://www.confirado.de/
12. ORISA: ORISA (2018). https://www.orisa.de/konfiguration/ueberblick
13. Zammori, F., Braglia, M., Frosolinia, M.: A measurement method of routing flexibility in manufacturing systems. IJIEC **2**, 593–616 (2011)
14. Nomden, G., van der Zee, D.-J.: Virtual cellular manufacturing: configuring routing flexibility. Int. J. Prod. Econ. **112**, 439–451 (2008)
15. Brandimarte, P.: Routing and scheduling in a flexible job shop by tabu search. Ann. Oper. Res. **41**, 157–183 (1993)
16. Özgüven, C., Özbakır, L., Yavuz, Y.: Mathematical models for job-shop scheduling problems with routing and process plan flexibility. Appl. Math. Model. **34**, 1539–1548 (2010)

Service Rate Control in Mn/Gn/1 Queue

Koichi Nakade(✉) and Shunta Nishimura

Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya 466-8555, Japan
nakade@nitech.ac.jp

Abstract. Service rate control in queues is an important problem in practice. For example, when the number of customers waiting for finished products is small production has a normal speed, but if it is greater, the production speed should be faster to meet the demand. For an exponential service time distribution, the optimality of the threshold type policy has been proved in literature. On the other hand, in production systems, production time follows a general distribution in general. In this paper, service control of speed depending on the number of customers is discussed. The analytical results of an M/G/1 queue with arrival and service rates depending on the number of customers in the system, which is called an Mn/Gn/1 queue, are utilized for computing performance measure of service rate control. Constant, uniform and exponential distributions on the service time are considered through numerical experiments. The results show that the optimal threshold depends on the type of the distributions even when the mean of service time is the same.

Keywords: Mn/Gn/1 queue · Service control · Threshold policy Admission

1 Introduction

Service rate control problems are widely found in practical situations. In a supermarket, if the queue of customers for payment is long, a cashier will be helped by someone, and in a communication network when the congestion occurs the faster line will be used. In a make-to-order production system, when the number of customers waiting for the finished products is small, production has a normal speed, but if it is greater, the production speed should be faster to meet the demand. In addition, the arrival rate of customers may depend on the number of waiting customers because some of the customers may be impatient. Such a system is represented as a queue with state-dependent arrival and service rates.

For the exponential service time distribution with a constant arrival rate, George and Harrison [1] discuss a service control problem and develop an asymptotic method for computing the optimal policy, and optimality of a threshold type policy has been proved in Dimitrakopoulos and Burnetas [2], in which optimal admission control is also discussed. In general, however, as production systems, service time follows a general distribution.

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 289–296, 2018.
https://doi.org/10.1007/978-3-319-99704-9_35

In this paper, control problems of service speed depending on the number of customers under various general service time distributions and Poisson arrivals of customers, which is called an Mn/Gn/1 queue, are formulated, and the effects of the types of distributions on the performance measure like a profit are discussed through numerical experiments. To compute performance measure under given service rate control, the analytical results of an Mn/Gn/1 queue by Abouee-Mehrizi and Baron [3] are utilized, which has a single server with arrival and service rates depending on the number of customers in the system. Constant, uniform and exponential distributions on service time are considered through numerical experiments. Optimal threshold policies are compared among these distributions. Admission control is also discussed by changing the upper bound of the queue length.

2 Model Description

We consider an Mn/Gn/1 queue, where Mn means a Poisson arrival process with a state-dependent arrival rate, and Gn means a general service time distribution with a state-dependent service rate. This service rate is determined by a decision maker. When the number of waiting customers including a customer in service, which is called a state of the system, is i, the arrival rate is λ_i. For example, when customers arrive in a Poisson process with rate λ and an arriving customer observes state i, he/she is assumed to enter the system with probability q_i. Then the actual arrival process in the system is a state-dependent Poisson process with rate $\lambda_i = \lambda q_i$ in state i (see Fig. 1). In addition, we assume that there is a finite integer K which is a minimal value i satisfying $\lambda_i = 0$, that is $q_i = 0$. It happens because if the queue length is too long, any customer cannot wait for service. On the other hand, if the manager wants to reduce the waiting time of customers because long waiting time leads to less customers' satisfaction or the system has to pay costs for the long delay, the system sets the threshold for queue length and refuses the further demand during the time in which the length attains this threshold. If this threshold is K, then $\lambda_K = 0$.

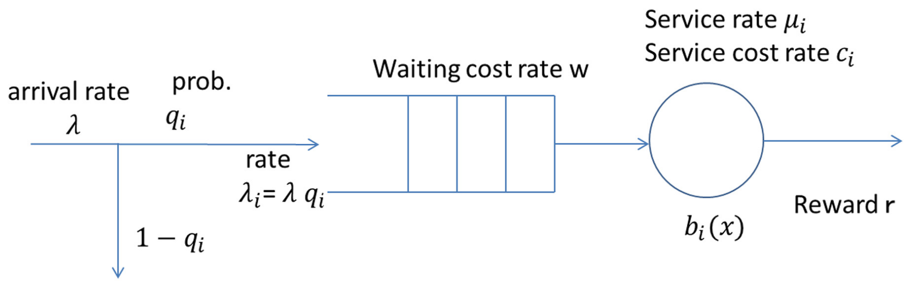


Fig. 1. Mn/Gn/1 queue

We explain the service control. There are J possible service rates $\mu^1, \mu^2, \ldots, \mu^J$, where $\mu^j < \mu^{j+1}$ for $j \in \{1, 2, \ldots, J-1\}$. When the state is i, the service rate decision is defined as a_i for each $i \in \{1, 2, \ldots, K\}$. Here, if $a_i = j$, the service rate is μ^j. The notation μ_i is the service rate in state *i,* and thus if $a_i = j$, the service rate is $\mu_i = \mu^j$. For each service rate μ^j, the service cost rate is c^j, where $c^j < c^{j+1} (j \geq 1)$. The sequence $\{a_i, i \in \{1, 2, \ldots, K\}\}$ is a service control policy in this model.

Assume that policy $\{a_i, i \in \{1, 2, \ldots, K\}\}$ is given. When the state becomes i just after some service is finished, new service starts and service time follows a general distribution function $B^j(x)$ when $a_i = j$. If during service a new customer arrives and the state becomes $i + 1$, then service rate becomes μ_{i+1}. In this case, if the remaining service time is η just before the arrival, after the arrival it is changed to $\frac{\eta\mu_i}{\mu_{i+1}} = \eta/\alpha_{i+1}$, where $\alpha_i = \frac{\mu_i}{\mu_{i-1}}, i \geq 1$. Here α_i denotes the ratio of service rates for state i and $i - 1$.

When policy $\{a_i, i \in \{1, 2, \ldots, K\}\}$ is fixed, this system follows an Mn/Gn/1 queue which is defined in Abouee-Mehrizi and Baron [2]. Here we denote the service time distribution, its density function and the remaining service time density function in a steady state by $B_i(x), b_i(x), h_i(x)$, respectively. As shown, $B_i(x) = B^j(x)$ when $a_i = j$. For computational convenience it is assumed that $c_0 = 0$ and $\alpha_1 = 1$.

The reward and cost consist of the followings: the waiting cost rate for each customer is *w,* the reward for each customer is *r,* and the service cost rate is c^j when the service rate is μ^j as shown above.

Let Z denote the average profit. For $i \in \{0, 1, \ldots, K\}$, $P_F(i)$ is a steady state distribution under the defined Mn/Gn/1/K queue with a given policy $\{a_i, i \in \{1, 2, \ldots, K\}\}$. Then Z is given as $Z = R\text{-}W\text{-}C$, where

$$R = r\sum_{i=0}^{K-1} P_F(i)\lambda_i, \quad W = w\sum_{i=1}^{K} iP_F(i), \quad C = \sum_{i=1}^{K} P_F(i)c_{a_i} \tag{1}$$

The objective in the model is to find an optimal service rate control policy $\{a_i, i \in \{1, 2, \ldots, K\}\}$ which maximizes the average profit *Z.*

The following notations are also used.

$\tilde{h}_i(s)$: Laplace transform of $h_i(x)$,

$\tilde{b}_i(s)$: Laplace transform of $b_i(x)$.

3 Analytical Results of Mn/Gn/1 Queue

In Abouee-Mehrizi and Baron [3], an Mn/Gn/1 queue is analyzed theoretically (In [3], some typos in equations are found and they are corrected in the following). It is an extensive result of Kerner [4], which analyzes an Mn/G/1 queue.

For the Mn/Gn/1 queue with an infinite buffer, under the condition that

$$\sum_{i=1}^{\infty} \frac{\lambda_0}{\lambda_i} \prod_{j=0}^{i-1} \frac{1 - \tilde{h}_j\left(\frac{\lambda_{j+1}}{\alpha_{j+1}}\right)}{\tilde{b}_{j+1}\left(\lambda_{j+1}\right)} < \infty,$$

the steady state distribution is given by

$$P(i) = \frac{\lambda_0 P(0)}{\lambda_i} \prod_{j=0}^{i-1} \frac{1 - \tilde{h}_j\left(\frac{\lambda_{j+1}}{\alpha_{j+1}}\right)}{\tilde{b}_{j+1}(\lambda_{j+1})}, \quad i = 1, 2, \ldots$$

$$P(0) = \frac{1}{1 + \sum_{i=1}^{\infty} \frac{\lambda_0}{\lambda_i} \prod_{j=0}^{i-1} \frac{1-\tilde{h}_j\left(\frac{\lambda_{j+1}}{\alpha_{j+1}}\right)}{\tilde{b}_{j+1}(\lambda_{j+1})}}$$

Here $\tilde{h}_0(s) = \tilde{b}_1(s)$, and $\tilde{h}_i(s)$ satisfies the following recursive equations.

$$\tilde{h}_i(s) = \frac{\lambda_i}{s - \lambda_i} \left[\frac{\tilde{b}(\lambda_i)\left(1 - \tilde{h}_{i-1}\left(\frac{s}{\alpha_i}\right)\right)}{1 - \tilde{h}_{i-1}\left(\frac{\lambda_i}{\alpha_i}\right)} - \tilde{b}_i(s) \right].$$

In the Mn/Gn/1/K queue, where the number of customers in the system is limited to K, the steady state distribution function $P_F(i)$ for $i = 0, \ldots, K-1$ is given by

$$P_F(i) = \frac{\lambda_0 P_F(0)}{\lambda_i} \prod_{j=0}^{i-1} \frac{1 - \tilde{h}_j\left(\frac{\lambda_{j+1}}{\alpha_{j+1}}\right)}{\tilde{b}_{j+1}(\lambda_{j+1})}, i = 1, \ldots, K-1,$$

$$P_F(0) = \frac{P_F^A(0)}{\frac{\lambda_0}{\lambda_{K-1}} \prod_{j=0}^{K-2} \frac{1-\tilde{h}_j\left(\frac{\lambda_{j+1}}{\alpha_{j+1}}\right)}{\tilde{b}_{j+1}\left(\lambda_{j+1}\right)} + P_F^A(0) \left(1 + \sum_{i=1}^{K-2} \frac{\lambda_0}{\lambda_1} \prod_{j=0}^{i-1} \frac{1-\tilde{h}_j\left(\frac{\lambda_{j+1}}{\alpha_{j+1}}\right)}{\tilde{b}_{j+1}\left(\lambda_{j+1}\right)}\right)},$$

where

$$P_F^A(0) = \frac{\alpha_K \mu_b^F}{\lambda_{K-1} + \alpha_K \mu_b^F}, P_F^A(1) = \frac{\lambda_{K-1}}{\lambda_{K-1} + \alpha_K \mu_b^F},$$

$$\frac{1}{\mu_b^F} = \frac{1}{\mu_{K-1}} - \frac{1}{\lambda_{K-1}} + \sum_{j=i}^{K-2} \left(\frac{1}{\mu_j} - \frac{1}{\lambda_j}\right) \prod_{i=j}^{K-2} \frac{1}{\alpha_{i+1}} \frac{\tilde{b}_{i+1}(\lambda_{i+1})}{1 - \tilde{h}_i\left(\frac{\lambda_{i+1}}{\alpha_{i+1}}\right)}$$

$$+ \frac{1}{\mu_1} \frac{\tilde{b}_1(\lambda_1)}{1 - \tilde{h}_0\left(\frac{\lambda_1}{\alpha_1}\right)} \prod_{i=1}^{K-2} \frac{1}{\alpha_{i+1}} \frac{\tilde{b}_{i+1}(\lambda_{i+1})}{1 - \tilde{h}_i\left(\frac{\lambda_{i+1}}{\alpha_{i+1}}\right)}$$

Using $P_F^A(0)$ and $P_F^A(1)$, we have

$$P_F(K-1) = (1 - F_F(K-2))P_F^A(0), \; P_F(K) = (1 - F_F(K-2))P_F^A(1)$$

where $F_F(i) = \sum_{j=0}^{i} P_F(j)$.

When the policy $\{a_i, i \in \{1, 2, \ldots, K\}\}$ is given, by deriving steady state probabilities and substituting them to Eq. (1), the average profit can be obtained.

4 Numerical Experiments

4.1 Parameter Settings

In the following, the constant, uniform and exponential distributions are applied as service distributions. For given i, the mean of service time is fixed as $\frac{1}{\mu_i}$.

(a) Constant distribution

$$B_i(x) = \begin{cases} 0 & (0 \le x < 1/\mu_i) \\ 1 & (1/\mu_i \le x) \end{cases}, \tilde{b}_i(s) = e^{-s/\mu_i}$$

(b) Uniform distribution on $[0, \frac{2}{\mu_i}]$

$$B_i(x) = \begin{cases} 0 & (x < 0) \\ \frac{\mu_i x}{2} & \left(0 \le x \le \frac{2}{\mu_i}\right) \\ 1 & \left(\frac{2}{\mu_i} < x\right) \end{cases}, \tilde{b}_i(s) = \frac{\mu_i}{2s}\left(1 - e^{-s\frac{2}{\mu_i}}\right)$$

(c) Exponential distribution

$$B_i(x) = 1 - e^{-\mu_i x}(x \ge 0), \tilde{b}_i(s) = \frac{\mu_i}{s + \mu_i}$$

Set $K = 5$, $\lambda = 15, q_n = 1 - \frac{\mathrm{n}}{150}$. Two types of service rates exist as $\mu^1 = 10$ and $\mu^2 = 20$. Service cost rates are set as $c^1 = 50$ and $c^2 = 150$, a waiting cost rate and reward for each service are $w = 2$ and $r = 10$, respectively.

Here, the threshold policy is applied. The threshold which is the minimal value satisfying $\mu_i = \mu^2$ is denoted as $i_B(1 \le i_B \le K + 1)$, and under the threshold policy with i_B, $a_i = 1$ for $i = 1, 2, \ldots, i_B - 1$, and $a_i = 2$ for $i = i_B, i_B + 1, \ldots, K$. Here,

$i_B = K + 1$ means $\mu_i = \mu^1$ for all $i = 1, 2, \ldots, K$, and $i_B = 1$ means $\mu_i = \mu^2$ for all $i = 1, 2, \ldots, K$.

4.2 Effect of Distributions

Table 1 shows probabilities, costs, and rewards for each i_B and each service time distribution. In this table, $p[i]$ shows the steady state probability $P_F(i)$. For example, when service time is constant, $i_B = 3$ is the best threshold and thus it is optimal among threshold type policies that the slower service is applied in states 1, 2, 3 and the faster service is used in states 4 and 5.

Table 1. Probabilities and Profits ($\lambda = 15$, $q_n = \frac{n}{150}$)

iB	6	5	4	3	2	1
(a) Constant distribution						
p[0]	0.0086	0.0102	0.0194	0.0422	0.1027	0.2736
p[1]	0.0297	0.0354	0.0672	0.1460	0.3554	0.3048
p[2]	0.0741	0.0885	0.1677	0.3644	0.2658	0.2090
p[3]	0.1722	0.2055	0.3897	0.2525	0.1584	0.1222
p[4]	0.3914	0.4670	0.2647	0.1464	0.0885	0.0681
p[5]	0.3240	0.1933	0.0914	0.0484	0.0291	0.0224
R	99.142	118.307	133.666	140.515	143.915	145.280
W	7.760	7.327	6.174	4.921	3.724	2.947
C	49.571	68.819	84.637	92.625	99.051	108.960
Z	41.811	42.161	42.855	42.969	41.140	33.373
(b) Uniform distribution						
p[0]	0.0238	0.0286	0.0442	0.0757	0.1414	0.2852
p[1]	0.0513	0.0617	0.0952	0.1631	0.3046	0.2652
p[2]	0.0976	0.1173	0.1811	0.3102	0.2393	0.1968
p[3]	0.1770	0.2127	0.3285	0.2298	0.1630	0.1314
p[4]	0.3146	0.3780	0.2381	0.1521	0.1045	0.0837
p[5]	0.3356	0.2017	0.1129	0.0692	0.0471	0.0377
R	97.617	117.303	130.675	137.538	141.246	142.958
W	7.428	6.910	5.919	4.854	3.851	3.153
C	48.809	68.735	82.886	91.323	98.318	107.219
Z	41.380	41.659	41.870	41.361	39.076	32.587
(c) Exponential distribution						
p[0]	0.0500	0.0608	0.0816	0.1178	0.1820	0.3079
p[1]	0.0750	0.0912	0.1225	0.1766	0.2729	0.2309
p[2]	0.1117	0.1358	0.1825	0.2632	0.2033	0.1720
p[3]	0.1654	0.2010	0.2701	0.1948	0.1505	0.1273
p[4]	0.2431	0.2955	0.1985	0.1432	0.1106	0.0936
p[5]	0.3549	0.2157	0.1449	0.1045	0.0807	0.0683
R	95.001	115.495	126.174	132.465	136.317	138.423
W	7.082	6.453	5.632	4.765	3.954	3.345
C	47.501	68.533	80.256	88.353	95.414	103.817
Z	40.418	40.508	40.286	39.347	36.948	31.260

For all distributions, as i_B increases, R and C decrease and W increases. When i_B is large, the low service rate is applied more and $P_F(K)$ is large, and thus less customers are permitted to receive service. As a result, the total arrival rate and the average service cost decrease. On the other hand, the low service rate leads to the long waiting time regardless of the less arrival rate of entering customers.

As the variance of service time increases, R and C decrease. $P_F(K)$ increases as the variance increases, and thus in the similar way as above the increase of variance leads to less amount of entering customers and less service cost. For constant, uniform and exponential distributions, the values of optimal i_B are 3, 4 and 5, respectively. Thus, the type of service time distribution affects the optimal threshold.

In the case that $\lambda = 15, q_n = 1 - \frac{\mathrm{n}}{150}$, as shown in Table 1, as the variance increases, the profit Z decreases for each i_B. Table 2 shows probabilities and profits, in the case that $\lambda = 20, q_n = 1 - \frac{n}{200}$, under several types of service time distributions for $i_B = 5$, 6. In this case, it is found that the uniformly distributed service time achieves more profits compared with the case of constant service time distribution with the same mean. When i_B is high, reward and service cost are almost the same, and the difference of waiting time cost becomes more important to profit Z.

Table 2. Probabilities and Profits $(\lambda = 20, q_n = 1 - \frac{n}{200})$

	Constant	Uniform	Exponent		Constant	Uni	Exponent
	(a) i_B = 5				(b) i_B = 6		
p[0]	0.0008	0.0067	0.0219	p[0]	0.0006	0.0050	0.0164
p[1]	0.0048	0.0204	0.0439	p[1]	0.0036	0.0154	0.0329
p[2]	0.0238	0.0576	0.0873	p[2]	0.0179	0.0434	0.0654
p[3]	0.1134	0.1583	0.1728	p[3]	0.0856	0.1192	0.1296
p[4]	0.5321	0.4292	0.3405	p[4]	0.4015	0.3232	0.2553
p[5]	0.3252	0.3278	0.3336	p[5]	0.4908	0.4937	0.5004
R	132.443	132.115	131.172	R	99.943	99.500	98.356
W	8.294	7.933	7.534	W	8.712	8.443	8.151
C	82.480	82.447	82.268	C	49.972	49.750	49.178
Z	41.669	41.735	41.370	Z	41.259	41.307	41.027

4.3 Admission of Arrivals

As shown in Sect. 2, parameter K can be considered as an admission control parameter. Table 3 shows the values of profits Z for various K and threshold i_B, under uniform service time distribution, when $c^2 = 130$ and 150. For $c^2 = 130$ the profit is greater as K is larger. This is because the greater K leads to more customers receiving service, which gives more profits. When cost parameter c^2 is 150, however, $K = 4$ maximizes the profit when threshold i_B is 3 or 4, and for $K = 5$ is the best when i_B is 2. The large K implies that the more customers receive the faster service, and when the service cost parameters are high, the service cost has more effect on Z compared with admission reward. For $c^2 = 150$, the combination of $i_B = 4$ and $K = 4$ gives the best profit.

Table 3. Profits under different Parameter K $(\lambda = 15, q_n = 1 - \frac{n}{150})$

		iB = 8	7	6	5	4	3	2	1
c2 = 130	K = 3					41.690	45.895	47.272	44.056
	4				42.096	46.404	49.087	49.278	45.979
	5			41.380	45.962	48.889	50.382	50.154	46.883
	6		40.118	44.400	47.827	49.889	50.928	50.544	47.317
	7	38.566	42.804	46.337	48.678	50.296	51.152	50.712	47.524
150	3					41.690	41.141	38.370	30.828
	4				42.096	42.116	41.436	38.937	32.054
	5			41.380	41.659	41.870	41.361	39.076	32.587
	6		40.118	40.528	41.174	41.555	41.192	39.062	32.813
	7	38.566	39.048	39.926	40.753	41.272	41.022	39.001	32.900

5 Conclusion

This paper has formulated a mathematical model of service rate control in a state-dependent M/G/1 queue. Throughout numerical experiments, it is found that under threshold policies, the value of optimal threshold depends on the type of service time distributions. Usually, as the variance of service distribution increases, the reward from by customer arrivals and the holding cost decreases and the profit also decreases. In some case of parameter sets, however, the total profit is greater under the uniform distribution of service time compared with the case of the constant distribution. In addition, the combination of optimal threshold of service and admission of arrivals is observed to depend on cost parameters.

The effects of various parameters such as the arrival rate and q_n into performance need to be investigated. Theoretical discussion for the optimality of threshold policies under general distributions are also important. They are left for further research.

References

1. George, J.M., Harrison, J.M.: Dynamic control of a queue with adjustable service rates. Oper. Res. **49**(5), 720–731 (2001)
2. Dimitrakopoulos, Y., Burnetas, A.: The value of service rate flexibility in an M/M/1 queue with admission control. IISE Trans. **49**(6), 603–621 (2017)
3. Abouee-Mehrizi, H., Baron, O.: State-dependent M/G/1 queueing systems. Queueing Syst. **82**(1–2), 121–148 (2016)
4. Kerner, Y.: The conditional distribution of the residual service time in the Mn/G/1 queue. Stochast. Models **24**(3), 364–375 (2008)

Understanding Changeability Enablers and Their Impact on Performance in Manufacturing Companies

Ann-Louise Andersen(✉), Kjeld Nielsen, Thomas D. Brunoe, Jesper K. Larsen, and Christopher Ketelsen

Department of Materials and Production, Aalborg University, Aalborg, Denmark
ala@mp.aau.dk

Abstract. Managing and capitalizing on product variety, customization, personalization, decreasing batch sizes, as well as rapid new product introductions are prevailing challenges facing today's manufacturing companies. Changeable and reconfigurable manufacturing systems have been widely accepted as means to respond to these challenges, due to their ability to accommodate continuous and cost-efficient change in functionality and capacity. However, enablers of reconfigurability that should be selected during manufacturing system design are in current research rarely regarded in terms of their inherent relations and impact on manufacturing performance. Therefore, the aim of this paper is to explore implementation relations between physical enablers of reconfigurability on system and equipment level and their effect on manufacturing performance. For this purpose, a quantitative questionnaire-based survey has been conducted in various Danish manufacturing companies. The findings suggest that most reconfigurability enablers correlate strongly in their implementation and their extent of implementation generally correlates with critical performance aspects such as profitability, ramp-up time, and life-time of production systems.

Keywords: Changeable manufacturing · Changeability
Reconfigurable manufacturing · Reconfigurability · Survey research

1 Introduction

Rapid market change driven by increasing global competition and technological innovation represents a prevailing challenge in manufacturing companies, whether it is in relation to change in product demand, change in product mix, or frequent introductions of new products [1, 2]. In order to respond to this challenge and sustain competitive advantage, manufacturing companies must develop manufacturing systems that can respond to change and adapt quickly to shifting customer needs [1]. However, at the same time manufacturing companies face increasing pressure for cost-efficiency and productivity, particularly in high-wage countries where extensive relocation of production has occurred in the recent decade [3]. This dichotomy between pressure for responsiveness and pressure for cost-efficiency is often recognized as the poly-lemma of production [3]. On one hand, high economies of scope and low planning-effort foster

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 297–304, 2018.
https://doi.org/10.1007/978-3-319-99704-9_36

successful adaption, whereas on the other hand, high economies of scale and sophisticated planning methods result in optimal utilization of resources and high cost-efficiency [3]. Resolution of this poly-lemma between economies of scale and scope and between value and planning orientation is key to delivering not only customized and premium products to niche markets, but also in order to have near mass production efficiency and achieve sustainable competitive advantage [3].

In order to resolve the poly-lemma of production, changeable manufacturing systems appear promising. A changeable manufacturing system is defined as having the ability to accomplish early, foresighted, and economically feasible adjustments in all structures and processes in accordance with internal and external change requirements [1]. Depending on the requirements and strategy for change, this can be accomplished through flexibility, reconfigurability, or a combination of both [1]. Flexibility represents pre-planned and built-in ability to change functionality and capacity with limited effort and without significant alterations of the system's existing structures, whereas reconfigurability represents functionality and capacity on demand through efficient alterations of existing physical and logical structures [2, 4]. Thus, reconfigurability is a particularly important type of changeability that contributes to the resolution of the production poly-lemma through both efficient adaption to dynamic functionality and capacity requirements over the system's lifetime, as well as customized flexibility on demand to resolve the scale and scope trade-off [2].

Designing changeable and reconfigurable manufacturing systems requires three fundamental activities; (1) identification of the system's lifetime requirements and drivers of change, (2) development of system design concepts with the right enablers and degree of change, and (3) development of a detailed system solution that embeds and realizes the required combination of change enablers [5]. In other words, the design of changeable and reconfigurable manufacturing systems takes outset in selecting the right combinations of enablers to improve changeability and enhance performance of the manufacturing system [6, 7]. However, in previous research, enablers of change such as the reconfigurability enablers are predominately regarded individually and on rather abstract levels with only limited consideration of their inherent relations when being implemented [5, 6, 8]. Moreover, the actual impact of their implementation in manufacturing systems is usually regarded on rather conceptual levels without empirical evidence, e.g. in terms of theoretically anticipated performance improvement such as life-time cost, productivity, reconfiguration time, profitability, ramp-up time, etc. [2, 9]. Therefore, the objective of the research presented in this paper is to understand and explore implementation relations between enablers of reconfigurability and the relations between their implementation and manufacturing performance, through empirical data from a questionnaire-based survey conducted in various Danish manufacturing companies. The remainder of the paper is structured as follows; Sect. 2 presents the background on changeability and reconfigurability enablers, Sect. 3 outlines the survey research method applied, Sect. 4 presents the results of the research, whereas Sects. 5 and 6 conclusively discuss findings, practical implications, and viable future research directions.

2 Background

The notion of changeability covers both flexibility and reconfigurability [1]. However, as described in the previous section, the importance of reconfigurability should be emphasized, due to its ability to contribute to resolution of the production poly-lemma. Therefore, this paper only addresses reconfigurability enablers of change.

The concept of the reconfigurable manufacturing system (RMS) was initially coined by Koren [10], including the six RMS core characteristics distinguished as being either necessary or supportive [2]. Scalability, convertibility, and customization are necessary characteristics, whereas modularity, integrability, and diagnosability are supportive characteristics. In recent seminal work by Wiendahl and ElMaraghy [1], these RMS characteristics were in combination with automatibility and mobility considered physical enablers of changeability on manufacturing system and assembly level. Additional high-level enablers of logical change have been proposed as well, e.g. cognitivability, adjustability, evolvability, neutrality, etc. [1]. However, since a fundamental aspect of reconfigurability is physical alterations of system structures and processes, focus will be on the physical enablers in the remainder of this paper. Table 1 outlines the aforementioned enablers of reconfigurability that are well-accepted in previous research.

Table 1. Enablers of reconfigurability.

Enabler	Description
Scalability	Capacity can be easily and efficiently increased or reduced
Convertibility	Easy and efficient change between product variants and product generations
Modularity	Major components are modular for easy and quick integration
Integrability	Current and future components are easily integrated through standard interfaces
Mobility	The ability to easily move major components
Automatibility	Dynamic change of the level of automation
Customization	Functionality/capacity is designed for a product family

From Table 1 is its evident that a change enabler can be viewed as a construct or feature of the system that improve and enhance the system's ability to change in the desired way [1, 6, 7]. Therefore, change enablers play a fundamental role in the design process of reconfigurable manufacturing systems. In this process, the right change enablers must first of all be selected in accordance with the requirement of change identified through the change enablers [5]. Secondly, decisions on how to realize the change enablers must be made, which involves considering on which structuring level they should be implemented and in which system elements they should be embedded [5]. Consequently, designing changeable and reconfigurable manufacturing systems that embed the right enablers is a complex task, as enablers are numerous and can be implemented in various ways to enhance system performance and ability to change in the desired way. In regard to this, there are two issues related to reconfigurability enablers that are neglected in previous research; enablers are considered mostly on rather aggregate levels without consideration of their relation when implemented and without consideration of their relations to manufacturing performance.

Napoleone et al. [9] propose a framework where modularity and integrability enable scalability and convertibility, which then influence customization. The framework is composed based on a review of literature and thus expresses commonly anticipated enabler relations initially proposed by Koren [2, 10]; system structures that are modular and has integrability are supportive for scalability and convertibility. Hawer et al. [6] consider interdependencies between changeability enablers through fuzzy cognitive maps and validate proposed relations through an expert survey. However, such examples of explicit consideration of enabler relations with empirical evidence are limited in previous research, which results in lack of support for selecting the right enabler combinations during design of reconfigurable systems in practice. Moreover, in previous research, the question of how reconfigurability enhance performance is mostly addressed conceptually, e.g. in terms of enabler impact on reconfiguration time, productivity, and life-cycle cost [2], in terms of a broad analytical comparison [11], or in terms of more quantitatively analytical approaches [12]. However, previous research does not explicitly address the actual manufacturing performance impact of reconfigurability enabler implementation, which limits knowledge on how to select enablers during design in order to enhance performance and changeability. Therefore, the objective of this paper is to empirically explore implementation relations between enablers of reconfigurability, as well as their relations to manufacturing performance.

3 Survey Research Method

In order to address the objective stated above, an exploratory questionnaire-based survey method was applied. In Table 2, latent constructs and all measured items from the questionnaire are listed. The latent constructs (RE1-RE7) represent the reconfigurability enablers from Table 1. As these are defined on a rather aggregate and theoretical level, different measurable items have been defined accordingly. Thus, each latent construct is measured by two items; one related to its implementation on equipment level and one related to its implementation on system/line level. Only construct RE6 is defined solely for system level and not equipment level. In the questionnaire, these items were rated by respondents in terms of their level of implementation on a five-point Likert scale from “not implemented” to “fully implemented”. The latent constructs (MP1-MP7) represent well-established financial performance aspects that relate to manufacturing. These items were measured in terms of level of perceived performance relative to competitors on a five-point Likert from “significantly poorer” to “significantly better”. For all items, “uncertain” responses were also possible.

In order to collect responses, the questionnaire was distributed to production specialists, engineers, operations managers, plant superiors, and managers with production responsibilities in various Danish manufacturing companies. The resulting sample contained 50 responses from different industries, which were almost equally spread between large and small/medium sized enterprises.

Table 2. Variables in questionnaire on reconfigurability enablers and performance.

Latent construct	Measured variable
RE1: Modularity	*Item1:* Production equipment has modular structures and contains "common building blocks" that can be easily replaced or upgraded
	Item2: All major components of the production lines are modular and contain "common building blocks" that can be easily added, removed or upgraded
RE2: Integrability	*Item3*: Components of the production equipment can be easily integrated through standard interfaces
	Item4: Components of the production lines can be easily integrated through standard interfaces
RE3: Customization	*Item5*: Production equipment is designed for processing a family of parts/products rather than only a single part/product
	Item6: Production lines are designed for producing a family of products rather than a single product on the same line
RE4: Scalability	*Item7*: Production equipment allows for changing production rate
	Item8: Production lines are built in small units, so that the line can increase and decrease capacity in small increments
RE5: Convertibility	*Item9*: Production equipment is designed for easy conversion between different tasks
	Item10: The production lines can be easily converted in physical structure between different operating tasks
RE6: Automatibility	*Item11*: The production lines can increase and decrease the degree of automation, e.g. utilizing manual, semi-automatic and fully automatic solutions over time
RE7: Mobility	*Item12*: Production equipment can be moved around to operate at different positions along the production line
	Item13: The production lines can be moved to different locations, e.g. within the production plant or to different plants
MP1: Sales growth	*Item14*: Sales growth relative to competitors throughout the last 3–5 years
MP2: Profitability	*Item15*: Profitability relative to competitors throughout the last 3–5 years
MP3: Time-to-market	*Item16*: Time to market relative to competitors throughout the last 3–5 years
MP4: New product success	*Item17*: New product success by sales volume relative to competitors throughout the last 3–5 years
MP5: Market share	*Item18*: Market share relative to competitors throughout the last 3–5 years
MP6: Life-time of systems	*Item19*: Lifetime of production systems and equipment relative to competitors throughout the last 3–5 years
MP7: Ramp-up time	*Item20*: Ramp-up time of new products relative to competitors throughout the last 3–5 years

4 Results

As a first step in analyzing the collected data, the quality of measurement items was evaluated showing adequate Cronbach alpha values above C $\geq$ 0.7. Secondly, data was checked for parametric assumptions of normality and homogeneity. However, both Kolmogorov-Smirnov test with $p \leq 0.05$ and Shapiro–Wilk test with $p \leq 0.05$ showed non-normally distributed data. Thus, non-parametric correlation analysis using Spearman's correlation coefficient was used for the subsequent data analysis. As the collected data included a few missing values from uncertain responses and due to some use of multi-item measures, relative importance indices (RIIs) were calculated for each latent construct in Table 2. These indices were used for the correlation test, where a correlation was deemed significant at $p \leq 0.05$. In Table 3, the results of the correlation analysis between reconfigurability enabler implementations are reported. Likewise, the correlations between reconfigurability enabler implementation and performance are similarly reported in Table 4.

Table 3. Correlation coefficients for reconfigurability enablers. Significance level is indicated by ** for 0.01 and * for 0.05. Italic indicates strong correlation $\geq$ 0.6.

	RE1	RE2	RE3	RE4	RE5	RE6	RE7
RE1							
RE2	*.724***						
RE3	.559**	.337*					
RE4	*.655***	.344*	.504**				
RE5	*.708***	.397**	.379**	*.744***			
RE6	.580**	.523**	.350**	.426**	.565**		
RE7	*.668***	.520**	*.762***	.502**	.553**	.528**	

5 Discussion

The aim of the correlation analysis presented here was to explore implementation relations between enablers of reconfigurability, as well as their relation to performance benefits usually associated with reconfigurability. In regard to the relations between reconfigurability enablers, the analysis indicates the strength of the link between the degree of implementation of each pair of reconfigurability enablers. Thus, the results in Table 3 indicate that most enabler implementations correlate strongly or moderately, e.g. the implementation of modularity is to different extents positively linked to the implementation of all remaining enablers. Generally, all correlations indicate significant positive associations, where particularly strong positive links exist between the implementation of modularity and the implementation of integrability, scalability, convertibility, and mobility respectively. These findings generally confirm the notion of modularity being a fundamental and supportive enabler or characteristic that is likely to lead to reconfigurability in terms of convertibility and scalability [2, 9].

Table 4. Correlation coefficients for reconfigurability enablers and performance. Significance is indicated by ** for 0.01 and * for 0.05. Italic indicates moderate correlation ≥ 0.4.

	RE1	RE2	RE3	RE4	RE5	RE6	RE7
MP1	.294*	.087	.133	.261*	.300*	.181	.104
MP2	.337*	.396**	*.433***	.217	.142	*.411***	.382**
MP3	.242	.274*	.145	.069	.215	−.002	.232
MP4	.202	.19	−.127	.209	.349*	.115	−.1
MP5	.235	.143	.168	.178	.286*	.073	.129
MP6	.233	.161	.231	.391**	*.423***	.235	.261
MP7	.285*	.165	.232	.232	.386**	.354*	.252

In regard to the relations between implementation of reconfigurability enablers and manufacturing performance, the results in Table 4 indicate some significant positive correlations, however, most of these only to a weak or moderate extent. The strongest significant relations exist between customization and profitability, between convertibility and life-time of systems, and between automatibility and profitability. Generally, profitability appears to have either weak of moderate correlation to most reconfigurability enablers. More notably, the implementation of convertibility seems to be positively correlated to new product success, life-time of systems, and ramp-up time of new products. This finding underpins the potential and benefits of reconfigurability for reusing production systems based process platforms that can be dynamically changed throughout the system's lifetime to suit new processing requirements, rather than designing and developing dedicated systems that become obsolete with market and product changes [2]. Similarly, the findings in Table 4 indicate that scalability is positively linked to life-time of production systems, which supports the notion of dynamic systems that can scale capacity in accordance with demand in a "pay-as-you-grow" way. Thus, the results of the pairwise analysis of implementation of reconfigurability enablers and different performance aspects generally support anticipated performance impacts of reconfigurability and changeability stated in previous research [2, 11]. Nevertheless, it should be considered that the findings reported in both Tables 3 and 4 are based on a rather small sample of 50 respondents, which should be further increased to make more valid conclusions. Thus, the findings from the explorative survey presented here should merely be regarded as initial empirical insight into the topic of reconfigurability enabler relations and their impact on performance, leading to further possibilities and new directions of research.

6 Conclusion

In this paper, relations between reconfigurability enabler implementations and manufacturing performance were explored through a questionnaire-based survey in Danish manufacturing companies. The results indicate that reconfigurability enablers in general correlate strongly and positively in their implementation, and that positive links between implementation of reconfigurability enablers and performance aspects such as profitability, ramp-up time, and life-time of production systems can be identified. However, these findings merely provide initial insight into the topic of how to better support the design of changeable and reconfigurable manufacturing systems, taking outset in the issue of selecting the right enabler combinations that improve changeability and enhance performance. Therefore, future research should to higher extent address the inherent interdependencies between reconfigurability enablers, rather than addressing them individually and on rather abstract levels. Moreover, as previous research is limited in terms of empirical evidence of how reconfigurability enhances manufacturing performance, the findings reported in this paper should be further explored, e.g. through larger surveys or case-studies of successful reconfigurability implementations.

References

1. Wiendahl, H., ElMaraghy, H.A., Nyhuis, P., et al.: Changeable manufacturing-classification, design and operation. CIRP Ann.-Manuf. Technol. **56**(2), 783–809 (2007)
2. Koren, Y.: General RMS characteristics. Comparison with dedicated and flexible systems. In: ElMaraghy, H.A. (ed.) Reconfigurable Manufacturing Systems and Transformable Factories, pp. 27–45. Springer, Heidelberg (2006). https://doi.org/10.1007/3-540-29397-3_3
3. Brecher, C., Jeschke, S., Schuh, G., et al.: Integrative Production Technology for High-Wage Countries. Springer, Heidelberg (2012). https://doi.org/10.1007/978-3-642-21067-9
4. ElMaraghy, H.A.: Flexible and reconfigurable manufacturing systems paradigms. Int. J. Flex. Manuf. Syst. **17**(4), 261–276 (2005)
5. Andersen, A., ElMaraghy, H., ElMaraghy, W., et al.: A participatory systems design methodology for changeable manufacturing systems. Int. J. Prod. Res. **56**(8), 1–19 (2018)
6. Hawer, S., Braun, N., Reinhart, G.: Analyzing interdependencies between factory change enablers applying fuzzy cognitive maps. Procedia CIRP **52**, 151–156 (2016)
7. Rösiö, C.: Considering reconfigurability characteristics in production system design. In: ElMaraghy, H. (ed.) Enabling Manufacturing Competitiveness and Economic Sustainability, pp. 57–62. Springer, Heidelberg (2012). https://doi.org/10.1007/978-3-642-23860-4_9
8. Russo Spena, P., Holzner, P., Rauch, E., et al.: Requirements for the design of flexible and changeable manufacturing and assembly systems: a SME-survey. Procedia CIRP **41**, 207–212 (2016)
9. Napoleone, A., Pozzetti, A., Macchi, M.: A framework to manage reconfigurability in manufacturing. Int. J. Prod. Res. 1–23 (2018). https://doi.org/10.1080/00207543.2018.1437286
10. Koren, Y., Heisel, U., Jovane, F., et al.: Reconfigurable manufacturing systems. CIRP Ann.-Manuf. Technol. **48**(2), 527–540 (1999)
11. Zhang, G., Liu, R., Gong, L., et al.: An analytical comparison on cost and performance among DMS, AMS, FMS and RMS. In: Dashcenko, A.I. (ed.) Reconfigurable Manufacturing Systems and Transformable Factories, pp. 659–673. Springer, Heidelberg (2006). https://doi.org/10.1007/3-540-29397-3_33
12. Niroomand, I., Kuzgunkaya, O., Bulgak, A.A.: The effect of system configuration and ramp-up time on manufacturing system acquisition under uncertain demand. Comput. Ind. Eng. **73**, 61–74 (2014)

A Changeable Jig-Less Welding Cell for Subassembly of Construction Machinery

Mads Bejlegaard(✉), Thomas Ditlev Brunoe, and Kjeld Nielsen

Aalborg University, Fibigerstraede 16, 9220 Aalborg Oest, Denmark
{bejlegaard, tdp, kni}@mp.aau.dk

Abstract. The cost and technological development of industrial robots suggests a substitution of labor-intensive processes. Jig-less welding is an example of an emerging concept that is derived from this development, providing high flexibility without compensating on efficiency. This paper presents a conceptual solution of a jig-less welding cell for a particular environment with the purpose of investigating potential, expected challenges to overcome before implementation. To investigate the expected, potential challenges the concept is applied to a case study that takes its outset in a low volume, high variety welding facility. A full-scale test on the setup have yet to be conducted.

Keywords: Robot welding · Jig-less welding · Fixture-les welding
Jigs · Fixtures · Changeability · Flexibility · Industry 4.0 conformant welding

1 Introduction

The fourth industrial revolution has arrived, promising new levels of responsiveness, flexibility, and productivity [8], enabled through various new and emerging technologies. This manufacturing paradigm will turn companies into a source of higher value jobs [3, 10] and individualized production will be a competitive factor among others [3, 6]. Thus, by exploiting the global market trends of volatile demands through new technologies the fourth industrial revolution is expected to create competitive advantages for high-wage countries. However, companies must determine areas where new technology will expectedly contribute to increased competitiveness based on their specific company characteristics, and figure out how they can benefit from these new technological opportunities.

The capability of using the manufacturing systems across existing product variety and reusing it for future product generations is critical because of the importance of time-to-market and because products lifecycles are getting shorter [14]. Though the lifetime of manufacturing system components such as robots and conveying systems are already longer than that of products, it is relevant to further extend the lifetime of manufacturing systems and strive for manufacturing systems that enable individualized production. However, investments in changeability must be economically feasible for which reason changeability becomes a trade-off between the amount of variety a system can handle and the efficiency with which this variety is manufactured. This

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 305–311, 2018.
https://doi.org/10.1007/978-3-319-99704-9_37

returns to the fact that the ability to balance economies of scale and economies of scope has become a major competitive factor [3, 4].

1.1 Changeability

In recent years, changeable manufacturing concepts as FMS (Flexible Manufacturing System) and RMS (Reconfigurable Manufacturing System) have been proposed in order for manufacturers to deal with product variety and volatile markets. Changeability is an umbrella term encompassing different types and degrees of changeability [4] considering both logical and physical changes on different factory structuring levels [16], which also applies to FMS and RMS. The FMS has often been criticized for covering disadvantages such as excess functionality, over-capacity, and the large initial investment. Conversely, RMS is promoted for its ability to continuously adapt to the exact functionality and capacity needed while performing an efficiency similar to that of the dedicated manufacturing line. However, this proves only successful across the variety represented within a product or part family because these capabilities are achieved by adding, removing, or exchanging modular elements of a system structure designed for a particular product or part family.

This paper addresses lower system levels (i.e. lower factory structuring levels), which implies that changeability is achieved through flexibility and reconfigurability. Changeability can be achieved in various ways depending on the object of change, and both flexibility and reconfigurability can be regarded as types of changeability. Built-in and pre-planned ability to change without physically altering the system structure is considered as flexibility whereas the ability to change the system structure to provide the exact capacity and functionality needed when needed is considered as reconfigurability [9, 15]. It can be difficult to choose the right changeability level for manufacturing systems since these decisions affects productivity and investment cost. This dilemma has become of great relevance to the case company subject to this paper.

1.2 Jig-Less Welding

In practice, manufacturing systems will most often require both flexibility and reconfigurability to meet a specific demand for a certain type of changeability. To address this, Andersen et al. [1] presented a model to evaluate different types of changeability best suited for a specific situation. For some welding tasks, Jig-less welding seem to offer both high flexibility together whit high productivity. The incentive for jig-less and fixture-less installation lies in time reduction related to changeovers and the cost reduction related to design, manufacturing, and installation of jigs and fixtures. These costs account for a great share of the total manufacturing cost.

Both jigs and fixtures are used for positioning and orientation of work-pieces in the welding process and both jigs and fixtures are costly auxiliary equipment. Therefore, this paper does not distinguish between jigs and fixtures but rather seeks to identify one alternative applicable to both of them. A literature search in Thomson Reuters Web of Science was carried out followed by a snowball approach to derive relevant literature from the literature first identified. To supplement the literature search a state of practice investigation was conducted to identify the prevalence of jig-less welding in industry. Five similar, global companies were visited.

At least for the last two and a half decade, jig-less and fixture-less assembly has been discussed [12]. Yet, in a review of challenges and outlook for the automotive assembly technologies from 2010 [11], flexible and adaptable assembly technology and strategy, e.g. robotic fixture-less assembly in the assembly process, was mentioned as one of more initiatives that the automotive industry will have to pursue to respond successfully to market demand. Likewise, trends in manufacturing and assembly for next generation of combat aircraft has been presented in 2014 [2], introducing a new concept for jig-less assembly. A number of flexible grippers to enable jig-less assembly in high volume automotive industry have also been developed [13, 17]. Additionally, another publication emphasizes the development of jig-less laser welding in the car industry [7]. However, low volume industry can potentially gain enormous benefits from jig-less assembly as well. This potential does not seem as distant as previously since the technological development (e.g. various sensors) have provided robots with greater flexibility [5]. Even though this development is not reflected in literature, the state of practice reveals that e.g. the company Yaskawa has released a number of jig-less applications, not only in the automotive industry, but also in Small and Medium Enterprises (SMEs), for instance within the agricultural industry and the construction machine industry, though with relative high repetition.

The concept of jig-less welding challenges the traditional understanding of increased flexibility having a negative effect on productivity. It seems that the technology has come to a level to which it is worth considering if it can be implemented as a new assembly technology for welding large and heavy, high variety, low volume steel components. This leads to the research question of this paper: *What are the potential challenges of implementing jig-less welding in industries where large and heavy steel plates are being welded together*.

To address this research question, a case study is performed. The case is a Danish SME that manufactures large and heavy body parts for construction machinery.

2 Case Study

The product components in this case study consist of large steel plates and can have a weight of up to 2 tons after they have been welded together. In this category, there are approximately 80 different product components, of which some come in a few variants. The case company has long had an ambition to get a one-piece flow, in order to reduce stock and reduce the manufacturing lead time. However, with the current manufacturing setup this has proven impractical due to long changeover times.

Tack welding of large steel plates requires large and heavy fixtures and a change from one variant to another requires change of fixture. Therefore, the case company experiences many time consuming changeovers across the high variety of product components, as there is typically one unique fixture per product component in both processes illustrated in Fig. 1. A changeover can account for as much as 20% of the actual process time of the tack welding process. However, the major cost driver related to auxiliary equipment (e.g. jigs and fixture) is the New Product Introduction (NPI) cost related to design, manufacturing, and installation, and the following cost of storing and maintaining such equipment.

Process #1: Tack welding (manual)	Process #2: Full welding (robot)

Fig. 1. The existing, conventional welding process sequence

The issue described above can to some extent be addressed by the traditional approach of balancing stock levels and productivity. Another way to counter these issues could be to increase the changeability in auxiliary equipment (e.g. fixtures and jigs) by substituting the existing equipment by standard modular equipment, reconfigurable equipment, or flexible equipment. All three of them have advantages. Another solution, which is the focus of this paper, is based on a total elimination of auxiliary equipment.

In a collaboration between Aalborg University, the case company, and the Danish Technological Institute, the concept of a new jig-less welding cell has been created. The welding cell is shown in Fig. 2. The collaboration between the three stakeholders has helped to uncover challenges as well as economic benefits that follow the implementation of jig-less welding in this particular application. This helped the case company to decide if they should look further in to jig-less welding as an alternative to the traditional approach. The challenges identified during the project are as follows:

- Traditionally, there have not been the same requirements to tolerances as those that are needed for jig-less welding. Generally, there is a need for more reliable mastering of the supplying processes and the focal process to ensure continuous, trouble-free operations. The manually performed processes possess the capabilities to compensate for fluctuating tolerances why reliable mastering of supplying processes is less urgent compared to the fully automated jig-less welding process.
- There will be a competence shift, both for operating the system but also for introducing new product component variants. On the shop floor robots substitute manually performed jobs. The design, manufacturing, and installation of auxiliary equipment (e.g. fixtures) are no longer necessary. However, NPIs will require new robot programs.

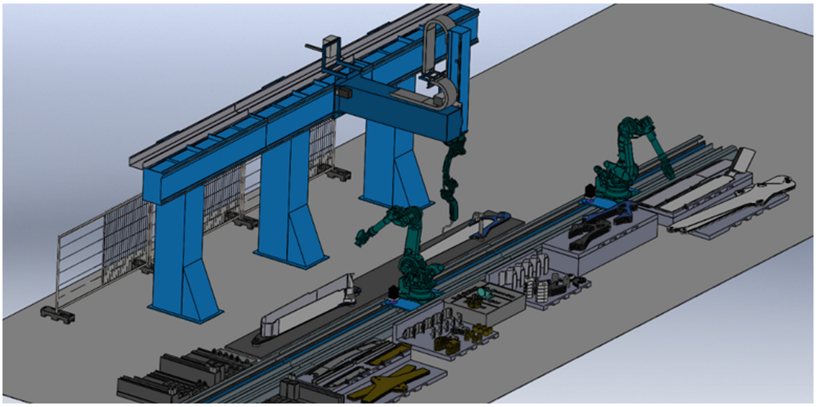


Fig. 2. Jig-less welding cell for both tack welding and full welding

- High variety, low volume environments involves high complexity, which makes the cooperation and coordination of the robots essential. Thus, the control unit must be able to coordinate and synchronize robots to ensure perfect path behavior and high precision.
- Adopting jig-less welding to a high variety, low volume environment implies more frequent introduction of new product components compared to situations with less variety and higher volume. Thus, the time spent on NPIs due to time-consuming programming of robots can be quite considerably in low volume, high variety environments.
- An implementation would benefit from a standardization of the product components. This is however not unique for this particular application. A standardization of the product will not only have positive influence on the needed hardware flexibility but also the ability to reuse pieces of welding programs.
- The investment in jig-less welding is quite capital intensive. However, from a lifetime perspective changeable systems as the jig-less welding cell will have a tendency to be reasonable investment over time, since the investment cost can be spread over more product generations compared to traditional systems with a more rigid structure. By eliminating the changeover time and decreasing the process time, it is likely to face excess capacity, which should be considered when dimensioning the system.
- Too high heat input will have a great impact on product component distortion. This leads to two challenges; robots will have to compensate for distortion and the lowest possible heat input should be found. Jig-less welding in this particular application implies some technological uncertainties and no reference applications exist to our knowledge, and therefore the project is subject to some degree of uncertainty.

Nevertheless, the proposed design of a jig-less welding cell is suggested to replace both the manual tack welding process, where ingoing parts are put together and the following welding process, where all welds are being fully welded in a welding robot. The latter process is planned phased out. Thereby, the two previous applied processes will be incorporated in one process and the jigs and fixtures becomes redundant. This novel concept will help the case company to reduce the changeover time. Additionally, the NPI cost of design, manufacturing, and installation of new manufacturing equipment is no longer existing but instead there will be a NPI cost related to programming of the new system when a new product component is introduced. Soft changes as programming is in this case less expensive than the hard changes of equipment currently seen.

3 Conclusion

The cost and technological development of industrial robots might suggest that robots should replace labor-intensive processes. This has led to the emergence of jig-less welding. Jig-less welding opens for automation of processes without giving up on either efficiency or flexibility. A number of industrial visits and a literature review did not uncover any alternative novel solution that suggests a substitution of jigs and fixture in the welding process in this particular industry. This paper investigates the potential challenges of implementing jig-less welding in industries assembling large and heavy steel plates. Despite the fact that jig-less welding will eliminate the cost related to design, manufacturing, installation, and storage of auxiliary equipment (e.g. jigs and fixtures) jig-less welding represents some challenges, which must be overcome before fully automatic jig-less welding can be implemented in the concerned industry.

References

1. Andersen, A., Brunø, T. D., Nielsen, K., et al.: Evaluating the investment feasibility and industrial implementation of changeable and reconfigurable manufacturing systems. Flex. Serv. Manuf. J. (2017, in review)
2. Balaji, H., Selvaraj, P., Rao, V.S.: Trends in manufacturing and assembly technologies for next generation combat aircraft. ARPN J. Eng. Appl. Sci. **5**, 667–673 (2014)
3. Brecher, C., Jeschke, S., Schuh, G., et al.: Integrative Production Technology for High-Wage Countries. Springer, Heidelberg (2012). https://doi.org/10.1007/978-3-642-21067-9
4. ElMaraghy, H.A., Wiendahl, H.P.: Changeability - an introduction. In: ElMaraghy, H.A. (ed.) Changeable and Reconfigurable Manufacturing Systems, pp. 3–24. Springer, London (2009). https://doi.org/10.1007/978-1-84882-067-8_1
5. Ha, J.: An image processing algorithm for the automatic manipulation of tie rod. Int. J. Control Autom. Syst. **11**, 984–990 (2013)
6. Jeschke, S., Brecher, C., Meisen, T., Özdemir, D., Eschert, T.: Industrial internet of things and cyber manufacturing systems. In: Jeschke, S., Brecher, C., Song, H., Rawat, Danda B. (eds.) Industrial Internet of Things. SSWT, pp. 3–19. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-42559-7_1
7. Kampker, A., Bergweiler, G., Hansen, J.O., et al.: Jigless laser welding in the car body production. ATZ Worldwide **119**, 72–75 (2017)
8. Koren, Y.: The Global Manufacturing Revolution: Product-Process-Business Integration and Reconfigurable Systems. Wiley, Hoboken (2010)
9. Koren, Y., Shpitalni, M.: Design of reconfigurable manufacturing systems. J. Manuf. Syst. **29**, 130–141 (2010)

10. McKinsey, G.I.: Manufacturing the future: the next era of global growth and innovation. McKinsey Global Institute (2012)
11. Michalos, G., Makris, S., Papakostas, N., et al.: Automotive assembly technologies review: challenges and outlook for a flexible and adaptive approach. CIRP J. Manuf. Sci. Technol. **2**, 81–91 (2010)
12. Mills, J.: Multi-manipulator control for fixtureless assembly of elastically deformable parts, pp. 1565–1572 (1992)
13. Paquin1a, V., Akhloufi2b, M.: Vision-Guided Universal Articulated Gripper for Jigless Robot Welding, vol. 68 (2012)
14. Berger, R.: Strategy consultants GmbH: mastering product complexity. In: Anonymous. Roland Berger Strategy Consultants GmbH, Online (2012)
15. Terkaj, W., Tolio, T., Valente, A.: Focused flexibility in production systems. In: ElMaraghy, H.A. (ed.) Changeable and Reconfigurable Manufacturing Systems, pp. 47–66. Springer, London (2009). https://doi.org/10.1007/978-1-84882-067-8_3
16. Wiendahl, H., ElMaraghy, H.A., Nyhuis, P., et al.: Changeable manufacturing-classification, design and operation. CIRP Ann.-Manuf. Technol. **56**, 783–809 (2007)
17. Yeung, B.H., Mills, J.K.: Design of a six DOF reconfigurable gripper for flexible fixtureless assembly. IEEE Trans. Syst. Man Cybern. Part C (Appl. Rev.) **34,** 226–235 (2004)

Challenges in Production and Manufacturing Systems Platform Development for Changeable Manufacturing

Daniel Grud Hellerup Sorensen(✉), Thomas Ditlev Brunoe, and Kjeld Nielsen

Aalborg University, Fibigerstræde 16, DK9220 Aalborg, Denmark
daniel@mp.aau.dk

Abstract. Development of platforms for products has proven a successful way to manage and address several challenges related to increasing variety and accelerating product development cycles. Thus, it is natural to assume that platforms may facilitate similar benefits for manufacturing systems, as they are both technical systems. Production and manufacturing systems platform development is, however, still an area of research lacking maturity. Development of platforms in this field comes with a set of challenges not necessarily found in product platform development. Looking towards other fields of research or science may be necessary to address these challenges. This paper aims to study challenges related to production and manufacturing systems platform development and describe how these have been addressed. It does so through an evolving case study based on four projects with an industrial collaborator. This leads to setting the stage for future research on production platforms.

Keywords: Manufacturing systems · Platform · Mass customization Case study

1 Introduction

With increasing product variety, shortened development lifecycles and accelerated time-to-market, manufacturers' ability to adapt is being strained, and addressing this challenge is proving to be a difficult task [1]. The standardisation, consistency and reusability of platforms, which has proven successful in managing product variety [2], is a seemingly attractive choice for managing production variety [3]. Platforms incorporating these aspects in production and manufacturing systems are called production platforms, and can be utilised to achieve appropriate levels of changeability.

Changeability and its underlying classes [4] are common responses to increasing variety as a form of robust process design [5]. For design of manufacturing systems utilising changeability (such as reconfigurable manufacturing), development and design of production platforms remains a challenge during the later design stages [6]. Concepts such as co-development [7], co-platforming [8] and, integrated product and

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 312–319, 2018.
https://doi.org/10.1007/978-3-319-99704-9_38

production modelling [9, 10] are gaining traction. This highlights a need for co-existing product and production platforms.

Due to the relative immaturity of the production platform field [3], it can be beneficial to draw inspiration from research in other fields dealing with technical systems. Product platforms and software architecture are both examples of such research fields, where inspiration has previously been drawn [11–14]. However, manufacturers attempting to develop and utilise production platforms still face numerous challenges. These include the platform development process itself, platform documentation, identification, modelling and utilisation.

This paper presents a series of challenges, lessons, and experiences on production platforms, structured as an evolving case study carried out over a period of three years. To frame the paper, the following research question is formulated:

- Which challenges do mature manufacturers face over time, when developing production platforms?

Firstly, the method for structuring the case study is presented based on design science in information systems research [15]. Second, the evolving case study is introduced, followed by the results and experiences of the case study related to the research framework. Finally, the paper ends with a discussion on the results and future research on production platforms.

2 Method

Hevner et al. [15] present a conceptual framework for information systems (IS) research by combining the design science and behavioural science paradigms. In the framework, IS research receives input from the environment in the form of requirements or needs, and from a knowledge base in the form of applicable knowledge such as theories, methods and models. This framework lends itself well to carrying out research on platforms, as the IS research framework focuses on developing and building theories and artefacts. Artefacts and theories are subsequently justified and evaluated, in the sense that they must provide some form of utility for addressing a particular problem. Justified theories and evaluated artefacts are added to the knowledge base and applied in an appropriate environment. In this way, the knowledge base itself acts as a platform evolving and being instantiated through IS research. The IS research framework is illustrated in Fig. 1.

Four types of artefacts are considered in the framework: *constructs*, *models*, *methods* and *instantiations*. Constructs are languages or templates for defining and communicating problems and solutions, while models use constructs to represent the problem and solution space. Methods are processes for solving problems, and instantiations demonstrate the feasibility of an artefact [15]. Artefacts can also be considered somewhat analogous to the viewpoints and views utilised in software and enterprise architecture [16].

Having used theories and artefacts from various fields during the four projects in the evolving case study, this paper feeds back information to the knowledge base on

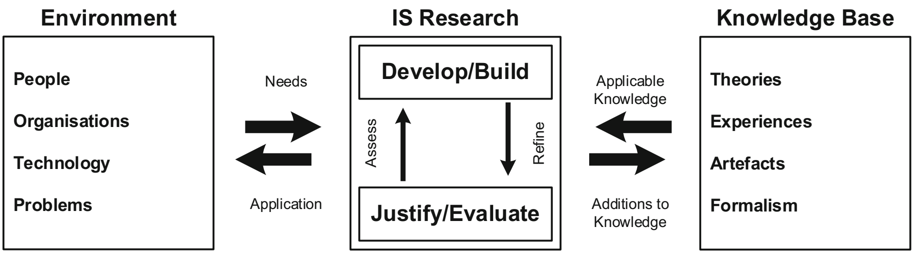


Fig. 1. Simplified illustration of Hevner et al.'s IS research framework [15].

platforms. Through the case study presented in Sects. 3 and 4 theories, methods, models and tools have been applied with varying degrees of success.

3 Case Presentation

The case company is a large Danish manufacturer of discrete consumer and OEM products, with most of the production located in Denmark, and a number of other locations in Europe, North America and Asia. Numerous factories, production segments and systems are part of the case study. While mainly focused on the production in Denmark, some factories and systems in other countries are included to provide a comprehensive picture of the production. Included in the scope of the case study is a variety of production systems and corresponding products, ranging from manual to fully automatic systems. The manufactured products are either purely mechanical or mechatronic in nature, and range from small to large product size in the context of the case company.

Initially, the case study included one production segment consisting of five production systems covering five mechanically different products in a family. As work progressed, the scope expanded. Development of production platforms is the overall goal for the on-going case study, with the expected outcome being a method for production platform development based on existing production systems, and a collection of documented production platforms.

In relation to the research framework presented above, the knowledge base for production platforms, and thus for the case study, is very limited. Therefore, the case study employed applicable theories and artefacts from knowledge bases on product platforms, software systems and enterprise architecture, to name a few. By doing this, a contribution to the knowledge base on production platforms can be made. Specific contributions are made in the form of artefacts. The case study environment (including people, organisations and technologies) provides the requirements for evaluating and context for implementing the artefacts below.

- Constructs such as modelling languages and documentation formats typically from related knowledge bases outside the production system area.
- Models developed from constructs to address or frame a specific concern related to a production system or platform development and documentation in general.

- Methods for utilising specific constructs or tools to address or frame a concern and an overarching method for production platform development.
- Instantiations in the form of concrete tools and examples aimed at improving the process of platform development and utilisation.

4 Results

Preliminary studies in the case company showed large potential savings in improving system robustness and utilisation. These, amongst several others, are benefits potentially provided by platforms [1, 2]. As the case study progressed, the understanding of the benefits, nature and purpose of platforms changed, as the following sections illustrate. The sections serve to highlight how, why and where experience was gained, lessons were learned and changes were made to the platforming approach. Figure 2 shows an overview of the four case study projects covered in this section.

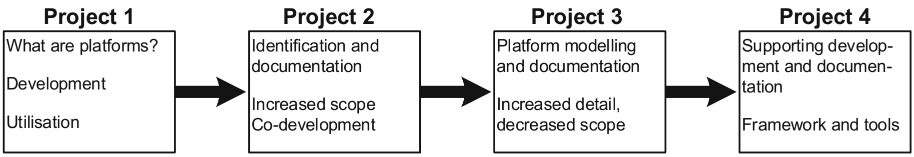


Fig. 2. Overview of the four case study projects. Project 4 is currently in progress.

4.1 Project 1: What are Production Platforms?

A persistent challenge throughout the case study, and particularly in the first project, was the focus on product platforms in literature. Along with numerous similar but varying definitions of platforms, this made it difficult to arrive at a consistent and coherent understanding of production platforms. The questions "what are production platforms?", "what are they for?" and "how do we make them?" were the focus in the initial project of the case study. It was the ambition to design reconfigurable manufacturing systems (RMS) via platforms, to achieve robustness and higher utilisation of equipment. At this point, most of the project's few participants had little to no knowledge on platforms. In the same vein, there was a need for clarifying the connection between platforms, RMS and the desired changeability characteristics.

Answering the first two questions, production platforms are defined as a collection of production equipment, interfaces, processes and knowledge from which production systems and their constituent elements can be efficiently derived and developed. To address the third question, a first attempt at an extractive platform development approach was made, basing development on a set of existing systems by selecting and restructuring parts of the systems to create a platform. Five existing systems producing five product variants were mapped to identify the functional elements of each. Function-means trees [17] and generic organ diagrams [18] were then used to identify candidate elements for a platform, and a workshop was carried out to generate new potential platform candidates. The platform candidates were then used to generate new reconfigurable production concepts addressing the needs for changeability.

4.2 Project 2: Figuring Out Production Platform Development and Documentation

In the second project, the scope was expanded to an entire factory covering 23 production systems and 25 product architectures. As the scope increased drastically, so did the number of participants. A key challenge in this project was the alignment of the participants' understanding of both platforms, but also the purpose of the project itself. Few had intimate knowledge of platforms, and concrete examples were needed to communicate it further throughout the organisation. Thus, during the second project of the case study, the focus was on identifying and documenting more platform candidates and on increasing the level of detail for a few select platform candidates. Project 2 was a co-development or joint-development project, as platforms for both products and production were under development simultaneously. On this note, a related challenge appeared in improving communication between the two departments. The project was also an attempt at breaking down the figurative "silos" in which each department isolated themselves.

Project 2 was generally carried out according to the Four Loops of Concern (FLC) as described in [11]. This method denoted both the vocabulary and approach for identifying, developing and documenting platforms. It is an iterative method consisting of four loops and four steps to complete each loop. The outcome of each loop is a collection of models addressing a specific set of concerns. For instance, the first loop addresses concerns about functional capability. It uses flow diagrams and function-means trees to capture the functional sequence and alternative solutions, respectively.

The results of the second project in the case study was (1) an evaluation of FLC for platform development, (2) several model and instantiation artefacts and (3) an initial documentation format for platforms. Constructs used in creating the models and instantiations include function-means trees, generic organ diagrams, interface diagrams, flow charts, block diagrams, radar diagrams and technical drawings and diagrams.

4.3 Project 3: Modelling and Documenting Production Platforms

For project 3, the focus was on modelling platforms and using said model as documentation of the platform. If a platform is to be used, it must be documented, maintained, and its existence must be known to the developers who are to use it. Finding concrete examples of how to document production platforms and store their information, proved an immense challenge. In project 2 of this case study, attempts were made at structuring the development and documentation process, but it still relied on individual text documents with static figures and tables. Current documentation on manufacturing systems consists of potentially hundreds of pages of information, and the document itself can be difficult to locate within the company.

The premise for project 3 was essentially to have a backend model of the platform containing all existing information on that specific platform (relations, properties, capabilities, alternatives, etc.). Based on the concerns of a specific stakeholder, a customised document was to be generated, containing only information relevant to that stakeholder. A number of modelling perspectives, formats and frameworks were considered for this task, notably the ArchiMate modelling language and the configurable component framework (CCF) [19]. CCF was selected for its integration of product and manufacturing system platforms in previous studies [9, 10, 20].

A specific platform candidate designed and developed in-house and carrying out a core process was selected for modelling using the software tool, configurable component modeler (CCM). CCF and CCM model elements of a system as independent configurable components each encapsulating interfaces, interactions, design rationale (constraints, functional requirements and design solutions) and compositional information. The output of CCM was transformed into documentation containing only the desired information addressing a specific set of concerns.

4.4 Project 4: Supporting Production Platform Development

Project 4 is currently in progress at the case company. At this stage, a comprehensive platform framework is being created to support the development, documentation and utilisation of platforms. This is an attempt at addressing the persistent challenge of consistency and coherency, both in the vocabulary and in the development process itself. The framework is also a step towards addressing the lack of research and tools in the field of production platforms. It incorporates both artefacts from the previous three projects and new artefacts currently being developed. It is based around a set of conceptual models denoting the structure and vocabulary for the framework, based on the conceptual model by Bossen et al. [14] and the ISO standard (ISO 42010) on architecture descriptions [16]. Two concrete parts of this framework is a classification scheme for production processes and a manufacturing system classification code, both used for identifying candidates for platform development.

The classification scheme is a consolidation of several existing classifications and taxonomies, incorporating four main categories of processes: manufacturing, material handling, test & inspection, control & planning. It is a supporting tool for platform candidate identification, with the classification coding facilitating comparison of existing manufacturing systems. Both the scheme and coding are treated in separate upcoming publications.

5 Discussion and Future Research

During the case study, the company progressed through four projects for platform development. The main challenges faced during the projects are summarised in the list below.

- Lack of consistency and coherency in vocabulary and development process.
- Misalignment of participant knowledge on platforms and project scope.
- Miscommunication between separate departments of the manufacturer.
- Lack of examples regarding documentation platforms.
- Lack of research and tools in production platform research.

In the initial project, knowledge on platforms was minimal. The scope was kept relatively limited to keep the project focused on learning essential aspects of platforms—their nature, development and utilisation. For the second project, the scope was expanded, including more production systems and product families with more variety. Experts for each system were brought in, and the focus was on following a structured method to create concrete examples. During the third project, as the scope was decreased the level of detail was increased, modelling a single element of a platform. The model was used to generate customized documentation on the platform. In the fourth and current project, a comprehensive platform development and documentation framework is under development. It takes advantage of the experiences and artefacts from previous projects, and develops new methods and instantiations.

As mentioned, both a classification scheme for production processes and a manufacturing system classification code is currently being developed. The classification scheme itself is an enabler for the classification code, which builds upon existing group coding systems for manufacturing systems. Using the classification coding, manufacturing systems in a company can be compared against each other in order to identify elements of commonality and potential areas for platforms.

Based on the FLC platform development method, a new and revised method is currently being developed. It utilises the concept of views and viewpoints described in ISO 42010 [16]. The method prescribes both the process (from development to documentation) and tools to support it, such as the previously mentioned classification scheme and coding.

Aside from the above works-in-progress, more research is still needed in the preliminary stages of platform development. This includes quantification of the potential of applying production platforms, and ways to determine the appropriate type or amount of production platforms for a given company [21]. Another area is the modelling of production platforms and subsequent mapping to corresponding product platform models. A sufficient level of modelling and mapping could allow manufacturers to evaluate the producibility of a new product, and help identify necessary changes required to make the product producible.

References

1. ElMaraghy, H., et al.: Product variety management. CIRP Ann. – Manuf. Technol. **62**(2), 629–652 (2013)
2. Simpson, T.W.: Product platform design and customization: Status and promise. AI EDAM **18**(1), 3–20 (2004)
3. Bossen, J., Brunoe, T.D., Nielsen, K.: Platform-based production development. In: Umeda, S., Nakano, M., Mizuyama, H., Hibino, H., Kiritsis, D., von Cieminski, G. (eds.) APMS 2015. IAICT, vol. 459, pp. 53–61. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-22756-6_7
4. ElMaraghy, H.A., Wiendahl, H.: Changeability – an introduction. In: ElMaraghy, H.A. (ed.) Changeable and Reconfigurable Manufacturing Systems, pp. 3–24. Springer, London (2009). https://doi.org/10.1007/978-1-84882-067-8_1
5. Salvador, F., de Holan, P.M., Piller, F.T.: Cracking the code of mass customization. MIT Sloan Manag. Rev. **50**(3), 71–78 (2009)

6. Andersen, A., Brunoe, T.D., Nielsen, K., Rösiö, C.: Towards a generic design method for reconfigurable manufacturing systems: analysis and synthesis of current design methods and evaluation of supportive tools. J. Manuf. Syst. **42**, 179–195 (2017)
7. Michaelis, M.T., Johannesson, H.: From dedicated to platform-based co-development of products and manufacturing systems. In: ElMaraghy, H.A. (ed.) Enabling Manufacturing Competitiveness and Economic Sustainability, pp. 196–202. Springer, Heidelberg (2012). https://doi.org/10.1007/978-3-642-23860-4_32
8. ElMaraghy, H., Abbas, M.: Products-manufacturing systems co-platforming. CIRP Ann.-Manuf. Technol. **64**, 407–410 (2015)
9. Michaelis, M.T., Johannesson, H., ElMaraghy, H.A.: Function and process modeling for integrated product and manufacturing system platforms. J. Manuf. Syst. **36**, 203–215 (2015)
10. Landahl, J., et al.: Using product and manufacturing system platforms to generate producible product variants. Procedia CIRP **44**, 61–66 (2016)
11. Sorensen, D.G.H., Bossen, J., Bejlegaard, M., Brunoe, T.D., Nielsen, K.: Production platform development through the four loops of concern. In: Hankammer, S., Nielsen, K., Piller, F., Schuh, G., Wang, N. (eds.) Customization 4.0, pp. 479–493. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-77556-2_30
12. Benkamoun, N., ElMaraghy, W., Huyet, A., Kouiss, K.: Architecture framework for manufacturing system design. Procedia CIRP **17**, 88–93 (2014)
13. Jepsen, A.D.: Architecture Descriptions. A Contribution to Modeling of Production System Architecture. Ph.D. Thesis, Technical University of Denmark (2014)
14. Bossen, J., Brunoe, T.D., Bejlegaard, M., Nielsen, K.: Conceptual model for developing platform-centric production architectures. In: Bellemare, J., Carrier, S., Nielsen, K., Piller, Frank T. (eds.) Managing Complexity. SPBE, pp. 83–98. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-29058-4_7
15. Hevner, A.R., March, S.T., Park, J., Ram, S.: Design science in information systems research. MIS Q. **28**(1), 75–105 (2004)
16. ISO, IEC, IEEE: Systems and software engineering — architecture description. International Organization for Standardization ISO/IEC/IEEE 42010:2011(E) (2011)
17. Andreasen, M.M., Hansen, C.T., Cash, P.: Function Reasoning. Conceptual Design, pp. 267–305. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-19839-2_11
18. Harlou, U.: Developing product families based on architectures. Ph.D. Thesis, Technical University of Denmark (2006)
19. Claesson, A.: A Configurable Component Framework Supporting Platform-Based Product Development. Ph.D. Thesis, Chalmers Tekniska Högskola (2006)
20. Levandowski, C.E., et al.: An integrated approach to technology platform and product platform development. Concur. Eng. **21**(1), 65–83 (2013)
21. Andersen, A., ElMaraghy, H., ElMaraghy, W., Brunoe, T.D., Nielsen, K.: A participatory systems design methodology for changeable manufacturing systems. Int. J. Prod. Res. **56**(8), 2769–2787 (2017). https://doi.org/10.1080/00207543.2017.1394594

Modelling for Service Solution of a Closed-Loop Supply Chain with the Presence of Third Party Logistics

Mitali Sarkar, Rekha Guchhait, and Biswajit Sarkar(✉)

Department of Industrial and Management Engineering, Hanyang University, Ansan, Gyeonggi-do 15588, South Korea
bsbiswajitsarkar@gmail.com

Abstract. Service, the word itself is a big issue in the corporate world. One of the most important parts of the reputation of a company depends how much it can provide service to customers. It is very difficult to maintain especially when it is related to a closed-loop supply chain. Quality of products is also a main factor of business that is known to all. In this model, a closed-loop supply chain with multi-retailer, single-manufacturer and single- third-party collector (3PL) is considered where service and quality issues are maintained throughout the supply chain. The model is solved by a classical optimization method and obtains global solutions in closed and quasi-closed forms. Numerical experiments are done to illustrate the model clearly. Numerical results prove the reality of the model.

Keywords: Closed-loop supply chain · Service · Quality · 3PL
Returned products

1 Introduction

Service is an essential ingredient for business in any supply chain nowadays. Each customer thinks about the good service from any company. If the service is very good in terms of some offers like more products, free gifts, or, discounted prices. There are different studies in this direction. Several authors found major relations within some closed-loop supply chains. Lee [1] worked on different service levels on inventory model. Krishnamoorthy and Viswanath [2] discussed a stochastic production inventory model under service time. Gzara et al. [3] developed a location-allocation model where service is given only for logistic cases. Chen et al. [4] formulated an inventory model for substitutable products and customer's service with objectives. Wheatley et al. [5] worked with service constraints for inventory-location model. Protopappa et al. [6] discussed multiple service levels for two-period inventory allocation problem. Cordes and Hellingrath [7] formulated a master model for service in personal capacity planning with integrated inventory and transport. Marand et al. [8] discussed a service-inventory model for pricing policy. Rahimi et al. [9] formulated a multi-objective stochastic inventory model with service level. This study proposes that in a three-echelon supply

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 320–327, 2018.
https://doi.org/10.1007/978-3-319-99704-9_39

chain, service is given by manufacturer to the retailer and retailer gives the same service to their customers.

As service depends upon price, thus demand is assumed as variable and depends upon price. Also, price is assumed as variable and depend on service. Aydinliyim et al. [10] worked on an inventory model, where products are retailed through online. Transchel [11] discussed an inventory model under two scenarios: price-based substitution and stock-out-based substitution. Wu et al. [12] developed an inventory model for a fixed life-cycled product, where selling price depends upon life expire date. Chen et al. [13] formulated a newsvendor model for multi-period and found an optimal pricing policy for selling. This study proposed a variable selling price with a maximum and a minimum range of selling price and depends upon service also.

To connect the traditional supply chain system to a green supply chain, waste management is under consideration in this proposed model. Rajesh et al. [14] discussed the involvement of third party logistics (3PL) system in India. Li et al. [15] developed a supply chain model under fuzzy environment where 3PL is a supplier. Zhang et al. [16] worked on a dynamic pricing policy for 3PL for heterogeneous type of customers. Huo et al. [17] worked on a supply chain system for a specific asset along with 3PL system under environment uncertainty from an economic perspective. Chung [18] invested the safety stock and lead time uncertainties for supply chain management in a certain situation of international presence. This study proposed a 3PL system for waste management and reuse of products through remanufacturing such that the use of raw materials can be diminished.

2 Problem Definition and Model Formulation

This section consists of the definition of the research problem and formulation of the research model.

2.1 Problem Definition

Recently, an industry, situated at West Bengal, India, is suffering from service issues. The aim of the research is to solve those issues related to the industry. If one can model their whole system, then it looks like a supply chain model with multi-retailer, single-manufacturer and single-third party. The main issues of the industry are not business flow issue only. The main issues of the industry are how to manage maximum service for the customer with minimum total cost. As quality of products and quality improvement of products are also another big issues; thus, the industry would like to solve their problems globally. It means that they should reach the global optimum solution with optimum lot size, quality, service, service price, service integrator price.

2.2 Model Formulation

A homogeneous-power three-echelon supply chain is considered here under third party logistic (3PL). Industry consists of three pillars of strengths as a single-manufacturer, a single-third party, and multi-retailer. The demand of the manufacturer for the industry is $d = \sum_{i=1}^{n} D_i = \sum_{i=1}^{n} D(\alpha_i, \beta_i, \theta_i) = \sum_{i=1}^{n} a_i \frac{(\alpha_i+\beta_i)_{max}-(\alpha_i+\beta_i)}{(\alpha_i+\beta_i)-(\alpha_i+\beta_i)_{min}} + c_i\theta_i^{\delta}$, where a_i and c_i are the scaling parameters for price sensitivity and service issues, α_i is the selling price of manufacturer, β_i is the increasing cost related to the service, θ_i is the service provided by the manufacturer to the customer, δ is the service parameter, for retailer i. D_i is the demand for retailer i.

Model of Manufacturer. After completion of production, delivery is started to retailer with single shipment per cycle [19]. Manufacturer has some investments e for service. Both, the manufactured and remanufactured products are maintained the quality κ, where $0<\kappa<1$. Customers buy any product within those products with same price [20]. Reusable products are collected a rate of τ of demand of customer by the 3PL, where τ is a random variable follows uniform distribution. The quality of collected products are considered as (μ), where $0<\mu<\kappa$. The quality is upgraded during remanufacturing.

Manufacturer faces a variable demand depends upon selling price and given service. He gives service to the retailer such that whenever the retailer sells that product to the customer, they give the same service towards customers.Q is the production lotsize per cycle of the manufacturer, where $\left(Q = \sum_{i=1}^{n} q_i\right)$ (units/production cycle). P is the production rate of manufacturer. The decision variables related to the manufacturer's model is $\alpha_i, \beta_i, \theta_i, q_i$. Other costs are given by the following equations as service provider cost, revenue, ordering cost, setup cost, holding cost, raw material cost, remanufacturing cost, quality improvement cost, goodwill lost cost, and, transportation cost of manufacturer. Though, the quality of product is maintaining by the manufacturing system but, yet the quality may not be perfect as demanded by customers. Thus, the manufacturing system may lose its goodwill. The average profit of manufacturer is as follows:

$$APR_M(\alpha_i, \beta_i, \theta_i, q_i) = \sum_{i=1}^{n} (\alpha_i+\beta_i)D_i + h_u\tau d\left(1-\frac{d}{2P}\right) - \left(\frac{e^2}{2} + \frac{O_m}{Q} + \frac{S}{Q} + C_m(1-\tau) + \tau(C_r+C_3) + C_q\kappa^2(1-\tau) + \tau C_q(\kappa^2-\mu^2)\right)d - h_f\left[\frac{Q[d+2P]}{2P} - \sum_{i=1}^{n} l_i \sum_{j=1}^{i} D_j\right] - (1-\kappa)g - C_t\sum_{i=1}^{n} l_{im}\left(\frac{q_i}{\varepsilon}\right) \quad (1)$$

where e is the service investment, setup cost per setup is S. Manufacturer sales each product with selling price α_i and an increasing price β_i due to service for each retailer. In the manufacturing house raw materials and finished products have to hold for sometimes. h_f is holding cost for finished products per unit per unit time and h_u is for used products of the manufacturer. Raw material cost for manufacturer is C_m,C_r is for remanufacturing, and C_3 average collection costper product.C_q is the quality improvement cost.O_m is ordering cost of manufacturer for 3PL, g is goodwill lost cost, and C_t is the transportation cost per container per unit distance.

Model of Retailer. Retailer takes the service from the manufacturer and gives the same service to their customers. Used products are taken by 3PL, which are recycled and remanufactured. Retailer's demand $\left(D_i^{'} = D^{'}\left(\alpha_i^{'}, \beta_i, \theta_i\right) = a_i \frac{\left(\alpha_i^{'}+\beta_i\right)_{max}-\left(\alpha_i^{'}+\beta_i\right)}{\left(\alpha_i^{'}+\beta_i\right)-\left(\alpha_i^{'}+\beta_i\right)_{min}} + c_i\theta_i^{\delta}\right)$

due to customer is given by the expression where $\alpha_i^{'}$ is the selling price of retailer i. q_i is the lot size quantity for each retailer i. Z is the shipment schedule of the retailers i. From this shipment schedule, manufacturer can decide which retailer among n should replenish first. The values of Z depend on the demand of the retailer and lead time of the retailer. The expression for Z is $Z = \frac{D_i^{'}}{l_i}$. The decision variables related to the retailer's model is $Z, \alpha_i^{'}, q_i$. Other costs of the retailer i are revenue, ordering cost, and holding cost. The selling price of each retailer is $\alpha_i^{'}$. Ordering cost of retailer i is A_i per order. h_i is the holding cost of retailer. The average profit of retailer i is

$$APR_R(Z, \alpha_i^{'}, q_i) = \sum\nolimits_{i=1}^{n} \left(\alpha_i^{'} + \beta_i\right) D_i^{'} - \sum\nolimits_{i=1}^{n} \frac{A_i D_i^{'}}{q_i} - \sum\nolimits_{i=1}^{n} \frac{h_i q_i}{2} \tag{2}$$

Model of Third Party Logistics. Demand of 3PL is governed by retailers. Total demand for 3PL is given by $D = \sum_{i=1}^{n} D_i^{'}$. Through third party, used products are collected from retailers and after recycling and remanufacturing it is forwarded to manufacturer. The costs related to the 3PL are as follows: revenue, transportation cost, container management cost, setup cost, collection and recycling cost, holding cost for products, investment for used product, and purchasing. The decision variables related to the 3PL's model is τ, q_i, α. Average profit of third party is given by the following expression

$$\begin{aligned} APR_P(\tau, q_i, \alpha) = {} & \left(C_3\tau - \frac{S}{Q} - \frac{S_3}{Q} - \tau R_c - \frac{\tau h_u}{2}\right) D - C_t\left[\sum\nolimits_{i=1}^{n} l_{ik}\left(\frac{q_i}{\varepsilon}\right) + l_{km}\left(\frac{D\tau}{\varepsilon}\right)\right] \\ & - C_\alpha \varepsilon^{s-1} D_{\max}\frac{Q}{D} - h_r\left(\sum\nolimits_{i=1}^{n} l_i\left(\frac{D_{\max} - D_i}{\varepsilon}\right) + \left(\frac{Q}{D} - \sum\nolimits_{i=1}^{n} l_i\right)\frac{D_{\max}}{\varepsilon}\right) + \gamma\tau^2 \end{aligned} \tag{3}$$

The number of required containers for a single shipment to retailer i is q_i/ε, where ε is the capacity of single container. l_i is the lead time of retailer i, i.e. time between delivery to retailer i and $i+1$. Distances between retailer i- 3PL is l_{ik}, and 3PL - manufacturer is l_{km}, R_c is average recycling cost collected by the 3PL, S_3 is the setup cost per setup for collecting EOL/EOU products at 3PL, γ is effective investment by 3PL to collects EOL/EOU products. Minimum number of containers $r_i = \frac{q_{max}}{\varepsilon}$. Hence, it is assumed that the maximum number of containers in the system is $\frac{q_{max}}{\varepsilon}$ in order to minimize the management and holding costs of containers such that $\tau_{max} = \frac{D_{max}T}{\varepsilon}$ (for instance see [19]), D_{max} maximum demand rate at the retailers. The cost of managing containers is C_α, s is scaling factor and it gives the relationship between a container size and management costs, For values $s > 1$, the management of a large container is expensive compare to smaller one and for $s < 1$ the management of a large container is cheaper than small container.

Therefore, the total profit of the supply chain is given by the expression

$$TP(Z,\alpha_i,\alpha_i',\beta_i,\theta_i,q_i,\tau,\varepsilon) = APR_M(\alpha_i,\beta_i,\theta_i,q_i) + APR_R\left(\alpha_i',q_i\right) + APR_P(\tau,q_i,\varepsilon)$$
$$= \sum_{i=1}^{n}(\alpha_i+\beta_i)D_i - \left(\frac{e^2}{2} + \frac{O_m}{Q} + \frac{S}{Q} + C_m(1-\tau) + \tau(C_r+C_3) + C_q\kappa^2(1-\tau) + \right.$$
$$\tau C_q(\kappa^2-\mu^2) - h_u\tau\left(1-\frac{d}{2P}\right)\Big)d - h_f\left[\frac{Q[d+2P]}{2P} - \sum_{i=1}^{n} l_i \sum_{j=1}^{i} D_j\right] - (1-\kappa)g -$$
$$C_t\sum_{i=1}^{n} l_{im}\left(\frac{q_i}{\varepsilon}\right) + \sum_{i=1}^{n}\left(\alpha_i'+\beta_i\right)D_i' - \sum_{i=1}^{n}\frac{A_iD_i'}{q_i} - \sum_{i=1}^{n}\frac{h_iq_i}{2} + \left(C_3\tau - \frac{S}{Q} - \frac{S_3}{Q} -\right.$$
$$\left.\tau R_c - \frac{\tau h_u}{2}\right)D - C_t\left[\sum_{i=1}^{n} l_{ik}\left(\frac{q_i}{\varepsilon}\right) + l_{km}\left(\frac{D\tau}{\varepsilon}\right)\right] - C_\alpha\varepsilon^{s-1}D_{\max}\frac{Q}{D} -$$
$$h_r\left[\sum_{i=1}^{n} l_i\left(\frac{D_{\max}-D_i}{\varepsilon}\right) + \left(\frac{Q}{D} - \sum_{i=1}^{n} l_i\right)\frac{D_{\max}}{\varepsilon}\right] + \gamma\tau^2 \tag{4}$$

The optimum values of the decision variables are found by using classical optimization techniques and finally test Hessian matrix to test the optimality condition.

3 Numerical Example

Numerical example gives a numerical result regarding this theoretical model. Data is taken from industry visit and Table 1 gives the input data for this numerical example. Table 2 gives the optimal results for the proposed model.

Table 1. Input data for numerical example

Retailer			Manufacturer and 3PL		
$i=$	1	2			
$\alpha'_{i_{max}}$	28(\$/item)	28(\$/item)	P = 10,000 (units/year)	h_f = 5.2 (\$/item/year)	S = 60 (\$/order)
h_i	8.2 (\$/item/unit)	8.1 (\$/item/unit)	C_m = 150 (\$/item)	μ = 20 (%)	γ = 3000 (\$)
A_i	39 (\$/item)	63 (\$/item)	C_q = 6 (\$/item)	C_α = 0.5 (\$/container/year)	O_m = 10 (\$/item)
l_i	0.007 year	0.008 year	g = 100 (\$)	R_c = 20 (\$/item)	h_r = 5 (\$/item/unit)
l_{im}	50 (km)	40 (km)	C_t = 0.01 (\$/container/km)	C_3 = 90 (\$/unit)	h_u = 0.2 (\$/item/unit)
l_{ik}	25 (km)	25 (km)	s = 2	κ = 80 (%)	e = 1.2 (\$)
$\alpha'_{i_{min}}$	5(\$/item)	5(\$/item)	C_r = 30 (\$/item)	l_{km} = 25 (km)	δ = 2
c_i	9000	9720	$\alpha_{i_{max}}$ = 18 (\$/item)	$\beta_{i_{max}}$ = 5 (\$/item)	$\alpha_{i_{min}}$ = 4 (\$/item)
a_i	0.0001	0.0081	S_3 = 50 (\$/order)	D_{max} = 4000 (units/year)	$\beta_{i_{min}}$ = 1 (\$/item)

Table 2. Optimum results for the model

Decision variables	Values
Z^* (retailer)	(2,1)
Q^* (units)	255.85
τ^* (rate)	0.11
ε^* (units)	5
$\alpha_{(1,2,)}$ ($)	(4.1, 4.2)
$\alpha'_{(1,2,)}$ ($)	(17.64, 17.67)
$\beta_{(1,2,)}$ ($)	(4.65, 4.76)
$\theta_{(1,2)}$ ($)	(0.83, 0.11)
$r^*_{(1,2)}$ (containers)	(10, 40)
$q^*_{(1,2)}$ (units)	(54, 201.85)
$TP(Z^*, \alpha_i^*, \alpha_i'^*, \beta_i^*, \theta_i^*, q_i^*, \tau, \varepsilon)$ ($/cycle)	1868.55

3.1 Sensitivity Analysis

From sensitivity analysis of Table 3, it can be concluded that some costs have inverse impact on the total profit such that if related costs increase, total profit decreases and vice-versa. Such type of costs are service investments (e), setup cost (S), ordering cost (O_m), finished products' holding cost (h_f) and used products' holding cost (h_u) of manufacturer, setup cost for 3PL (S_3), ordering cost $(A_1, \text{and} A_2)$ and holding cost $(h_1 \text{and } h_2)$ of two retailers in which A_2 is most sensitive for retailers. Average recycling cost (R_c) and transportation cost per container (C_t) have direct impact on total profit whereas container managing cost (C_α) is the most sensitive for manufacturer followed by the container's holding cost (h_r), which is the second most sensitive parameter for manufacturer.

Table 3. Sensitivity analysis of total profit for key parameters

Parameters	Changes in inputs (in %)	Changes in total profit (in %)	Parameters	Changes in inputs (in %)	Changes in total profit (in %)
	−25	+0.32		−25	+0.13
e	−10	+0.14	S	−10	+0.05
	+10	−0.16		+10	−0.05
	+25	−0.42		+25	−0.13
	−25	+0.05		−25	+16.69
S_3	−10	+0.02	h_f	−10	+6.68
	+10	−0.02		+10	−6.68
	+25	−0.05		+25	−16.69
	−25	+0.20		−25	+0.21
h_u	−10	+0.08	O_m	−10	+0.09

(continued)

Table 3. (*continued*)

Parameters	Changes in inputs (in %)	Changes in total profit (in %)	Parameters	Changes in inputs (in %)	Changes in total profit (in %)
	+10	−0.08		+10	−0.09
	+25	−0.020		+25	−0.21
	−25	+3.03		−25	+10.61
A_1	−10	+1.21	A_2	−10	+4.25
	+10	−1.21		+10	−4.25
	+25	−3.03		+25	−10.61
	−25	+0.05		−25	+0.05
h_1	−10	+0.02	h_2	−10	+0.02
	+10	−0.02		+10	−0.02
	+25	−0.05		+25	−0.05
	−25	−40.95		−25	−0.10
R_c	−10	−16.37	C_t	−10	−0.04
	+10	+16.36		+10	+0.04
	+25	+40.87		+25	+0.10
	−25	+670.10		−25	+1675.22
h_r	−10	+268.04	C_α	−10	+670.10
	+10	~		+10	~
	+25	~		+25	~

"~" stands for no feasible solution.

Thus, whenever the third party logistic is involved in the SCM, industry manager needs to more careful about managing containers properly such that it can optimize holding cost because managing large size of containers is always a challenge for industry, otherwise it can create more lead time for shipments, which creates again holding cost issue for both finished products and used products. As recycling is better than holding those used products as long, according to sensitivity analysis, suggestion to industry manager is that investing on quick recycling rather than holding used products might be more profitable for industry.

4 Conclusions

The main applicability of the model was to provide service to the industry and finally to customers. Due to always optimum service facility, customers would be benefitted. Due to the service from the third-party, the reused products could be used for remanufacturing and the manufacturing cost was reduced, which was the indicator of the reduced optimum selling prices of products. Thus, due to remanufacturing, the customer was being benefitted with more services. Numerical experiment proved that the industry obtained the optimum cost at the optimum service to the customer. The model did not consider about the defective products during collecting used products, which is quite natural in general, that is a limitation of the model as the rate of getting defective items may be random. This model can be extended by using service of 3PL and using imperfect production system and inspection.

References

1. Lee, J.: Inventory control by different service levels. Appl. Math. Model. **35**, 497–505 (2011)
2. Krishnamoorthy, A., Viswanath, N.C.: Stochastic decomposition in production inventory with service time. Eur. J. Oper. Res. **228**, 358–366 (2013)
3. Gzara, F., Nematollahi, E., Dasci, A.: Linear location-inventory models for service parts logistics network design. Comput. Ind. Eng. **69**, 53–63 (2014)
4. Chen, X., Feng, Y., Keblis, M., Xu, J.: Optimal inventory policy for two substitutable products with customer service objectives. Eur. J. Oper. Res. **246**, 76–85 (2015)
5. Wheatley, D., Gzara, F., Jewkes, E.: Logic-based benders decomposition for an inventory-location problem with service constraints. Omega **55**, 10–23 (2015)
6. Protopappa-Sieke, M., Sieke, M., Thonemamm, U.W.: Optimal two-period inventory allocation under multiple service level contracts. Eur. J. Oper. Res. **252**, 145–155 (2016)
7. Cordes, A.-K., Hellingrath, B.: Master model for integrating inventory, transport and service personal capacity planning. Int. Fed. Autom. Control **49**(30), 186–191 (2016)
8. Marand, A.J., Li, H., Thorstenson, A.: Joint inventory control and pricing in a service-inventory system. Int. J. Prod. Econ. (2017). https://doi.org/10.1016/j.ijpe.2017.07.008
9. Rahimi, M., Baboli, A., Rekik, Y.: Multi-objective inventory routing problem: a stochastic model to consider profit, service level and green criteria. Transp. Res. Part E **101**, 59–83 (2017)
10. Aydinliyim, T., Pangburn, M., Rabinovich, E.: Inventory disclosure in online retailing. Eur. J. Oper. Res. **261**, 195–204 (2017)
11. Transchel, S.: Inventory management under price-based and stockout-based substitution. Eur. J. Oper. Res. **262**, 996–1008 (2017)
12. Wu, J., Chang, C.-T., Teng, J.-T., Lai, K.-K.: Optimal order quantity and selling price over a product life cycle with deterioration rate linked to expiration date. Int. J. Prod. Econ. **193**, 343–351 (2017)
13. Chen, X.A., Wang, Z., Yuan, H.: Optimal pricing for selling to a static multi-period newsvendor. Oper. Res. Lett. **45**, 415–420 (2017)
14. Rajesh, R., Pugazhendhi, S., Ganesh, K., Muralidharan, C., Sathiamoorthy, R.: Influence of 3PL service offerings on client performance in India. Transp. Res. Part E **47**, 149–165 (2011)
15. Li, F., Li, L., Jin, C., Wang, R., Wang, H., Yang, L.: A 3PL supplier selection model based on fuzzy sets. Comput. Oper. Res. **39**, 1879–1884 (2012)
16. Zhang, J., Nault, B.R., Tu, Y.: A dynamic pricing strategy for a 2PL provider with heterogeneous customers. Int. J. Prod. Econ. **169**, 31–43 (2015)
17. Huo, B., Ye, Y., Zhao, X., Wei, J., Hua, Z.: Environmental uncertainty, specific assets, and opportunism in 3PL relationships: a transaction cost economics perspective. Int. J. Prod. Econ. (2018). https://doi.org/10.1016/j.ijpe.2018.01.031
18. Chung, W., Talluri, S., Kovács, G.: Investigating the effects of lead-time uncertainties and safety stocks on logistics performance in a border-crossing JIT supply chain. Comput. Ind. Eng. **118**, 440–450 (2018)
19. Glock, C.H., Kim, T.: Shipment consolidation in a multiple-vendor-single-buyer integrated inventory model. Comput. Ind. Eng. **70**, 31–42 (2014)
20. Sarkar, B., Ullah, M., Kim, N.: Environmental and economic assessment of closed-loop supply chain with remanufacturing and returnable transport items. Comput. Ind. Eng. **111**, 148–163 (2017)

Product-Process Modelling as an Enabler of Manufacturing Changeability

Thomas Ditlev Brunoe(✉), Daniel G. H. Sorensen, Mads Bejlegaard, Ann-Louise Andersen, and Kjeld Nielsen

Aalborg University, Fibigerstræde 16, DK9220 Aalborg, Denmark
tdp@mp.aau.dk

Abstract. Today's competitive environment demands increased product variety, more rapid product introductions and increasingly efficient operations in manufacturing. Changeable manufacturing, encompassing reconfigurability and flexibility, provides a mechanisms for addressing these new demands, however there is a significant gap between the concept of changeable manufacturing, and what is actually enabled through operational methods. This paper analyzes how integrated modelling of products and processes can be applied when designing, managing, and operating changeable manufacturing systems. This is structured using generic changeability classes and generic changeability enablers. It is concluded that integrated product-process modelling has a potential to support changeability, especially within the classes reconfigurability, flexibility and transformability. However a theory-practice gap still exists, calling for more research on specific methods and feasibility of such approach.

1 Introduction

The markets of today are characterized by an increased demand for product variety, serving both smaller niche markets, as well as individual customers, where products are manufactured to each individual customers' requirements in the business strategy Mass Customization. This implies that many manufacturers face an increased product variety induced complexity that needs to be handled efficiently in their manufacturing systems.

Product life cycles are also continuously getting shorter, as competition drives more frequent product releases. This implies that manufacturing systems, if dedicated to specific products, will have shorter life cycles as well. If manufacturing systems are not dedicated, they will need to be changed more frequently to adapt to new product generations. Worst case, different generations of products need to be manufactured at the same time, increasing the complexity even more. Combining the increased product variety with the reduced product life cycles implies a significant increase in the number of changes in manufacturing systems necessary to remain competitive. The level of complexity and amount of change depends on the product and industry, but this trend is considered general across industries.

Many different approaches have been proposed to deal with these challenges. Within the area of Mass Customization, it is suggested that the development within three capabilities ensures a successful handling of this complexity [12]. These capabilities include (1) choice navigation – helping customers find or configure the right

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 328–335, 2018.
https://doi.org/10.1007/978-3-319-99704-9_40

product, (2) solution space development – designing product families which efficiently are able to match the customers' demand for variety, and (3) robust process design – the capability to establish business processes and manufacturing processes which can efficiently handle product variety. Salvador et al. suggest three mechanisms to achieve robust process design: Adaptive human capital, Flexible automation, and process modularity [12], although they do not go deeper into detail on how this can be implemented.

Koren [2] proposed the reconfigurable manufacturing system as a means to achieve a system with a sufficient ability to change, in order to address the above challenges. Although reconfigurability is an important enabler of creating robust process design, recent research suggests that companies must consider more diverse types of changeability, reconfigurability being only one of more types [8]. Wiendahl et al. [4] introduced five different classes of changeability, based on the type and significance of change in the product characteristics and market demand: Changeover ability, Flexibility, Reconfigurability, Transformability, and agility. Below, these concepts will be elaborated.

A significant stream of literature focuses on the design of changeable manufacturing systems [3, 4]. Several publications report that designing manufacturing systems for changeability does indeed have the potential to increase competitiveness [2, 5, 11], however there still seems to be a gap between the potential in applying research results and what is actually being applied in industry.

One common theme across the different publications on how to achieve a changeable manufacturing system, is a coordination between the product domain and the manufacturing domain, referred to by some as co-development or co-evolution [7]. This implies that when making decisions in product development, these must be coordinated with the development of the manufacturing system and vice versa. Doing this, however requires knowledge about the relations between products and processes. This may be achieved by introducing formal models representing both the product variety and the variety of manufacturing processes, from here referred to as product-process models [6]. It is obvious that a model representing product variety and characteristics, and at the same time the manufacturing systems and their relations is useful for co-developing products and correspondingly changeable manufacturing systems. However, current literature does not present any insight into how and by which mechanisms product-process models may contribute to the changeability of a manufacturing system. This leads to the research question of this paper:

How may an integrated product-process model contribute to increasing the changeability of a manufacturing system?

This research question is addressed by analyzing each changeability class, as outlined below and assessing this mechanisms in product-process modelling can support this specific class of changeability.

1.1 Changeability Classes

The remainder of the paper will address the changeability classes from Wiendahl [4] one by one, analyzing which mechanisms provided by product-process modelling may help companies increase manufacturing system changeability. Figure 1 outlines the different changeability classes and their relations to different scopes of product change, production levels and decision levels, as suggested by Wiendahl et al. [4]. The changeability class "Agility", concerns major changes to an entire company implying pursuit of entirely new markets, new products and new manufacturing systems, and is considered out of scope of what is meaningful to address using models of existing products and processes. Hence this changeability class is not addressed further in this paper. Figure 1 outlines the different changeability classes and, how each changeability class relates to different scopes of product change, different production levels and different levels of decisions.

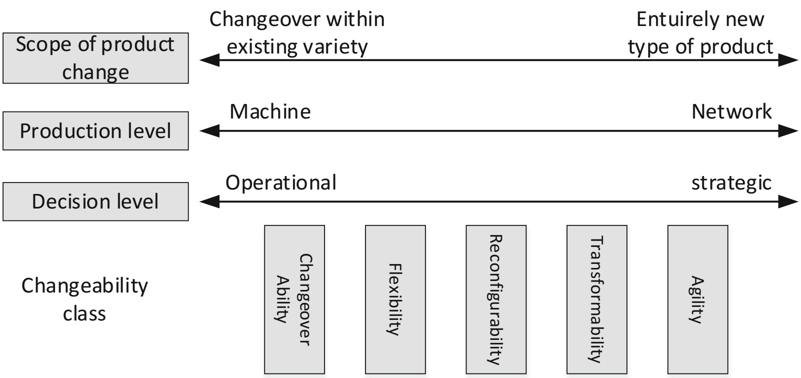


Fig. 1. Changeability classes and relations to product change, production levels and decision levels

1.2 Product-Process Modelling

The basic purpose of product-process modelling is establishing a models, which describe products, components, characteristics and variety, while also describing manufacturing systems in terms of equipment, processes and process capabilities [6]. A product-process model will also describe the relations between the product and the process domain on a generic level, so that for any given component or product, it is possible to determine whether and which equipment would be able to perform the required manufacturing processes. Conversely, the model will provide information on which products or components depend on a given equipment or processes [6]. Several different approaches have been proposed for developing product-process models applying different modelling languages, e.g. cladistics [1], the configurable component [10], or object oriented modelling using the Unified Modelling Language (UML) [6]. Either one of these approaches however provides the possibility to describe the relations between products and the manufacturing system. This will be addressed below in relation to the changeability classes.

It is important to note that product-process modelling can be performed at very different levels of detail. As an example, describing process capabilities at a very high level may be done by characterizing a factory as being able to "produce large steel components". On the other hand process capabilities may be described on a very detailed level, as an example "MIG Weld AISI1005 steel T joint with a 300 A current at 0.1 m/s". Both representations describe steel processes, but at very different levels. Different detail levels would likely imply different benefits in relation to changeability, however in this paper, we address product-process modelling as a general mechanism, not distinguishing between specific levels of detail.

1.3 Example of Product Process Modelling

Numerous methods exist for product modelling and process modelling, each serving different purposes. However, to illustrate one approach to do this, the approach introduced recently by the authors of this paper is applied [6]. The basic approach of this method is that in a company applying the method, a company specific ontology is developed, which models the different types of processes exist in a company, and which different types of components the company manufactures. Furthermore, the ontology dictates by which attributes processes and components must be described, and how the component attributes link to the process attributes to be able to determine for any component, which processes would be able to manufacture this. A simple example of such ontology is illustrated in Fig. 2. For an injection moulding process.

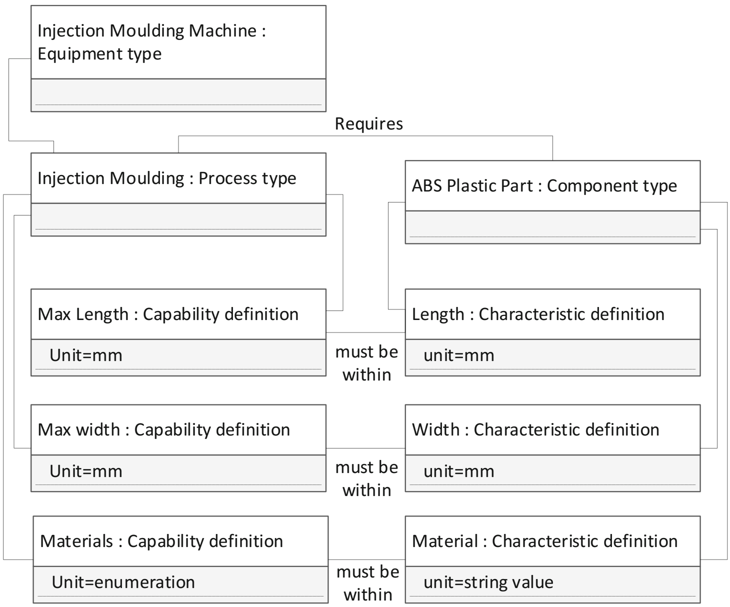


Fig. 2. Example of a product-process ontology.

Once the ontology is in place, specific equipment implementing the processes can be specified, by assigning values to the attributes. Furthermore, specific components can also be specified, also adhering to the ontology. This is illustrated in Fig. 3. By taking this approach, it is ensured that all processes of the same process type are described in exactly the same way, and all components of the same component type are described in the same way. Since the relations between the attributes for the component types and the process types have already been defined generically, this is not necessary to do for the specific instances.

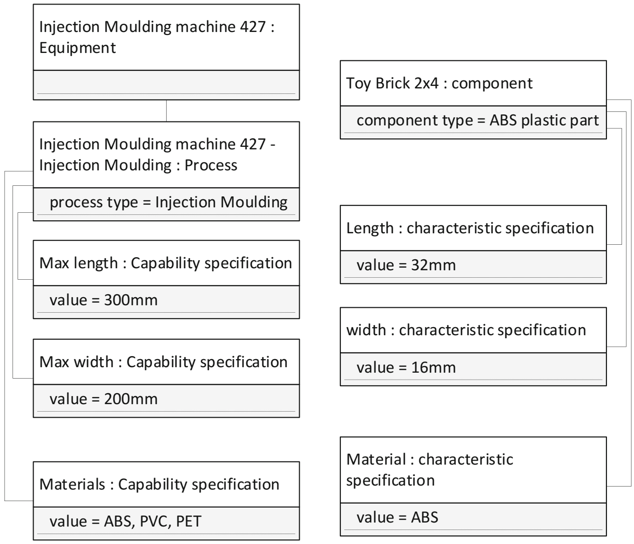


Fig. 3. Example of how specific instances of components and equipment can be modelled based on the ontology in Fig. 2.

2 Analysis of Enabling Mechanisms

2.1 Changeover Ability

The changeability class "Changeover ability" refers to the "operative ability of a single machine or workstation to perform operations on a known workpiece or subassembly at any desired moment with minimal effort and delay" [8].

In relation to achieve changeability on changeovers, product-process modelling can benefit in several different ways. If a model describes the relation between product characteristics and process characteristics, changeover instructions for operators, could be generated automatically based on this information, helping operators achieving faster changeovers. If a model also contains information on the relations between process settings and changeover time, it would also be possible to calculate timing and cost for different sequences of product combinations. This is due to the fact that changeovers from one product to another often depends on how similar these products are. This similarity could be derived from product models, thus indicating the time needed for changing over. This could help in optimizing the production sequence for minimizing changeovers and thus increasing utilization.

2.2 Flexibility

Flexibility is somewhat similar to changeover ability, however flexibility refers to a tactical ability rather than an operative ability and addresses the ability to change a system rather than a machine or workstation [8]. Flexibility concerns the ability to change within products that are already introduced in the production system, i.e. known variety [8]. This happens typically by re-programming, re-scheduling and re-routing the system logically [8].

When having an integrated product-process model which describes product characteristics, process capabilities for specific equipment and the relations between these two domains, it is possible to determine for a specific product, which equipment will be able to perform the required processes. With this information it is possible to generate all feasible routes through a production for a specific product. These alternative feasible routes can form the basis for deciding the actual routing of products through a production. If the process model, or other information repositories hold information on processing cost for different equipment, costs for alternative routings may also be calculated supporting routing decisions even better. Taken even further, the information may utilized for making automated routing of products, without requiring human decisions, given that sufficient priority rules are implemented. This could be one step towards developing a self-optimizing manufacturing system. This will however also require capacity constraints to be implemented in the model.

2.3 Reconfigurability

Reconfigurability is the ability to accommodate larger changes than flexibility. Reconfigurability is thus the tactical ability to alter the manufacturing systems ability to manufacture new product, which are however very similar to those currently being manufactured [8]. Reconfiguration may happen by adding removing or changing the physical structure of the modules in the manufacturing system [8].

Since reconfiguring a manufacturing system changes the capability or capacity, the benefits from the above changeability classes do not apply. This changeability class implies that new products are introduced. When introducing a new product, a product-process model will enable assessment of whether a new product can be manufactured within the current flexibility envelope, or a reconfiguration is in fact necessary. This is possible because the model would specify relations between processes, equipment, and generic product types or component types. Introducing a new specific product, the relations to equipment is immediately known and thus information on which equipment will produce this product is easily available. A part of this information will indicate for which processes the current flexibility is insufficient, requiring new investments in equipment. This relation could also be applied during product development, since different scenarios for changes in products could be evaluated in terms of the required change in the manufacturing system, which could be incorporated into design for manufacturing activities, taking into account equipment investments.

Finally, if a company possesses a manufacturing system platform, containing modules, not currently in use in a specific factory, an integrated product-process model would be able to identify platform equipment which is not currently located in the factory manufacturing the product in question. This could lead to shorter reconfiguration times, since proven solutions for manufacturing equipment can be utilized rather than developing new unproven solutions from scratch.

2.4 Transformability

Transformability refers to the tactical ability to change the structure of an entire factory to accommodate new products or product families, thus implying larger changes than what is addressed with reconfigurability [8]. This is achieved by making larger changes to the factory than reconfiguration, i.e. designing entirely new manufacturing systems with new facilities [8].

The changes which are addressed by transformability is somewhat similar to those addressed by reconfigurability, however differentiated by the magnitude of product change. For this reason, the potential benefits from applying product-process modelling a quite similar. If however a complete rebuild of a manufacturing system is required rather than a reconfiguration, a product-process can be applied to analyze which existing physical equipment can be reused in a future manufacturing system, since the requirements for equipment can be derived from the model and compared to existing equipment. For those processes that cannot be performed by existing equipment, the product-process model can be used to aggregate requirements for process capability as well as requirements for flexibility and possible even reconfigurability. The latter assumes that future minor product changes can be modelled in advance. The same potential benefits related to identifying solutions in a manufacturing system platform also applies to transformability.

3 Discussion and Conclusion

As indicated above, performing integrated product-process modelling where generic processes are linked to generic component types and product types, holds a potential for supporting changeability within different changeability classes. This potential lies in the possibility to support decisions on various levels, from operational to tactical. Also a potential comes from the possibility to automate and make manufacturing systems more autonomous or self-optimizing.

To the authors' knowledge no empirical results have been published on the implementation of such system, and hence it is assumed that no or few companies have actually done this in practice. It is on the other hand observed in several companies, that the task of reconfiguring manufacturing systems, or deciding on a level of flexibility is a difficult task, where companies need tools for supporting the process. An integrated product-process modelling approach would at least contribute to reducing the complexity of these tasks by providing better decision support. It is expected that making such implementation will be a major project, involving several entities within a company. However, the potential benefits are also expected to be significant. Future research will address this by elaborating methods for doing the modelling and running pilot tests on lab manufacturing systems and eventually on real life manufacturing systems.

References

1. Salvador, F., De Holan, P.M., Piller, F.: Cracking the code of mass customization. MIT Sloan Manag. Rev. **50**(3), 71–78 (2009)
2. Koren, Y.: The Global Manufacturing Revolution: Product-Process-Business Integration and Reconfigurable Systems. Wiley, Hoboken (2010)
3. ElMaraghy, H.A., Wiendahl, H.P.: Changeability - an introduction. In: ElMaraghy, H.A. (ed.) Changeable and Reconfigurable Manufacturing Systems, pp. 3–24. Springer, London (2009). https://doi.org/10.1007/978-1-84882-067-8_1
4. Wiendahl, H., ElMaraghy, H.A., Nyhuis, P., et al.: Changeable manufacturing-classification, design and operation. CIRP Ann.-Manufact. Technol. **56**(2), 783–809 (2007)
5. Andersen, A., Brunoe, T.D., Nielsen, K., et al.: Towards a Generic design method for reconfigurable manufacturing systems - analysis and synthesis of current design methods and evaluation of supportive tools. J. Manuf. Syst. **42**, 179–195 (2017)
6. Andersen, A., ElMaraghy, H., ElMaraghy, W., et al.: A participatory systems design methodology for changeable manufacturing systems. Int. J. Prod. Res. **56**(8), 1–19 (2018)
7. Andersen, A., Brunoe, T.D., Nielsen, K.: Investigating the potential in reconfigurable manufacturing: a case-study from Danish industry. In: Umed, S., Nakano, M., Mizuyama, H., et al. (eds.) Advances in Production Management Systems: Innovative Production Management Towards Sustainable Growth, pp. 274–282. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-22756-6_34
8. Putnik, G., Sluga, A., ElMaraghy, H., et al.: Scalability in manufacturing systems design and operation: state-of-the-art and future developments roadmap. CIRP Ann.-Manufact. Technol. **62**(2), 751–774 (2013)
9. Bejlegaard, M., Brunoe, T.D., Bossen, J., et al.: Reconfigurable manufacturing potential in small and medium enterprises with low volume and high variety: pre-design evaluation of RMS. Procedia CIRP **51**, 32–37 (2016)
10. ElMaraghy, H.A., AlGeddawy, T.: Co-evolution of products and manufacturing capabilities and application in auto-parts assembly. Flex. Serv. Manuf. J. **24**(2), 142–170 (2012)
11. Brunoe, T.D., Soerensen, D.G., Andersen, A., et al.: Framework for integrating production system models and product family models. Procedia CIRP **72**, 592–597 (2018)
12. AlGeddawy, T., ElMaraghy, H.: A model for co-evolution in manufacturing based on biological analogy. Int. J. Prod. Res. **49**(15), 4415–4435 (2011)
13. Michaelis, M.T., Johannesson, H., ElMaraghy, H.A.: Function and process modeling for integrated product and manufacturing system platforms. J. Manuf. Syst. **36**, 203–215 (2014)

A Model of Dynamic Scheduling of Restaurant Operations Considering the Order and Timing of Serving Dishes

Tomomi Nonaka(✉), Terumi Nobutomo, and Hajime Mizuyama

Department of Industrial and Systems Engineering, Aoyama Gakuin University, 5-10-1 Fuchinobe, Chuo-ku Sagamihara, Kanagawa 252-5258, Japan
nonaka@fc.ritsumei.ac.jp

Abstract. Japanese and French restaurants provide dishes in an order specified by tradition; for example, from appetizers to desserts. On the other hand, customers in a Japanese-style bar or casual restaurant often order several dishes at one time. They may have implicit preferences as to the order and timing of serving the dishes according to the characteristics of the foods and their situations. For example, light meals that can be served quickly tend to be served first to cater to customer desires. This paper proposes a dynamic scheduling approach for restaurant service operations considering the order and timing of serving dishes. Customers specify their requests for the order of serving dishes to floor staff, and then a model configures cooking and serving schedules dynamically according to the customers' requests. In this paper, three models are proposed. In the first model, cooked dishes are stocked in a storage space until the customers' requirements for the order have been satisfied. The second model coordinates cooking schedules by considering the order sequence, cooking time, and lot assignment to adapt to customer requirements. The third model combines the first and second models.

Keywords: Dynamic scheduling · Service · Customer satisfaction
Operations management · Restaurant

1 Introduction

In the customer-facing service industry, this is not merely a pursuit of improved efficiency but is also required in order to improve or maintain customer satisfaction [1]. In research targeting the restaurant service industry, many studies have evaluated waiting time in terms of resource constraints such as numbers [2, 3]. They have considered the number of people that can be accommodated inside of a restaurant, the number of tables, and the number of staff. Hwang et al. modeled the restaurant service provision process and constructed a simulation model that evaluates the waiting time in different seat numbers and the number of floor staff and kitchen staff [4]. However, cooking time and meal time are constants in Fung's model, and the cooking schedule is not considered. In the model of Hwang et al., the order arrival rate and cooking rate are defined as variables, as in Fung et al., the cooking schedule is not considered. It demonstrated

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 336–341, 2018.
https://doi.org/10.1007/978-3-319-99704-9_41

that cooking time is shortened by helping other cooking places but the cooking schedule was not taken into consideration.

Few studies have dealt with restaurants' cooking schedules, and few have focused on the order of cooking offerings and customer satisfaction. In restaurants, when a customer orders multiple dishes at the same time, it is conceivable that the order of the offerings and the time required to provide them as expected by customers are different, depending on the characteristics of the selections. In Japanese and French cuisine courses, the order of cooking is traditionally decided in advance. In restaurants, customers sometimes order multiple dishes one by one rather than courses for the purpose of eating accompanied by drinking and slowly tasting multiple dishes. In this scenario, customers may implicitly specify the order of supply and timing according to their requests. In improving customer satisfaction, the order of dishes is considered to be an important factor. Considering the operations at the realization site, it is possible to secure enough human resources at high-end and other restaurants and to adjust the cooking sequence and schedule according to the pace of each customer's meal.

On the other hand, efficiency is essential, especially in popular restaurants. It is necessary for cooking staff to devise a cooking order individually in response to incoming customer orders. In kitchens where a POS system is installed, customers' orders are divided into appropriately assigned cooking areas or facilities. By looking at an incoming group of customers' orders, the cooking staff devise an efficient order of cooking as in a batch set of compilation. One concern with the current approach is that acceptability or inadequacy of the device depends on the experience value or intuition of the individual. Basically, cooking staff cook the orders allocated to them in order from the chronological beginning of the order list Since this is a closed process within the staff, it is difficult for staff to consider the precedence relationship with the orders allocated to other cooking areas and equipment. Additionally, at restaurant service sites that have substantial subordinate work and heterogeneous services, there are many dynamic factors to be considered in the field and operating according to a complete schedule given from the outside is difficult. Therefore, this study proposes a model that schedules restaurants' cooking and serving tasks in consideration of the order and timing of dishes for food service. In this model, when a customer places a request for each dish at the time of ordering, the schedule of cooking and serving is dynamically constructed based on that order. This aims to improve customer satisfaction by considering the order and timing that customers expect when ordering.

2 Proposed Model

2.1 Modeling

This paper targets restaurants where customers order multiple single items at a time. The schedule of cooking and serving is decided based on four methods. In addition to the conventional provision method, the following three methods are proposed. Next, the three proposed methods are assessed by simulation.

- Floor scheduling considering the order of arrangement requested by customers (Proposed method (1))

- Cooking scheduling considering the ordering sequence (Proposed Method (2))
- Cooking considering the order of serving and floor scheduling (Proposed method (3)).

An example of a restaurant model is shown in Fig. 1. In this example, the restaurant is composed of three areas: the floor area, an area for stocking cooked goods, and a kitchen. The area of product placement is placed between the kitchen and the floor and cooked goods are kept there until they are served. The number of floor areas, the space for cooked goods, and the number of kitchens may be n to n; not one by one. The kitchen is divided into several zones for similar cooking work. For example, drinkers (make drinks), cooktops (to prepare ingredients), shops, fried grounds, and so on. Cooking facilities such as refrigerators and ovens are treated as one zone.

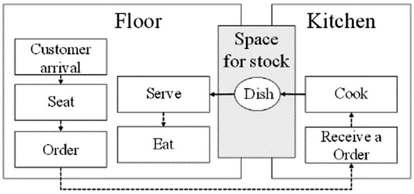


Fig. 1. Restaurant layout and service flow.

A number is allocated to the zone, and the dish ID and standard cooking time to be created there are set. The standard cooking time is set according to a given standard, and the actual cooking time fluctuates depending on the current condition of the kitchen. The store staff model is set for each role responsibility such as the floor charge and cooking. It is assumed that the customer model can be constructed in table units that may be ordered any number of times while visiting. At the time of ordering, the customer notifies the store staff of the desired arrangement order for serving the requested items.

The flow of ordering, cooking, and serving in these three areas is shown in Fig. 1. On the floor, the customer orders the selected items and the order is conveyed to the kitchen. The order is allocated to the cooking area or zone for each facility, and the cooking staff in charge of that zone cook the items based on the transmitted order. The items that have been cooked are placed in the storage area and the floor staff, who move around the floor, bring items from the storage area to the customer. The customer then eats the cooked items and issues new orders as desired.

In this study, we focus on the following two points that can manipulate the serving order requested by customers. The first is the timing of when customers' orders are conveyed to the kitchen. The timing of ordering and the contents of the orders are different for each customer. Under these inputs as originally issued, the restaurant side may not be able to operate; but the timing of supplying the order requests to the kitchen can be adjusted. In this way, kitchen staff can process the ordered items in turn. In this scenario, it is not necessary to consider the cooking schedule while cooking. Moreover, this makes it possible to exploit ingenuity in efficient cooking such as lot summary, which is being done at present without changing current operations. The second point of influence is when the floor staff delivers the cooked goods from the storage area. The timing of when to deliver the goods from the storage area is adjusted by the operations of the floor staff.

2.2 Algorithm

2.2.1 Conventional Provision Method

When a customer orders a dish, an order is placed in a difference queue for the zones where each dish is created. Cooking is done in a "first in, first out" (FIFO) order from a different queue when facilities in that zone are empty. However, when the same dish is ordered, simultaneous cooking can be performed by summarizing lots, and the cooking time is shortened. In this study, we set constraints on lot summarization when the same dish is entered one by one. Cooking completed cuisine is arranged by a staff member from the floor area.

2.2.2 Floor Arrangement Scheduling (Proposed Method 1)

In floor scheduling based on the order of supply requested by customers, the cooking order is the same as in the conventional method. The cooked goods are once placed in the storage area, and the floor staff adjusts the timing of serving according to the customer's requested order. The dishes placed in the store are served as in the customer's requested order. However, if it the resulting order is not the desired order, items are kept in the storage area until the dish intended to be served first is ready.

2.2.3 Cooking Scheduling (Proposed Method 2)

In cooking scheduling based on the order of supply requested by the customer, the cooking sequence is dynamically configured according to the order of provision desired by the customer. There are two types of precedence relationships in orders. The first is a precedence relation concerning the request order in the same order when the customer has ordered multiple dishes. The second is a prior relationship to orders from other customers in the zone. When customers order multiple dishes simultaneously, they are scheduled according to the constraints of the precedence relationship. Hence, cooking is completed simultaneously at or after the time at which the previous dish is cooked within the request provision order.

The flow of the cooking schedule from the order is shown in Fig. 2. First, when ordered by the customer, the order is stored in the order adjustment pool of the zones where each of the dishes is created. Then, according to the cooking scheduling algorithm, the chosen order is moved from an organized pool to a different queue. Which orders move to the differential queue depends on the cooking scheduling algorithm.

The conditions for moving from the order adjustment pool to a different queue are as follows. Considering the cooking time for the preceding dish and for the target dish, movement to the different queue is controlled so that cooking is not completed earlier than for the preceding dish. The following key points apply in this approach:

- The first order among those not cooked in the same order is processed

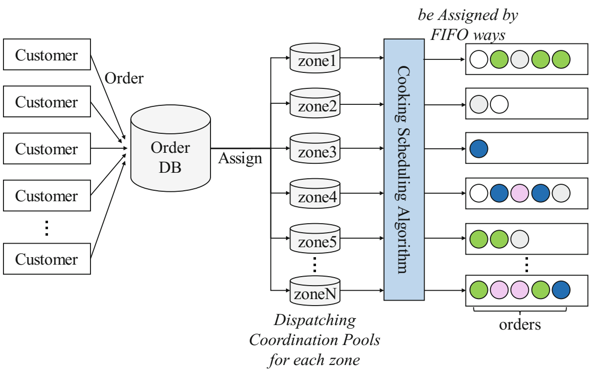


Fig. 2. A dispatching rule and cooking scheduling algorithm.

- Within the same order, it is later than the time when the cooking time of the order preceding the request provision order is finished cooking is subtracted from its own cooking time.

At the start and completion of the cooking of all the dishes, the presence or absence of dish allocation judgment is confirmed for all zones. After moving to a different queue, a dish is cooked in FIFO order when equipment in the zone is not busy, as in the conventional method. The procedure for lot summarization is the same. The cooked dishes are arranged as they are in the conventional method.

Figure 3 shows an example of a cooking schedule. The order from each customer is shown on the right of the figure, the time is shown on the horizontal axis of the Gantt chart, and the order to be cooked is shown on the vertical axis in terms of zones. When an order of A, B, C, D enters from Table 1, first all four orders are stored in the order adjustment pool for each zone. After that, the first order A moves to the different queue.

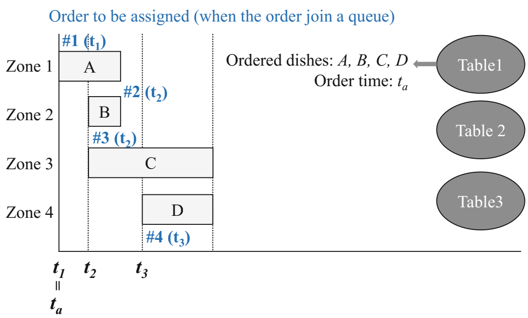


Fig. 3. Gantt chart for cooking scheduling in Proposed method (2).

When cooking of A is started at time t1, then order B, one after the request provision order, moves to the different queue at time t2. When the cooking of B is started at time t2, order C moves to the different queue. This is because this time is later than the time at which the cooking time of order C is subtracted from the cooking end time of order B. Next, order D moves to the different queue at time t3 when the difference between the cooking end time of the previous order C and its own cooking time are equal. In this example, at the time of movement for the four orders, equipment is empty in all zones. Because of this, cooking is started at the same time as it moves to the different queue.

2.2.4 Cooking and Floor Scheduling (Proposed Method 3)

With the cooking scheduling of Proposed method (2) alone, cooking cannot always be completed in the order of the customer's request, necessarily depending on fluctuations in cooking time from the standard cooking time and the setting situation for different tasks. Therefore, in this method, the serving order is adjusted by combining Proposed methods (1) and (2). Order differences for each zone of the kitchen are controlled by the cooking scheduling algorithm in the same way as Proposed method (2). Thus, the cooked commodity is served as it is when satisfying the order of provisions requested at the completion of cooking, as in the case of Proposed method (1); otherwise, it is stored in the storage area. The timing of serving is adjusted by the operation of the floor staff.

3 Conclusions

This study proposed a model constructed by algorithms that dynamically configure scheduling and cooking in restaurants and catering scheduling considering the order and timing of cooking for food service. A future task is to further refine the customer model to include such elements as differences in the ordering frequency and the timing of drinks and meals, verification by computer experiment.

Acknowledgement. This work was partially supported by JSPS KAKENHI Grant-in-Aid for Scientific Research(B) 17H01827.

References

1. Sureshchandar, G.S., Rajendran, C., Anantharaman, R.N.: The relationship between service quality and customer satisfaction - a factor specific approach. J. Serv. Mark. **16**(4), 363–379 (2002)
2. Guerriero, F., Miglionico, G., Olivito, F.: Strategic and operational decisions in restaurant revenue management. Eur. J. Oper. Res. **237**(3), 1119–1132 (2014)
3. Hwang, J.: Restaurant table management to reduce customer waiting times. J. Foodserv. Bus. Res. **11**(4), 334–351 (2008)
4. Hwang, J., Lambert, C.U.: The interaction of major resources and their influence on waiting times in a multistage restaurant. Int. J. Hosp. Manag. **27**(4), 541–551 (2008)

A Literature-Based Analysis of the Cyber-Physical Systems Under the Lens of Reconfigurability

Napoleone Alessia(✉), Macchi Marco, and Pozzetti Alessandro

Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Milan, Italy
Alessia.napoleone@polimi.it

Abstract. Cyber-physical systems (CPSs) are an increasingly known set of technologies and applications promising to enable manufacturing firms improving their responsiveness to deal with the unpredictability of market requirements. Indeed, from an operational perspective, responsiveness can be achieved because CPSs are an enabler of the reconfigurability of factories. Reconfigurability is a capability that has been theorized since almost two decades. Therefore, today we can consider such grounded theory as a lens to frame emerging CPS-related knowledge. This paper is an effort to give a contribution in this direction. In particular, starting from the acknowledgement that a relevant characteristic of reconfigurability is modularity, this research proposes a literature-based analysis of the Cyber-Physical Systems of the future smart factory.

Keywords: Cyber-Physical System (CPS) · Cyber-Physical Production System (CPPS) · Reconfigurability · Modularity · Production levels · Coordination levels

1 Introduction

The current scenario is challenging manufacturing firms, pushing them to be more and more responsive [1, 2]. Indeed, firms need to rearrange quickly their operations in order to pursue ever-changing goals at an affordable cost, producing according to new requirements and technology changes [3, 4]. Nowadays, disruptive technological advances are promising to enable firms in meeting these challenges and gain competitive advantage; amongst the technological advances, Cyber-Physical Systems (CPSs) are recognized as the basic units of the future smart factories [5, 6].

According to [7], CPSs are the merger of cyber (electric/electronic) systems with physical things. Using their words, a CPS "helps mechanical systems to perceive the physical world, process these perceptions as data on computers, make calculations, and inform systems to take actions to change process outcomes".

Within manufacturing firms, reconfigurability is nowadays a more and more valuable and desired characteristic. Indeed, over time, a wide base of knowledge has

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 342–349, 2018.
https://doi.org/10.1007/978-3-319-99704-9_42

been developed on reconfigurability (see [8]). However, the current digital revolution, which leads to the development of CPSs, can strengthen and renew the achievable reconfigurability (according to literature, CPSs enable the reconfigurability of factories [7]). For this reason, this paper investigates on the possibility to interpret the recent CPS-related knowledge under the lens of the grounded reconfigurability theory. Indeed, based on the available literature on reconfigurability, this paper proposes a literature-based analysis of the Cyber-Physical Systems of the future smart factory. To this end, the paper has the following structure. Section 2 adopts a physical perspective. It reviews CPS-related literature by applying the concept of modularity at different production levels of a firm. Section 3 adopts a cyber-perspective. It reviews CPS-related literature by looking at the roles of modules at different coordination levels. Section 4 summarizes the results of Sects. 2 and 3 and drives the main conclusions of the paper.

2 Modularity at Different Production Levels: A Physical Perspective

As stressed in reconfigurability-related literature, the capability to reconfigure should be referred to different production levels. More precisely, [9] identified six levels (these were then applied by [10]). However, in real cases, it is often not easy to identify clearly this high number of levels, also because their boundaries are sometimes faded. Thus, for the purpose of this paper, four instead of six levels are considered, in accordance to [11]. These levels are: workstation (correspondent to the individual production phase), system (e.g. cells, lines or production departments), factory and network.

As modularity is one of the core characteristics of reconfigurability [12], it can be applied at the identified production levels. By changing production levels, modules characterizations and functionalities change. To give an example, for [13] the modules of a reconfigurable system at workstation level are the reconfigurable machines. To them, the number of machine configurations can increase the number of system configurations exponentially. Overall, building on modularity as a characteristic of reconfigurability, the functionality of the system at a higher production level can be changed by modifying its modules at a lower production level.

In order to identify relevant literature for the review, we used Scopus as the primary search database. The search consisted of a topic search with two blocks being "cyber-physical system" and "manufacturing". Among the identified papers, the ones referring to either "modularity" or "module" were critically analysed in order to find either explicit or implicit reference to reconfigurability. The following table (Table 1) sorts CPSs-related references according to the production level at which they applied the modularity concept.

Overall, the analyzed CPSs-related literature focused on modularity at the four aforementioned production levels. To conclude and synthesize this section we can state that, similarly to what already consolidated in reconfigurability literature, modularity of CPSs supports their reconfigurability. Furthermore, within the analyzed literature, some authors were more oriented to characterize systems at a certain production level from a

Table 1. Production levels at which CPSs-related references applied the modularity concept

References	Production level
[14, 15, 16, 17]	Factory
[18, 19, 20, 21]	Factory – System
[22, 6, 23, 24, 25]	System
[26, 27]	System – Workstation

physical point of view; others were more oriented to identify the role of such systems, their functionalities at a certain production level and, therefore, the supported tasks. This last perspective introduces the need to extend the analysis to relationships between modules. This aspect is going to be deepened in the following section.

3 Roles of Modules at Different Coordination Levels: A Cyber-Perspective

A relevant property of CPSs is their ability to communicate and interact with each other [23, 25]. Overall, literature has widely remarked that future factories will be made of modules (CPSs) that, empowered by the knowledge gained through interactions, will be self-responsible and autonomously reacting to changes [21, 28, 29]. Cyber manufacturing systems are interacting and cooperating entities enabled by the Industrial Internet of Things [30].

Nonetheless, there are two other aspects that need to be taken into account, besides the self-responsibility and autonomy. On one hand, the need to achieve systemic goals should be guaranteed; to our concern, the systemic goal is to assure reconfigurability as a capability of a manufacturing firm to be responsive with unpredictable changes of market requirements. On the other hand, the inherent properties of the Cyber-Physical modules lead to a lack of systemic view.

Regarding the need to achieve systemic goals of reconfigurability, according to literature [31, 32], reconfiguring a system means changing its functionality (exploiting its convertibility) or modifying its production capacity (exploiting its scalability). Thus, modules within a system (at a certain production level) may need to be changed according to a systemic goal of reconfigurability, i.e. a goal of convertibility or scalability at a higher production level. In addition, independently from the systemic goal, an effective reconfiguration should rely on diagnosability, which allows quick identification of the sources of quality and reliability problems during reconfigurations [3], thus reducing the ramp-up time of reconfigurations. Diagnosability can be seen as an intermediate goal in order to achieve scalability and convertibility [11].

To reach the above stated goals, CPSs are not assuring a systemic view, if they are taken solely as single modules [33]. Indeed, even if interactions allow CPSs to develop some knowledge about other CPSs within a certain production level, they lack of the systemic view required to make optimal decisions to reach systemic goals [5, 22, 34–38]. This aspect can be better understood by relying on the interpretation of CPSs as modules with their specific roles at different production levels and, consequently, their own functionalities and supported tasks. In other words, CPSs as modules have a "view" which is restricted to the production level they belong to, as it happens with any complex organization of intelligent resources (endowed with different intelligence).

Therefore, we consider appropriate referring to an additional dimension: the coordination level. Indeed, according to: (i) the systemic goals (of scalability, convertibility and diagnosability) and to (ii) the systemic knowledge typically possessed at a higher production level, the Cyber-Physical Modules should be smartly coordinated. To support this statement, we further reviewed papers (obtained through the topic search with "cyber-physical system" and "manufacturing"), by selecting and critically analysing the ones referring to the concept of coordination and its goal. Thus, in the following table (Table 2) we gathered and sorted references that described the coordination of CPSs (at a given production level) made by systems with broader views (at the next higher production level). Thus, in such table, we specified the coordinated levels, jointly with the systemic goals, identified (in the second column of the table) as (i) scalability, (ii) convertibility, (iii) diagnosability or (iv) a systemic optimization.

Table 2. Coordination at different production levels according to CPSs-related references

Coordinated level [References]	Systemic goal
Factory [33] – System [40] – Workstation [42]	Not specified
Factory [39] - System [36, 41]	Diagnosability
System [22, 14]	Scalability
System [34, 5, 35, 23, 37, 38]	Systemic optimization

Through literature, coordination requirements for either systemic optimizations or reconfigurability goals are illustrated in the reminder.

3.1 Coordination Requirements for Systemic Optimizations

To coordinate the factory level, [33] presented a theoretical framework for a first implementation of an Industrial Internet System (IIS) for CPPS. To them, to achieve coordination of the cyber-physical capabilities of a distributed body of CPSs, it is mandatory having a correct structure and organization of the communication functions.

To coordinate the system level, [34] presented a software system that, aiming at coordinating the different CPSs, uses predictive analysis like data mining combined with a decision support system.

According to [35], a CPS is coordinated through the definition of a global goal of the processing chain, localised goals of the chain components, and interoperability architecture.

By proposing a general architecture for smart manufacturing workshop, [23] stressed that the function modules should work in a collaborative mode. Moreover, all the equipment, hardware, and software should be integrated in a common platform. Eventually, information should be exchanged with a MES in order to make optimal decisions.

For [40], the complexity for defining open-knowledge-driven manufacturing execution system (OKD-MES) is in maintaining awareness of overall system state to avoid disruptive actions as various functions may be requested from a system. They illustrated an approach for designing OKD-MES on top of CPSs that controls robot workstations and conveyor-based transportation system. The OKD-MES is then the coordination system, aware of the overall execution of various functions supported by the CPSs.

An Engineering Support System for sustainable optimization of automation tasks supervision was proposed by [38]. This leads the control engineer to obtain a supervision and control solution that allows to optimize the performance of the system according to the desired key performance indicators.

To coordinate the workstation level, [42] proposed a vertical cyber physical integration of cognitive robots in manufacturing. In her solution, the cognitive robots are vertically integrated into the manufacturing industry and coordinated with the manufacturing execution system.

3.2 Coordination Requirements for Reconfigurability Goals

To coordinate the factory level, [39] designed a proactive intention recognition and action recommendation system designed for cyber-physical industrial environments that is able to recommend actions and generate hints for end users without the need of explicit requests. Its contribution is set in a combined changeover, maintenance, and replacement scenario for production factories (which can be considered as supportive to the diagnosability goal). Thus, such system is capable to coordinate the modules of the production system, and it is coordinated with the ERP.

To coordinate the system level, according to [42], the decentralization gained through the exploitation of CPSs can be successful only by ensuring a constant synchronization with a central system.

For [22], the smart factory (composed of CPSs) should adjust product type and production capacity in real-time. Thus, reconfigurable production lines – capable to reconfigure their process paths and recombine manufacturing units dynamically – should be implemented in the smart factory in order to ensure scalability. A holonic architecture that allows the reconfigurability of manufacturing systems was proposed by [14]. It presupposes the presence of a coordinator holon, capable to request the state of the holons and evaluate the best sequence available processes to comply with the transformation of the product holon using the available resource holon. To them, this allows the development of scalable solutions.

According to [41], “CPS is a new research area that aims to seamlessly integrate computers, sensors, and actuators into an application platform so that application software can easily interact with the physical environment”. They developed a middleware, which includes components to help monitor services in a service process, identify the cause of problems when they occur, and perform reconfigurations if necessary (which all support the diagnosability goal). The middleware leads to create some coordination level.

3.3 Concluding Remarks

From a cyber-perspective, the analysis made in this section confirmed that the Cyber-Physical Modules, that have their specific roles (thus functionalities), within a broader system, need to be smartly coordinated. Depending on the production level of reference, their coordination requirements change, and the need for a coordinating system, allowing optimizing systemic goals, while positioned at next higher production level, arises.

Overall, three further observations need to be added: (i) a few authors explicitly referred to scalability goals. Those who referred to scalability did not specifically focus on “how” the coordination should allow achieving this goal; (ii) we could not find authors explicitly referring to convertibility goals; (iii) authors were slightly sensitive to diagnosability goals.

Based on these evidences, we can state that CPSs can be related to reconfigurability as systemic goals, nonetheless further research should be done on the relationship between the coordination requirements of modules at a certain production level and such goals.

4 Conclusions

This paper represents an effort to exploit the soundness of reconfigurability theory as a solid foundation for interpreting the relatively recent knowledge on Cyber-Physical Systems (CPSs). To this end, the concept of modularity, which is a core characteristic of reconfigurability, has been applied to CPSs. Given the twofold nature of such systems (made of physical and cyber components), two variables, i.e. (i) the production level and (ii) the coordination level have been described in order to provide a literature-based definition of the Cyber-Physical Modules of the future smart factory.

On the one hand, the physical part of modules changes according to the production level of reference. On the other hand, also the cyber part changes according to coordination level of references. Depending on the production level, modules have different “views”, thus different needs for coordination. Summarising, moving from lower to higher levels the modules “view” becomes wider, thus influencing and extending their capability to make autonomous decisions. Moreover, having a restricted view introduces the need at higher production levels to coordinate modules at lower production levels.

Further research could aim at associating CPSs to other core characteristics of reconfigurability: integrability, diagnosability, scalability, convertibility and customization. Particularly, as also observed in Sect. 3.3, further research should be made on the relationship between the coordination requirements of modules at a certain production level and the reconfigurability goals.

References

1. Koren, Y., Wang, W., Gu, X.: Value creation through design for scalability of reconfigurable manufacturing systems. Int. J. Prod. Res. **55**(5), 1227–1242 (2017)
2. Shaik, A.M., Rao, V.V.S.K., Rao, C.S.: Development of modular manufacturing systems - a review. Int. J. Adv. Manuf. Technol. **76**(5–8), 789–802 (2015)
3. Koren, Y., Shpitalni, M.: Design of reconfigurable manufacturing systems. J. Manuf. Syst. **29**(4), 130–141 (2010)
4. Mehrabi, M.G., Ulsoy, A.G., Koren, Y.: Reconfigurable manufacturing systems: key to future manufacturing. J. Intell. Manuf. **11**, 403–419 (2000)
5. Brettel, M., Friederichsen, N., Keller, M., Rosenberg, M.: How virtualization, decentralization and network building change the manufacturing landscape: an industry 4.0 perspective. Int. J. Mech. Aerospace, Ind. Mechatron. Manuf. Eng. **8**(1), 37–44 (2014)
6. Penas, O., Plateaux, R., Patalano, S., Hammadi, M.: Multi-scale approach from mechatronic to cyber-physical systems for the design of manufacturing systems. Comput. Ind. **86**, 52–69 (2017)
7. Trappey, A.J.C., Trappey, C.V., Govindarajan, U.H., Sun, J.J., Chuang, A.C.: A review of technology standards and patent portfolios for enabling cyber-physical systems in advanced manufacturing. IEEE Access **4**, 7356–7382 (2016)
8. Koren, Y., et al.: Reconfigurable manufacturing systems. CIRP Ann. Manuf. Technol. **48**(2), 527–540 (1999)
9. Wiendahl, H.P., et al.: Changeable manufacturing - classification, design and operation. CIRP Ann. Manuf. Technol. **56**(2), 783–809 (2007)
10. Andersen, A.-L., Brunoe, Thomas D., Nielsen, K.: Reconfigurable manufacturing on multiple levels: literature review and research directions. In: Umeda, S., Nakano, M., Mizuyama, H., Hibino, H., Kiritsis, D., von Cieminski, G. (eds.) APMS 2015. IAICT, vol. 459, pp. 266–273. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-22756-6_33
11. Napoleone, A., Pozzetti, A., Macchi, M.: A framework to manage reconfigurability in manufacturing. Int. J. Prod. Res. (2018)
12. Koren, Y.: The rapid responsiveness of RMS. Int. J. Prod. Res. **51**(23–24), 6817–6827 (2013)
13. Bi, Z.M., Sherman, Y., Lang, T., Verner, M., Orban, P.: Development of reconfigurable machines. Int. J. Adv. Manuf. Technol. **39**(11–12), 1227–1251 (2008)
14. Contreras, J.D., Garcia, J.I., Pastrana, J.D.: Developing of industry 4.0 applications. Int. J. Online Eng. **13**(10), 30–47 (2017)
15. Liu, Y., Xu, X.: Industry 4.0 and cloud manufacturing: a comparative analysis. J. Manuf. Sci. Eng. **139**(3), 347011–347018 (2016)
16. Wang, K.: Intelligent predictive maintenance (IPdM) system – industry 4. 0 scenario. WIT Trans. Eng. Sci. **113**, 259–268 (2016)
17. Rosenberg, E., Haeusler, M.H., Araullo, R., Gardner, N.: Smart architecture-bots and industry 4.0 principles for architecture. In: Proceedings of 33rd eCAADe Conference, vol. 2, pp. 251–259 (2015)
18. Otto, J., Vogel-Heuser, B., Niggemann, O.: Automatic parameter estimation for reusable software components of modular and reconfigurable cyber-physical production systems in the domain of discrete manufacturing. IEEE Trans. Ind. Inform. **14**(1), 275–282 (2018)
19. Pereira, A.C., Romero, F.: A review of the meanings and the implications of the Industry 4.0 concept. Procedia Manuf. **13**, 1206–1214 (2017)
20. Ito, Y.: Layout design for flexible machining systems in FCIPS and convertibility to CPS module in smart factory. J. Mach. Eng. **4**(17), 5–28 (2017)
21. Monostori, L.: Cyber-physical production systems: roots, expectations and R&D challenges. Procedia CIRP **17**, 9–13 (2014)

22. Chen, B., Wan, J., Shu, L., Li, P., Mukherjee, M., Yin, B.: Smart factory of industry 4.0: key technologies, application case, and challenges. IEEE Access **6**, 6505–6519 (2017)
23. Zheng, M., Ming, X.: Construction of cyber-physical system–integrated smart manufacturing workshops: a case study in automobile industry. Adv. Mech. Eng. **9**(10), 1–17 (2017)
24. Hwang, J.S.: The fourth industrial revolution (industry 4.0): intelligent manufacturing. Engineering **3**(5), 616–630 (2017)
25. Energetics Incorporated: Cyber-physical systems : situation analysis of current trends, technologies, and challenges. National Institute of Standards and Technology, p. 67 (2012)
26. Choi, S.H., Jeong, I.B., Kim, J.H., Lee, J.J.: Context generator and behavior translator in a multilayer architecture for a modular development process of cyber-physical robot systems. IEEE Trans. Ind. Electron. **61**(2), 882–892 (2014)
27. Zhang, Y., Qian, C., Lv, J., Liu, Y.: Agent and cyber-physical system based self-organizing and self-adaptive intelligent shopfloor. IEEE Trans. Ind. Inform. **13**(2), 737–747 (2017)
28. Uhlmann, E., Geisert, C.: Intelligent production systems in the era of industrie 4. 0 – changing mindsets and business models. J. Mach. Eng. **17**(2), 5–24 (2017)
29. Shamim, S., Cang, S., Yu, H., Li, Y.: Examining the feasibilities of industry 4.0 for the hospitality sector with the lens of management practice. Energies **10**(4), 499 (2017)
30. Jeschke, S., Brecher, C., Meisen, T., Özdemir, D., Eschert, T.: Industrial internet of things and cyber manufacturing systems. In: Jeschke, S., Brecher, C., Song, H., Rawat, D.B. (eds.) Industrial Internet of Things. SSWT, pp. 3–19. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-42559-7_1
31. ElMaraghy, H.A.: Flexible and reconfigurable manufacturing systems paradigms. Int. J. Flex. Manuf. Syst. **17**(4), 261–276 (2006)
32. Rösiö, C.: Supporting the design of reconfigurable production systems, 130 (2012)
33. Rojas, R.A., Rauch, E., Vidoni, R., Matt, D.T.: Enabling connectivity of cyber-physical production systems: a conceptual framework. Procedia Manuf. **11**, 822–829 (2017)
34. Trstenjak, M., Cosic, P.: Process planning in industry 4.0 environment. Procedia Manuf. **11**, 1744–1750 (2017)
35. Morgan, J., O'Donnell, G.E.: Multi-sensor process analysis and performance characterisation in CNC turning—a cyber physical system approach. Int. J. Adv. Manuf. Technol. **92**(1–4), 855–868 (2017)
36. MPDV, Industry 4.0: MES supports Decentralization, MPDV Mikrolab GmbH, https://www.mpdv.com/uploads/tx_news/NEWS_International_2015_web.pdf. Accessed 10 July 2018
37. Li, D., Tang, H., Wang, S., Liu, C.: A big data enabled load-balancing control for smart manufacturing of Industry 4.0. Cluster Comput. **20**(2), 1855–1864 (2017)
38. Mazzolini, M., Cavadini, F.A., Montalbano, G., Forni, A.: Structured approach to the design of automation systems through IEC 61499 standard. Procedia Manuf. **11**, 905–913 (2017)
39. Haupert, J., Bergweiler, S., Poller, P., Hauck, C.: IRAR: smart intention recognition and action recommendation for cyber-physical industry environments. In: Proceedings of 2014 International Conference Intelligent Environments IE 2014, pp. 124–131 (2014)
40. Iarovyi, S., Mohammed, W.M., Lobov, A., Ferrer, B.R., Lastra, J.L.M.: Cyber-physical systems for open-knowledge-driven manufacturing execution systems. Proc. IEEE **104**(5), 1142–1154 (2016)
41. Lin, K. J., Panahi, M.: A real-time service-oriented framework to support sustainable cyber-physical systems. In: IEEE International Conference on Industrial Informatics, pp. 15–21 (2010)
42. Valente, A.: Reconfigurable industrial robots - an integrated approach to design the joint and link modules and configure the robot manipulator. Adv. Reconfigurable Mech. Robots II **36**, 779–794 (2016)

The Platform of Intelligent Manufacturing System Based on Industry 4.0

Jinghui Yang(✉), Guorong Huang(✉), and Qi Hang(✉)

Shanghai Polytechnic University, No. 2360 Jinhai Road, Pudong, Province Shanghai, China
jhyang@sspu.edu.cn, phil_huangguorong@163.com, 13072102591@163.com

Abstract. Intelligent manufacturing has become a development trend for manufacture industry. But there only have few labs that can demonstrate more comprehensive concepts of intelligent manufacturing. To fill the blank of this area and promote the development of intelligent manufacturing, we start this project and build up a platform that demonstrate how intelligent manufacturing system is working and upon which we can explore the feasible scheme for companies and teach students about intelligent manufacturing visually. We combine hardware like industrial robots, enterprise management software like MES, ERP and cloud platform to build a sustainable system of intelligent manufacturing. This platform is designed for scientific research, experimental teaching, enterprises training and work out solution for enterprises.

Keywords: Industry 4.0 · Intelligent manufacturing · Smart factory System integration

1 Introduction

Among the major changes emerge in the field of information technology and industry in recent years, intelligent manufacturing, which is a product of the depth of integration of information technology and industrialization [1]. To empower the competitiveness of national manufacturing industry, the research efforts of intelligent manufacturing are carried out throughout the world under governmental projects such as NNMI(National Network for Manufacturing Innovation, USA), Industry 4.0 (Germany), Horizon 2020: Factories of Future (EU), etc., aimed at bringing innovations to manufacturing processes, productivity, and quality [2]. China as a manufacture powerhouse also proposed 'Made in China 2025' as a national strategic plan in 2015.

As a lab of a university, It is designed a website that enable customers to personalized toy house with different styles, materials or colors. The goal of this research is to not only establishing a teaching scene of smart factory or to imitate an existing assemble line, but also to explore reasonable application of cross-layer integration, production lifecycle traceability, preventive maintenance and production line virtualization.

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 350–354, 2018.
https://doi.org/10.1007/978-3-319-99704-9_43

2 Research Objectives

The white book of German Industire 4.0 generalizes three major strategies for cross-layer integration which are vertical integration, horizontal integration and end to end integration. It says that "Industrie 4.0" can serve to create horizontal value networks at a strategic level, provide end-to-end integration across the entire value chain of the business process level, including engineering, and enable vertically integrated and networked design of manufacturing systems [3]. Our project is based on the recommendations of the white book of German Industire 4.0. Vertical integration, horizontal integration and end to end integration are our research objectives.

2.1 Vertical Integration

Vertical integration and networked manufacturing systems describes the intelligent cross-linking and digitalization within the different aggregation and hierarchical levels of a value creation module from manufacturing stations via manufacturing cells, lines and factories, also integrating the associated value chain activities such as marketing and sales or technology development [4]. It can be carried out in two ways: backward integration and forward integration. In the era of global economy and internet, vertical integration becomes even more common to integrate not only whose components but upstream and/or downstream of a industry chain.

2.2 Horizontal Integration

Horizontal integration is to amalgamate firms or departments which have similar or the same functions. It aims to cut intermediate expenditures among departments or companies to reduce the production cost and to carry out mass production. One typical example is that many companies is willing to integrate the storage management system and production management system and quality inspection division and other production related departments to establish resource sharing system for work efficiency promotion and production costs reduction. CPS (cyber Physical System) is mostly used to sustainably support and implement models, designs and implementations of horizontal integration through value networks. Being part of a socio-technical system, CPS are using human-machine interfaces for interacting with the operators [5].

2.3 End to End Integration

The end-to-end engineering across the entire product lifecycle describes the intelligent cross-linking and digitalization throughout all phases of a product life cycle: from the raw material acquisition to manufacturing system, product use, and the product end of life [4]. The goal of achieving end-to-end digital integration throughout the engineering process is to integrate the digital and real worlds across a product's entire value chain and across different companies while incorporating customers' requirements. Modeling plays a key role in managing the increasing complexity of technological systems.

3 Research Contents and Methods

3.1 Personalization Production

Personalization production is one of the highlights of this project and the strongest part for user experience. It is to yield products based on customers' practical requirements. At first, we have succeeded to improve personalization product from selecting a key chain to designing a toy house. Customizing a key chain is to select one style out of several given ones and with human-computer interaction and automatic transport system to deliver the final product to customers. We take a further step to the toy house personalization which customers can design their fond toy house from choosing the materials to coloring their house.

3.2 Vertical Integration in Our Platform

In this research, we actualized vertical integration (see Fig. 1) between equipment layer and business management layer and end to end integration. To produce customized house design and automatic produce scenario, we built connections among hardware devices, which for instance are 4 industrial robots, 2 AGV, 2 production lines and 3D printer, with industrial bus for interconnections and PLC for logic control.

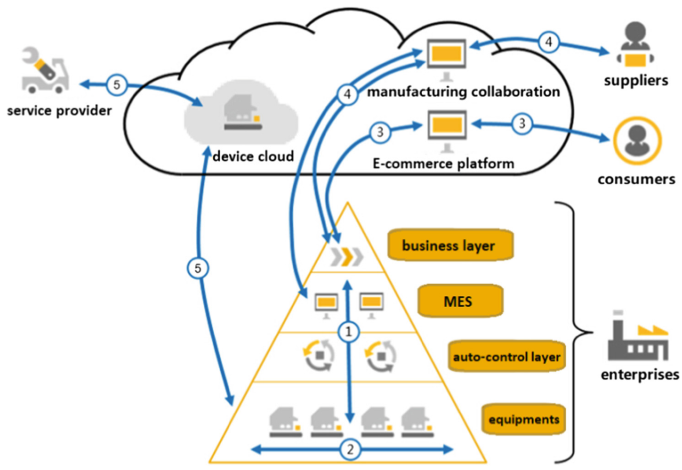


Fig. 1. Vertical integration of our platform

Moreover, cooperating with SAP University Alliances, we set up a complete software system include MES, ERP and SAP HANA. After MES get all the data from ERP system, the industrial automatic system will control all the robots to assemble the product. In this scene, we successfully integrate industrial robots production line with ERP and MES for the customization platform.

3.3 Preventive Maintenance

To strategically work on preventive maintenance, it means to monitor the platform precisely and process data rapidly. To achieve the goal, we preset the vibration sensors, velocity sensors, temperature sensors onto the assemble robots of the production line so that we can get running statuses of these robots while continuous production process. These statuses data will storage at the cloud database servers through IoT (Internet of Thing). In this project, the robots state information of this project will upload to the SAP HANA cloud for classification learning of the failure robots may occur. Moreover, this project will establish a model to analysis the state information of the robots in case that if the evidences of failure occur, we can implement preventive maintenance immediately.

4 Application of the Platform

4.1 Support Multidisciplinary Integration

The mechanism, functions, structures and development of complex products are complicated and concerned with multidisciplinary knowledge and require an approach of collaboration among product development teams and organizations [6]. Currently, innovation talent training is one of the important teaching forms in the universities but lacks the integration of the different disciplines. This paper integrated personalized customization, customer end-to-end integration, vertical integration, product lifecycle traceability, automated production and preventive maintenance of intelligent manufacturing into the platform.

4.2 Provide Solution for Enterprises

Intelligent manufacturing system provides core support to build up intelligent factories. At present, manufacturing industry in China is still at the stage of co-existence mechanization, electrification, automation and informatization which has a long way to intelligent manufacturing. Our work is to help enterprises solve the bottleneck of technological development with the integration of intelligent manufacturing system though three driving links which are intelligent factory, intelligent production and intelligent interconnection.

5 Conclusion and Prospect

5.1 Technical Feasibility

The design of this project is an experimental platform of intelligent production line that demonstrates personalized and customized production. This platform is designed and installed small toy houses. We set up a production line demonstrating typical concepts of industrial 4.0 and intelligent manufacturing in the laboratory. This experimental platform mainly includes six intelligent modules: personalized and customized production; vertical integration from the equipment layer to the business layer; preventive maintenance of equipment; This system embodies the latest smart manufacturing technology and is an interpretation of the concept of smart manufacturing or Industry 4.0.

5.2 Sustainable Development

The current globalization is faced by the challenge to meet the continuously growing worldwide demand for capital and consumer goods by simultaneously ensuring a sustainable evolvement of human existence in its social, environmental and economic dimensions. In order to cope with this challenge, industrial value creation must be geared towards sustainability. The eco-system which builds tunnels among human, equipment and final products with the usage of sensors, industrial software, network communication systems and new forms of human-computer interaction. Eventually, cooperating closely with the enterprises, this project aims to build an ecosystem based on the platform of the lab.

5.3 Resources Sharing Management

This platform is also an innovation of resource integration, it applies the economic characteristics of the Internet platform to the scientific research and teaching platform. Through the integration of this equipment, we integrate robotic equipment, enterprise management software suppliers and universities' research teams to create a solid technology platform. Through joint teaching of schools and training of companies, the participants' knowledge and technology markets are promoted.

This project is supported by discipline construction of mechanical engineering of Shanghai Polytechnic University (XXKZD1603).

References

1. Kagermann, H., Lukas, W., Wahlster, W.: Abschotten ist keine Alternative. In: VDI Nachrichten, no. 16 (2015)
2. Kang, H.S., et al.: Smart manufacturing: past research, present findings, and future directions. Int. J. Precis. Eng. Manuf. Green Technol. **3**, 111–128 (2016)
3. Acatech: Recommendations for implementing the strategic initiative INDUSTRIE 4.0. acatech (2013)
4. Acatech: Umsetzungsstrategie Industrie 4.0 Ergebnisbericht der Plattform Industrie 4.0. acatech (2015)
5. Hirsch-Kreinsen, H., Weyer J.: Wandel von Produktionsarbeit – Industrie 4.0. Soziologisches Arbeitspapier 38, TU Dortmund (2014)
6. Zhang, H.M., Fan, W.H., Wu, C.: Concurrent design approach and its collaborative environment for integrated complex product development. J. Integr. Des. Process Sci. **8**(3), 89–97 (2004)

Achieving Balanced Workload Distribution Amongst Cross-Trained Teams

Oladipupo Olaitan(✉), Erlend Alfnes, Jørn Vatn, and Jan Ola Strandhagen

Norwegian University of Science and Technology (NTNU), Trondheim, Norway
oladipupo.a.olaitan@ntnu.no

Abstract. This research is focused on improving the flow of items through the cross-trained teams of a leather furniture manufacturing company, which manufactures a high mix of products. Presently, a Push control strategy is applied to control production, but this causes uneven build-up of items for processing (i.e. workload) at the cross-trained teams. Hence, this research investigates the application of the CONstant Work In Process (CONWIP) strategy to control Work in Progress (WIP) and at the same time ensure balanced workload distribution amongst the teams. It uses the release signal from downstream to monitor the work rate of individual teams and regulate the release of new items for them to process. Results of simulation experiments conducted on the system show that the application of CONWIP, particularly with consideration of the cross-trained teams in its item release decisions, ensures a balanced distribution of workload amongst the teams. This eradicates the constant need for human intervention to redistribute items between the cross-trained teams, which is a current challenge for the case study company.

Keywords: CONWIP · Cross-trained workforce · Workload control

1 Introduction

The research presented in this paper is part of a project titled SØM 4.0, which is aimed at streamlining and improving the process flow at a furniture manufacturing company. The manufacturing line consists of four upstream lines that produce and supply components for subsequent assembly at a downstream stage. Chair covers are manufactured through the cutting and the sewing sections, before being assembled with foam from another line, to make the upholstery. The upholstery sub-assembly then undergoes assembly with wood and steel components, which also come from two other production lines. Each of the high variety of product models manufactured in the system requires unique components from the upstream component production lines. The cover production line is the main manufacturing stream into which raw materials are released and operations are planned according to specific customer orders. The other manufacturing lines must then supply components to meet the planned arrival dates of the covers for assembly. As a result, this paper focuses on streamlining the flow of items through the cover production line.

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 355–363, 2018.
https://doi.org/10.1007/978-3-319-99704-9_44

The rest of the paper is organised as follows: Sect. 2 provides a background on related literature, followed by an overview of the cover production line. In Sect. 3, the company's existing Push control strategy and the implemented CONWIP control strategy are described. Section 4 will describe the setup of the simulation experiments conducted to compare both strategies. The results of the experiments are analysed and discussed in Sect. 5, followed by conclusions and practical insights for practitioners.

2 Background

Pull production control strategy involves the use of cards, called Kanbans, to control production and regulate system inventory [1]. The Kanbans limit the number of parts in the system, because parts require Kanbans to authorise their processing in the system, and parts that are unable to obtain Kanbans are kept in a queue that serves as a backlog list. There have been strategies developed to suit manufacturing environments that differ from that for which the traditional Kanban control strategy (TKCS) was originally developed. An example is the CONWIP strategy [2], which provides a means of applying pull control in multiproduct environments, and in environments with relatively higher levels of variability, because of its more open assignment of Kanbans amongst products – i.e. its Kanbans can be product-anonymous [3]. Other strategies that have been developed subsequently, such as Generic Kanbans [4] and Extended Kanbans Control Strategy (EKCS) [5], also offer the possibility to have an open assignment of cards when different types of products or components are involved [6].

2.1 Item Release Rules

For a single product system, items in the backlog list are released based on their order of arrival into the queue. However, in multiproduct systems, in which many attributes would differentiate product types from one another, there is usually a need to define rules based on which items are selected for release from the backlog list. As such, the application of pull control strategies in multiproduct environments comes with a new challenge of deciding on the item to select for release into the system upon the availability of a new Kanban. Research works have found that defining rules for the sorting and release of items into a system can be used to improve its performance [7, 8]. For example, a study found that implementing a backlog sequencing rule has significant impact on the performance of CONWIP, specifically the capacity slack-based rules which they implemented [7]. Item release rules operate by selecting for release the item type whose attribute most fits the attribute favoured by the rule. Some of the attributes that are considered are the items' due dates, lengths of processing times, numbers of processing steps, planned release dates or the amount of slack from their due dates etc., and the item that ranks top based on the attribute is released.

Alternatively, there are rules that do not only consider the current items in the backlog list, but also those that are currently in the system [9, 10]. For instance, the rule applied in a study aims to always maintain a balanced mix of item types in the system. Thus, it selects the next item type for release in order to ensure that a desired balance is maintained in the mix of item types [10]. Similarly, the capacity slack-based rule of another study seeks to achieve balance in the system, but of the overall system workload [7]. It considers the current workload situation on the shop floor when taking item release decisions, and selects for release the item that will not violate the workload balance. Such studies set limits on the system workload and quantify every item release in terms of its workload implication on the system.

This study will apply a similar two-layered item release rule in which the planned finished dates are first applied in sorting items in the backlog list, followed by selecting them for release based on the availability of a suitable operator team to process them downstream. Releasing items according to their planned finish dates should ensure that they arrive close to their planned dates for downstream processes, while the consideration of available capacity at the teams ensures that process-based constraints are considered when releasing items.

2.2 Overview of Cover Production Line

The cover production line of the case study system is a typical example of high mix production. The product line consists of 36 different models, most of which are offered in two or three different sizes (small, medium and large). Additionally, each model size is offered in fabric or leather material, which can also come in different variety of colours and material textures. The product differentiation starts right from the first production step in the cutting section, where the model design and materials are configured specifically for a product.

The materials for the covers are cut in Step 1 (S1) followed by them undergoing variety of sewing operations between Steps 2 and 10 (i.e. S2 to S10). S1 is the cutting section, while S2–S10 constitute the sewing section.

The outputs from the sewing section are chair covers that undergo assembly with foam, and subsequent assembly with wood and steel components to derive the finished furniture. This work focuses on the sewing section, which has the most labour intensive and value-adding processes of the whole production. The routing possibilities through these processing steps differ from one product model to another, as shown in Fig. 1. Also, at S8 there are four cross-trained operator teams that are skilled in the processing of specific product models only, and the teams have different levels of proficiency for product models.

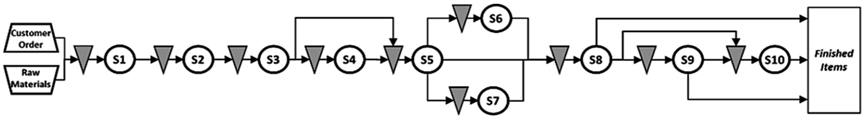


Fig. 1. Process flow chart from cutting to sewing

The company currently applies Push control strategy to release items that arrive from cutting into sewing. However, the direct release of semi-finished items from the cutting section (S1) into the downstream sewing section creates a constant need for human intervention in the automated transport system to redistribute workload between the four teams and ensure smooth flow of items through the system.

3 Production Control in the Cover Production Line

In this section, the logic of the current Push control strategy of the company is described, followed by a description of the logic of the implemented CONWIP control strategy. The two control strategies are subsequently compared using simulation experiments, which are set up based on 4 months of historical data from the case study company.

The approaches to controlling WIP, taking item (trolley) release decisions and assigning trolleys to the cross-trained teams are the main targets for improvement in this work; therefore, the current and the new approaches will be described in the following subsections using similar set of notations as follows:

- $MC_{g[i-j]}$ = the set maximum WIP limit for team g between stages i and j.
- $MC_{[i-j]}$ = the set maximum WIP limit in the system between stages i and j.
- $CC_{gt[i-j]}$ = the current WIP level of team g between stages i and j at time t.
- $CC_{t[i-j]}$ = the current WIP level in the system between stages i and j at time t.
- A_{gt} = the availability of team, g, at time, t, i.e. it checks whether the team has reached its set maximum at that time.

$$A_{gt} = \begin{cases} 1, \text{if } CC_{gt[i-j]} < MC_{g[i-j]}, \\ 0, \text{otherwise.} \end{cases}$$

- S_{gm} = preference level of model, m, for team, g. S_{gm} can have a value of 90, 80 or 0, which respectively identify that team, g, is a primary, secondary or incompatible team for model, m. Those values are mainly to differentiate the levels of proficiency of teams for the different product models. The higher the value of S_{gm} the stronger the preference of a product model for a team.

It should be noted that under both control strategies, the respective teams process the trolleys that have been released to them according to the trolleys' due dates.

3.1 Push Control Strategy

As shown in Fig. 2, there is currently no limit on the system WIP; therefore, the only WIP restriction that applies is that which is used to determine the availability of the primary team for a trolley's model. The current level of $CC_{gt[8-8]}$ with respect to $MC_{g[8-8]}$ at the time of arrival, t, of the trolley determines the team it selects for its processing.

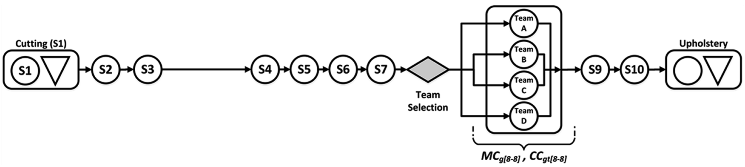


Fig. 2. Process flow with push control

When a trolley arrives at S8 for processing, it is released to the team with the highest value of $\left(A_{gt}\text{x } S_{gm}\right) + S_{gm}$. This expression checks for the availability of the primary team for the model conveyed by the trolley and releases it to the team (i.e. the team with $S_{gm} = 90$), if the team is available. If the primary team is not available, it checks for the availability of an alternative (secondary) team (i.e. from other teams with $S_{gm} > 0$). If no alternative team is available, then the S_{gm} added in the expression implies that the trolley is nevertheless released to its primary team, even if it would violate the team's maximum WIP level restriction. It should be noted that the routing of a trolley between S4 and S7 and between S9 and S10 varies depending on the product model the trolley contains, as previously illustrated in Fig. 1.

3.2 CONWIP Control Strategy

CONWIP control strategy involves setting a maximum limit on the number of units of items that are allowed in a section of the system. It keeps track of the current number of items in this section and ensures it does not exceed a predefined limit.

As shown in Fig. 3, CONWIP has been implemented to control the WIP level between S7 to S8, such that the number of trolleys within this section does not exceed a set maximum WIP limit, $MC_{g[7-8]}$. The first five stages are left out of the CONWIP control loop, because they are relatively short operations. As such, there is relatively low competition for the resources used for these five operations, and it is not necessary to stop the trolleys from undergoing these five operations before determining if they should access the more resource-intensive operations or not. The same justification applies for the omission of the last two stages from the CONWIP loop, which makes the signal for the release of a new trolley into the CONWIP loop to be sent as soon a trolley is completed at S8.

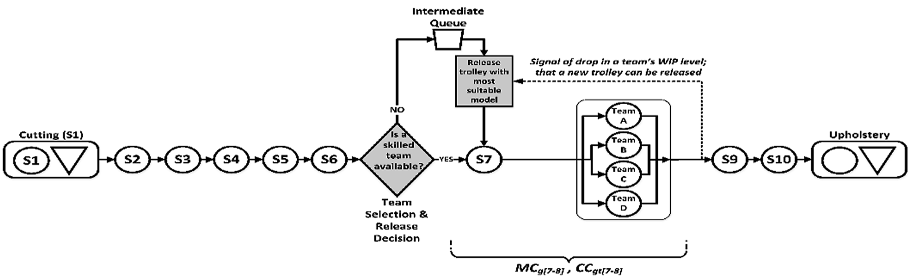


Fig. 3. Process flow and release decision points for trolleys – CONWIP

When a trolley arrives at S7, there are two conditions under which it can be immediately released downstream:

1. If the trolley is urgent, i.e. it arrived one day or less from its planned finish date, it is sent immediately to the next stage of its processing. Because of its urgency, it is also assigned to the team with the lowest $CC_{gt[7-8]}$ and not necessarily its primary team.

2. At least one of the teams skilled to process its contents must be available (i.e. one of the teams with $S_{gm} > 0$ must have $A_{gt} = 1$), and the trolley is released to the team with the $\text{Max}[A_{gt} \text{x} S_{gm}]$ amongst the available teams. This ensures that if the best skilled team is not available, an alternative team is selected to process the trolley.

Both conditions are aimed at improving the delivery precision to the subsequent upholstery stage and ensuring a balanced distribution of workload amongst the teams.

If none of the conditions for the immediate release of a trolley downstream is fulfilled, it is held in an intermediate queue until existing trolleys have been completed and released from S8. Once an existing trolley has been completed and released from S8, and $CC_{gt[i-j]} < MC_{g[7-8]}$, a signal is sent upstream to the intermediate queue to release a new trolley into S7. The decision on the new trolley to release considers the team that completed the last trolley whose release from S8 triggered the signal. It searches from the queue head and releases the first trolley containing a product model with $S_{gm} = 90$, where g is the team that processed the last trolley released from S8. If there is no trolley containing a model with $S_{gm} = 90$ in the queue, the search is repeated for trolleys containing models with lower values of S_{gm}.

Essentially, the release decision is combined with the selection of the team that will process the trolley upon its arrival at S8. Because of the cross-training situation, it is important to ensure to fill the exact capacity that is signalled to have become available downstream by ensuring that the team from which a trolley was completed is that for which a new one is released. The trolley released into the CONWIP loop does not have to contain an exact same model as that which was released from it, but it must contain a model that can be processed by the same team.

4 Simulation Experiments to Compare Strategies

To compare the current strategy's performance with the implemented CONWIP control, simulation experiments were conducted in FlexSim™ Modelling software using historical data from the case study company. The data covered a three-month period, during which 12,208 trolleys of cover pieces were produced. The data, which is available online [11], was used directly in running the simulation model, with a direct replication of the actual release dates and times of trolleys, their required processing steps and times, as well as the company working days, shift durations and the numbers of available operators per workstation/team during the period. The model was run as a terminating simulation, with the terminating condition being the exit of the last of the 12,208 trolleys from the system. The control strategy under operation determined the actual release times of the trolleys into the sewing section (or their CONWIP loops), as explained in Sect. 3. With this, it would be possible to attribute any differences observed in the two strategies' performances to the differences in their logics for releasing trolleys into the system and for assigning trolleys to teams.

4.1 Parameters and Settings of Compared Strategies

In addition to the general system settings, system parameters that are specific to each control strategy were set as shown in Table 1. As shown in Table 1, the maximum WIP limits for the teams were set such that each operator in the team would be working on a trolley and have an additional two that are waiting in the queue.

Table 1. Team WIP limits

Approach	Team A $MC_{A[i-j]}$	Team B $MC_{B[i-j]}$	Team C $MC_{c[i-j]}$	Team D $MC_{D[i-j]}$
Push $i = 8, j = 8$	54	48	42	33
CONWIP $i = 7, j = 8$	72	64	56	44

The aim of having the additional two trolleys is to protect the operators against starvation, and the value of two was derived from the highest ratio between any two stages' throughput rates. Because the teams' WIP limits under CONWIP include trolleys that are still undergoing processing at S7, an additional trolley per operator was added in the teams' WIP limits. The overall CONWIP limit between S7 and S8 thus becomes the total of the team's WIP limits, i.e. 236 trolleys.

5 Discussion of Results and Conclusions

The performance measure of interest is the balanced distribution of workload amongst the cross-trained teams, which is measured based on the numbers of trolleys that are either queued for or undergoing processing at each of the teams. Under the Push and the CONWIP control, the workload is recorded for each of the teams across the entire simulation period. As shown in Fig. 4, CONWIP achieved a more balanced workload distribution between the teams than the existing Push control.

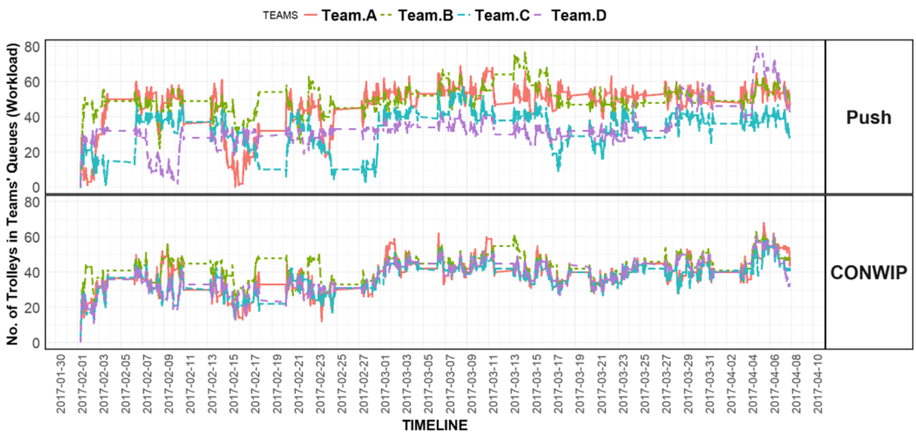


Fig. 4. Teams' workloads as measured by number of trolleys

The instances with large deviations between the plots in the graph are those in which the shift leader would have needed to manual redistribute the workload between the teams. Therefore, CONWIP, in combination with the item release rule implemented, eradicates the constant need for human intervention, as currently experienced under Push.

5.1 Conclusions and Practical Insights

In this work, CONWIP has been applied in a high mix manufacturing system to streamline the flow of the high mix of products through the system. Because of the cross-trained workforce that is involved in the system, an item release rule that synchronises CONWIP's item release with the outputs of specific teams. This rule ensured that the teams receive items to process according to their individual work rates, and the constant need for human intervention to redistribute items between the teams can be eradicated. Results of the simulation experiments show that taking the item release decision with this consideration ensures a balanced distribution of workload amongst the teams.

The increased affordability of technologies for tracking items through manufacturing processes should facilitate the implementation of CONWIP as described in this work. Less sophisticated technologies can also be used; for example, physical cards or electronic display boards can be colour-coded for the teams, such that cards sent upstream for the release of a new item can be attributed to a specific team.

Acknowledgement. This research has been carried out as part of SØM 4.0 project, as funded by the Norwegian Research Council's BIA programme. The authors wish to thank the project partners for facilitating this work.

References

1. Ohno, T.: The origin of Toyota production system and Kanban system. In: Proceedings of the International Conference on Productivity and Quality Improvement, pp. 3–8 (1982)
2. Spearman, M.L., Woodruff, D.L., Hopp, W.J.: CONWIP: a pull alternative to Kanban. Int. J. Prod. Res. **28**, 879–894 (1990)
3. Duenyas, I.: A simple release policy for networks of queues with controllable inputs. Oper. Res. **42**, 1162–1171 (1994)
4. Chang, T.M., Yih, Y.: Generic Kanban systems for dynamic environments. Int. J. Prod. Res. **32**, 889–902 (1994)
5. Dallery, Y., Liberopoulos, G.: Extended Kanban control system: combining Kanban and base stock. IIE Trans. **32**(4), 369–386 (2000)
6. Baynat, B., Buzacott, J.A., Dallery, Y.: Multiproduct Kanban-like control systems. Int. J. Prod. Res. **40**, 4225–4255 (2002)
7. Thürer, M., Fernandes, N.O., Stevenson, M., Qu, T.: On the backlog-sequencing decision for extending the applicability of ConWIP to high-variety contexts: an assessment by simulation. Int. J. Prod. Res. **55**, 4695–4711 (2017)
8. Framinan, J.M., Gonzalez, P.L., Ruiz-Usano, R.: The CONWIP production control system: review and research issues. Prod. Plan. Control Manag. Oper. **14**, 255–265 (2003)

9. Hopp, W.J., Roof, M.: Setting WIP levels with statistical throughput control (STC) in CONWIP production lines. Int. J. Prod. Res. **36**, 867–882 (1998)
10. Ryan, S.M., Fred Choobineh, F.: Total WIP and WIP mix for a CONWIP controlled job shop. IIE Trans. **35**, 405–418 (2003)
11. Olaitan, O.A.: Data from historical production records (dataset). Mendeley Data Repository. https://doi.org/10.17632/ksznggyhpmt.1. Accessed 07 June 2018

Global Supply Chain - Supply Chain Management

Exploring the Role of Information Systems in Mitigating Gate Congestion Using Simulation: Theory and Practice at a Bulk Export Terminal Gate

Mihai Neagoe[1(✉)], Mohammad Sadegh Taskhiri[1], Hong-Oanh Nguyen[2], and Paul Turner[1]

[1] ARC Centre for Forest Value, Discipline of ICT, College of Sciences and Engineering, University of Tasmania, Hobart, Australia
Mihai.Neagoe@utas.edu.au

[2] Australian Maritime College, College of Sciences and Engineering, University of Tasmania, Hobart, Australia

Abstract. Using an Australian wood chip export terminal as a case study, this research presents a terminal gate simulation model that improves understanding of the complex interactions at the terminal gate and describes the potential of information and digital systems alternatives for mitigating congestion. The alternatives modelled include: a terminal appointment system to schedule truck arrivals; integrating weigh-bridge information to eliminate one stage of the unloading process; and, reducing conveyor operation time.

Simulation results indicate that a terminal appointment system can reduce turnaround times by up to 23%, primarily through a reduction in waiting times. Integrating weigh-bridge information can improve turnaround by up to 18%, while reducing the conveyor operation time can improve turnaround by up to 5%. The paper highlights that achieving these simulated results in practice actually relies on a range of factors and assumptions hard to embed in the simulation. These factors influence the nature of the complex interactions at the terminal gate and include the extent to which stakeholders are willing to share information and develop or retain levels of trust between each other.

The paper argues that one potentially effective strategy for aligning stakeholders' interests involves engaging them all in the decision-making processes in finding and developing a suitable congestion management solution. This approach mitigates concerns regarding system abuse, ensures all technological and business requirements of stakeholders are considered and, enhances the implementation process to deliver increased effectiveness of the solution.

This research is part of a major ongoing research project undertaken in Australia funded by the Australian Research Council through the Industrial Transformation Research Program.

Keywords: Information sharing · Discrete event simulation · Land interface Willingness · Trust

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 367–374, 2018.
https://doi.org/10.1007/978-3-319-99704-9_45

1 Introduction

Between 2012 and 2015, exports from Australian wood chip port terminals increased by more than 40% to 10.1 million tons per year [17]. Based on recent port authorities' annual reports, this upward trend has continued in 2016 and 2017. This volume surge has been a major contributing factor to growing port terminal congestion, especially in land-side delivery operations. Wood chip supply chains involve sales of a high-volume, low-margin, price sensitive commodity product. The profitability of the chain can be adversely impacted by port terminal congestion. These impacts affect stakeholders along the entire wood chip supply chain. Surprisingly, there has been limited analysis of alternative approaches to addressing terminal congestion particularly with regard to this type of bulk port terminal.

This research presents a terminal gate simulation model that improves understanding of the complex interactions at the terminal gate and describes the potential for information and digital system alternatives to mitigate congestion. The paper highlights that achieving these simulated results in practice actually relies on a range of factors and assumptions hard to embed in the simulation. These factors influence the nature of the complex interactions at the terminal gate and include the extent to which stakeholders are willing to share information and develop or retain levels of trust between one another.

Information Systems and Terminal Gate Congestion Management. Land-side throughput at port terminal gates is directly impacted by the number, operating hours and productivity of each gate [14]. Approaches to managing gate congestion can be divided into two categories: (i) Gate availability management, (ii) Gate operational management. Gate availability may be increased by *extending the gate working hours* [1, 9] supported by gate automation technologies utilising Radio-frequency Identification (RFID) and Optical Character Recognition (OCR) [14] for land-side transporters and other port users.

Gate operational management may be improved by *terminal appointment systems* (TAS) [7, 12], vessel dependent time windows (VDTW) [4], and *peak hour pricing or incentive programs* [10]. TAS schedule truckers' arrivals at the terminal to deliver and pick-up cargoes at specified time intervals. Analytical approaches such as programming [20], queuing theory [4] and simulation [11] explored the potential impact of TAS and have typically found that significant reductions in truck turnaround and waiting times can be achieved. However, empirical investigations following implementation of TAS have reported mixed results due to a range of factors, including incompatibility between system requirements and business [9], manipulation by opportunistic users [15] and use of congestion management systems as revenue alternatives [7]. Terminal gate congestion management has received significantly more attention in the context of containerized goods. Given the similarities between container and bulk terminal operations [3] we consider insights gained in container terminals to have similar relevance in the context of bulk operations.

This paper argues that aligning stakeholders' interests involves engaging them all in the decision processes around finding and developing a suitable congestion management solution. This approach should mitigate concerns regarding system abuse, capture and align technological and business requirements of stakeholders and enhance the implementation process to positively impact solution effectiveness.

2 Methodology

2.1 Field-Site: Wood Chip Terminal and Land-Side Operations

The bulk wood chip export terminal used for the simulation modelling in this project operates in a medium-size port in Australia. Wood chips are delivered to the terminal from three processing facilities by a dedicated fleet of trucks and are stored at the terminal in preparation for vessel arrivals. Sufficient product has to be available to complete the loading at the time of vessel arrival since the vessel hourly loading rate costs are far greater than those of truck unloading. The truck delivery cycle average, depending on the distance from the facilities, can be 40, 90 or 300 min for a round-trip, excluding terminal unloading.

At the terminal, trucks are weighed before and after unloading on a weighbridge. Operators swipe an RFID card that records arrival and departure time, gross and net truck weight and the product delivered. Trucks can be unloaded by two hydraulic ramps. Product falls into a common collector bin and is moved to stockpiles using by conveyor belt.

On average trucks wait to unload between 7–10 min. However, close to 30% of the trucks wait between 15 and 45 min to unload. In the context of relatively short delivery cycles, excessive waiting times can lead to substantial truck productivity losses. Terminal visits and discussions with staff also confirmed the terminal was regularly experiencing significant truck congestion at the terminal gate and unloading ramps.

2.2 Discrete Event Simulation Model of Terminal Gate Operations

A simulation approach allows for representation of some of the complex interactions taking place at a terminal [11] and insights into operations that may support the development of tangible solutions for industry [8]. Simulation also allows a 'what-if' analysis under certain scenarios and comparison between multiple alternatives [6]. This research deployed a discrete event simulation model to represent terminal gate operations.

The literature on dry bulk terminal distinguishes between export terminals, and import terminals [18] as they and generally serve only one of the two functions. Researchers have primarily focused on ores as the primary dry bulk commodities of interest: coal export [19], coal and iron import [3] and bauxite imports [5]. Munisamy [16] is one of the few examples of a timber terminal related research. One of the main problems explored in the dry bulk terminal literature is how to increase the capacity of dry bulk terminals [5, 19] with the aim of reducing vessel waiting times and associated penalties. Throughput capacity increases on the maritime side are not always met with a similar approach on the land side. Financial penalties for vessel waiting times (demurrage) are one of the most frequently mentioned reasons for optimizing and improving the loading or unloading process at terminals.

Terminal arrival and departure data were collected from reports generated by the weigh-bridge. Three months of truck arrivals were included, totaling more than 15,000 trips. The duration of individual unloading stages was determined using geo-fences implemented in a commercial navigation software which used inputs from on-board GPS data from one trucking operator. The data collected were then fitted to distributions, using the Arena Input Analyzer, so they could be sampled during the simulation using a Monte Carlo sampling technique. The simulation model logic follows closely the process flow at the terminal and is illustrated in Fig. 1 and includes the alternatives modelled to address congestion.

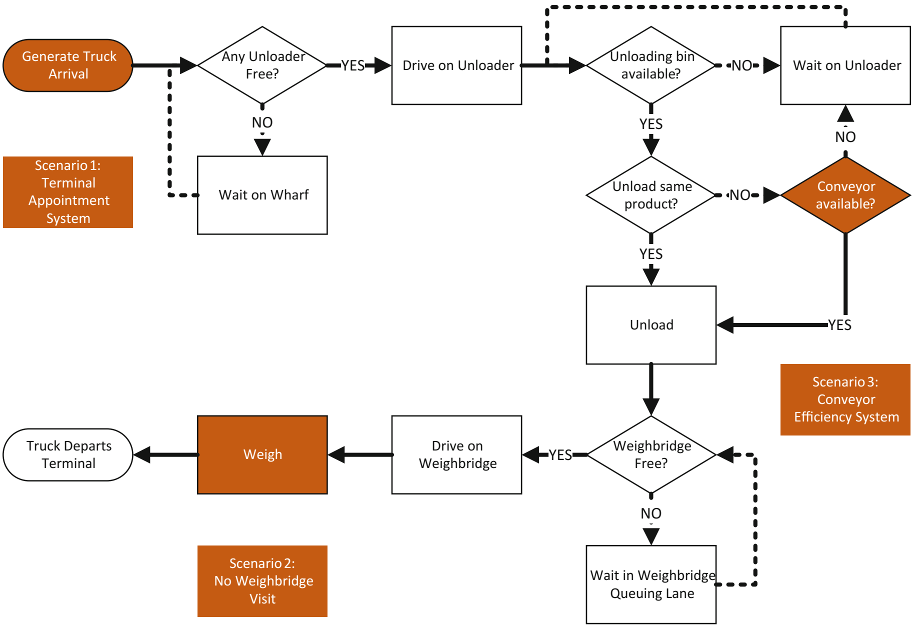


Fig. 1. Simulation model logic

The model is based on a number of assumptions drawn from observations at the terminal and the distribution fitting process:

- Two companies carry two types of products that cannot be mixed. Unloading of one product must be completed prior to unloading the other;
- Each company operates a fleet with two types of trucks in different proportions. The payloads of the two types of trucks are represented through normal distributions fitted on empirical data: $\mu_1 = 25.8$, $\sigma_1 = 0.798$ and $\mu_2 = 33.7$, $\sigma_2 = 1.82$;
- Both unloading ramps can unload both types of truck. Unloading times vary depending on the payload of the truck and are described by a lognormal distribution ($\mu = 5.16$, $\sigma = 3.97$);
- Concurrent unloading of the same product can take place if the other unloading ramp has completed 60% of the unloading stage;

- The conveyor belt system allows a new product to be unloaded when one unloading ramp has reached 80% of the unloading stage;
- The possibility of breakdowns is not considered at this time;
- The weigh-bridge weighing in time was not included to maintain consistency with existing terminal measurements;
- The travel time between the weigh-bridge and unloading ramp and back across the weigh-bridge is considered to be fixed at 1 and 2 min respectively.

The inter-arrival time (IAT) is best represented by a gamma distribution ($k = 1.49$, $\theta = 6.97$) and, the weigh-bridge weighing time on departure is described by a normal distribution ($\mu = 3.46$, $\sigma = 1.68$).

3 Simulation Results

The simulation generated a base scenario and baseline terminal performance figures using the distributions fitted from empirical data which closely replicate the situation currently observed at the terminal. Three scenarios were then introduced, each representing an instantiation of a congestion management system:

- Scenario 1: implementation of a terminal appointment system (TAS) and slot truck arrivals in 10-min intervals. Operators have some flexibility in arrivals. The deviation from the on-time arrival is described by a normal distribution ($\mu = 0$, $\sigma = 2.5$);
- Scenario 2: integration weigh-bridge information system and centrally storing truck tare weights and eliminate the need for trucks to empty-weigh;
- Scenario 3: reduction of conveyor operation time by 45 s through an improved software solution;

Table 1 provides a summary of the baseline and test scenarios. In each case, 1 year of operations was simulated with 1000 iterations per scenario. The indicators represent average results across the iterations. Except for Scenario 1, (where the inter-arrival time is changed to reflect the TAS, arrival distributions stay constant.

The most noticeable effect on the waiting and turnaround time was following the introduction of the TAS in Scenario 1. Average waiting times per truck decreased by 5.3 min (76%) compared to the base scenario and turnaround times by 5.2 min (23%). A similar reduction in average truck turnaround times took place in Scenario 2 (18%), however, since the arrival times followed a similar distribution, the total waiting decreased marginally (6%). Scenario 3 simulates the reduction by 45 s of the bin unloading, therefore, improvements are noticed in the cases where successive trucks carrying different products may arrive in short intervals. Average waiting times are 1.2 min lower (17%) than those in the base scenario, a difference also reflected in the turnaround times with a similar absolute amount. The gain in turnaround time is a relatively modest 5%.

The simulation results show significant improvements compared to the base scenario. However, the model rests on two important assumptions. Firstly, the feasibility of the technical implementation coupled with the willingness of stakeholders to

Table 1. Simulation scenario analysis results

Indicators (Averages)	*Base scenario*	*Scenario 1 Terminal appointment system*
Throughput (t)	1,566,894	1,563,346
Truck Visits	52,683	52,559
IAT (min)	9.98	10
Waiting/Truck (min)	6.9 (m = 0, M = 180)	1.6 (m = 0, M = 137)
Turnaround/Truck (min)	22.2 (m = 7, M = 192)	17.0 (m = 7, M = 158)
Indicators (Averages)	*Scenario 2 Weigh-bridge data integration*	*Scenario 3 Conveyor efficiency system*
Throughput (t)	1,566,388	1,566,527
Truck Visits	52,653	52,666
IAT (min)	9.98	9.98
Waiting/Truck (min)	6.4 (m = 0, M = 143)	5.7 (m = 0, M = 133)
Turnaround/Truck (min)	18.1 (m = 6, M = 158)	21.1 (m = 7, M = 143)

*m = minimum value, **M = maximum value

participate; secondly, that other factors outside the simulation stay unchanged. The next section discusses some implications of these assumptions.

4 Discussion: Theory Versus Practice

Reported partial failures of implemented congestion management systems at port terminals are attributed to: limited trust between parties leading to low use [9] and system misuse [15] or abuse [7] by certain stakeholders. The unique relation between the terminal's land-side users and the terminal [13] combined with the short-term focus and drive for efficiency in the logistics industry to steer inter-organizational relationships away from trust, stability and strategic alignment [2].

With the exception of purely technical equipment improvements, successful implementations of the majority of other approaches actually rely on some information sharing between stakeholders. TAS, in particular, embeds a platform that relies on information sharing and cooperation between stakeholders for success. The behavioral changes from terminal's users are often marginalized in techno-centric implementations of TAS accentuating the gap between theory and practice. These factors influence the nature of the complex interactions at the terminal gate and highlight the need for effective strategies to aligning stakeholders' interests when addressing congestion. This should include engaging them all in the decision processes directed towards finding and developing suitable solutions. The aim of this approach is to mitigate concerns regarding system abuse, ensure that technological and business requirements of stakeholders are captured and facilitate the implementation process to enhance the effectiveness of the solution.

In the context of this argument, it is important to acknowledge some of the limitations regarding the simulation model presented above. The input distributions were based on approximately three months of truck visits representing a sample that may not describe the full range of interactions between the trucks and the terminal. The scope of the model was also limited to the terminal gate and the unloading equipment. Although the maritime side may operate independently of the land-side, discussions with stakeholders have already suggested that vessel arrivals are, in part, responsible for some of the arrival time fluctuations.

Future research aims to include additional scenarios in the simulation, including potential equipment and infrastructure expansion and testing the robustness of the model under changing environmental variables. Discussions with stakeholders continue as part of this research and are currently exploring perceptions of the scale of the congestion problem, the ways it may be addressed and aspects pertaining to sharing information with the terminal and with other port users. This research is part of a major ongoing research project undertaken in Australia funded by the Australian Research Council through the Industrial Transformation Research Program.

5 Conclusion

The land-side interface of a maritime terminal is often considered less important than the maritime side. We argue, however, that both sides are equally important. Analytically, terminal gate congestion management solutions display great potential in mitigating gate congestion. A large proportion of the literature centres on the efficiency benefits terminals can achieve and often fails to acknowledge the impact on the stakeholders affected by these systems. In practice, stakeholders seem to be rarely involved in finding and developing suitable congestion management solutions. Their business and supply chain requirements may be overlooked, which can, in some cases, lead to the lower-than-expected impact of congestion mitigation systems.

Simulation results corroborate literature findings regarding the expected impact of congestion management approaches. The TAS, as well as the weigh-bridge data integration, can reduce turnaround times by as much as 5 min or 23%, much of it from reducing waiting times. Reducing the conveyor operation time can improve turnaround by approximately 5%. The underlying challenge of achieving similar results to those achieved in simulation approaches rests upon, among other factors, the willingness of stakeholders to share information and to develop trust, stability and strategic alignment.

References

1. Bentolila, D.J., et al.: Off-peak truck deliveries at container terminals: the “Good Night” program in Israel. Marit. Bus. Rev. **1**(1), 2–20 (2016)
2. Braziotis, C., Tannock, J.: Building the extended enterprise: key collaboration factors. Int. J. Logist. Manag. **22**(3), 349–372 (2011)
3. Bugaric, U.S., et al.: Optimal utilization of the terminal for bulk cargo unloading. Simul. Trans. Soc. Model. Simul. Int. **88**(12), 1508–1521 (2015)
4. Chen, G., et al.: Managing truck arrivals with time windows to alleviate gate congestion at container terminals. Int. J. Prod. Econ. **141**(1), 179–188 (2013)

5. Cimpeanu, R., et al.: A simulation model for the management and expansion of extended port terminal operations. Transp. Res. Part E Logist. Transp. Rev. **98**, 105–131 (2017)
6. Crainic, T.G., et al.: Simulation of intermodal freight transportation systems: a taxonomy. Eur. J. Oper. Res. **270**, 401–418 (2017)
7. Davies, P.: Container terminal reservation systems design and performance. In: METRANS International Urban Freight Conference, Long Beach, CA, pp. 1–24 (2013)
8. Dragović, B., et al.: Simulation modelling in ports and container terminals: literature overview and analysis by research field, application area and tool. Flex. Serv. Manuf. J. **29** (1), 4–34 (2017)
9. Giuliano, G., O'Brien, T.: Reducing port-related truck emissions: the terminal gate appointment system at the Ports of Los Angeles and Long Beach. Transp. Res. Part D Transp. Environ. **12**(7), 460–473 (2007)
10. Holguín-Veras, J., et al.: Overall impacts of off-hour delivery programs in New York city metropolitan area. Transp. Res. Rec. J. Transp. Res. Board. **2238**, 68–76 (2011)
11. Huynh, N.: Reducing truck turn times at marine terminals with appointment scheduling. Transp. Res. Rec. J. Transp. Res. Board. **2100**, 47–57 (2009)
12. Huynh, N., et al.: Truck appointment systems. Transp. Res. Rec. J. Transp. Res. Board. **2548**, 1–9 (2016)
13. Jaffee, D.: Kink in the intermodal supply chain: interorganizational relations in the port economy. Transp. Plan. Technol. **39**(7), 730–746 (2016)
14. Maguire, A., et al.: Relieving congestion at intermodal marine container terminals: review of tactical/operational strategies. In: Proceedings of 51st Annual Transportation Research Forum, vol. 1, pp. 631–645 (2010)
15. Morais, P., Lord, E.: Terminal appointment system study. Transp. Res. Board. **1**(March), 123 (2006)
16. Munisamy, S.: Timber terminal capacity planning through queuing theory. Marit. Econ. Logist. **12**(2), 147–161 (2010)
17. Ports Australia: Trade statistics for 2014/2015
18. van Vianen, T., et al.: Simulation-based determination of the required stockyard size for dry bulk terminals. Simul. Model. Pract. Theory **42**, 119–128 (2014)
19. Wadhwa, B.L.C.: Optimizing deployment of shiploaders at bulk export terminal. J. Waterw. Port Coast. Ocean Eng. **126**, 297–304 (2000)
20. Zehendner, E., Feillet, D.: Benefits of a truck appointment system on the service quality of inland transport modes at a multimodal container terminal. Eur. J. Oper. Res. **235**(2), 461–469 (2014)

Influence of Setup Cycles on the Throughput Time of Rush Orders

Friederike Engehausen(✉) and Hermann Lödding

Hamburg University of Technology, Hamburg, Germany
{friederike.engehausen, loedding}@tuhh.de

Abstract. Many companies use rush orders in production to meet the heterogeneous delivery times customers demand. Rush orders receive high priority in production and thereby achieve short throughput times. In the context of sequence-dependent setup times, the throughput time of rush orders can be much higher as they have to wait on their respective setup family. This paper presents two different strategies for accelerating rush orders at workstations with sequence-dependent setup times and shows their influence on the throughput time.

Keywords: Sequence-dependent setup times · Rush orders
Production planning and control · Job shop production

1 Introduction

Companies react to customers demanding delivery times that are lower than standard throughput times by prioritizing rush orders in sequencing [1]. Nevertheless, the acceleration of rush orders leads to a delay of standard orders [2, 3]. Trzyna therefore recommends a maximum of 30% rush orders in a job shop production [1].

In case of a maximum acceleration, the waiting time of rush orders is only determined by the remaining operation time of the preceding order and – if another rush order is in queue – this previous rush order's operation time [1]. Trzyna's model works well if setup times are independent from the sequence in which orders are processed. Nevertheless, setup times often depend on which order has been processed before [4]. In this case, it is common practice to bundle orders in setup families and to define a repetitive pattern for their cyclic production. A changeover between orders within a family requires only minor setup efforts, while the changeover between orders of different setup families causes major setup efforts [5]. As an example, the setup times in the production of abrasive papers have strong sequence-dependencies as a changeover from coarse- to fine-grained paper requires extensive cleaning of up to several hours whereas the changeover from fine- to coarse-grained paper can be undertaken within a few minutes.

Companies then have to decide whether a rush order shall be processed immediately or whether it has to wait until its respective setup family is processed within the setup cycle. A short throughput time of rush orders and a high productivity at the

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 375–383, 2018.
https://doi.org/10.1007/978-3-319-99704-9_46

workstation by saving as many major setup efforts as possible are therefore conflicting targets when rush orders are integrated in a setup cycle.

This paper is structured in four sections. After this introduction, we present the current state of research, on which the model presented in section three is based. The last section gives a brief summary of the paper and an outlook on planned research.

2 Current State of Research

2.1 Modeling Throughput Time

The throughput time is one of the internal logistic objectives and can be analyzed on two different levels: the order throughput time and the operation throughput time. The time between an order's release to the production and its completion is referred to as the order throughput time. It summarizes the throughput times of all operations and has often a large share in the delivery time, which is one of the external logistic objectives perceived by the customers [5].

The operation throughput time is defined as the time between the end of the previous operation's processing and the end of the operation's processing. Wiendahl introduces the throughput element to describe an order's throughput at a workstation (Fig. 1). The inter-operation time comprises the post-process waiting time, the transport time and the pre-process waiting time. The setup and processing times are summarized as the operation time. Accordingly, the throughput time can also be calculated as the sum of inter-operation and operation time [6].

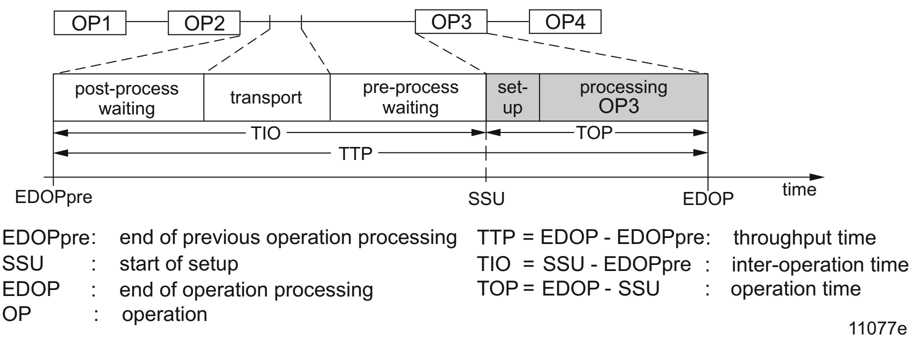


Fig. 1. Operation related throughput element [6]

The operation time of an order is indicated in shop calendar days which is the quotient of the work content and the maximum possible output rate of the workstation. This is necessary to define how much of the workstation's capacity is occupied by the order [7]:

$$\mathrm{TOP} = \frac{\mathrm{WC}}{\mathrm{ROUT}_{max}} \tag{1}$$

with

$$\mathrm{WC} = \frac{\mathrm{LS} \cdot t_p + t_{su}}{60} = \frac{\mathrm{TP} + t_{su}}{60} \tag{2}$$

where TOP is the operation time (SCD), WC the work content (h), ROUT_{max} the maximum possible output rate (h/SCD), LS the lot size (units), t_p the processing time (min/unit), t_{su} the setup time (min) and TP the lot processing time (min).

2.2 Modeling the Throughput Time of Rush Orders

Assuming that rush orders are processed with the highest priority, Trzyna develops a model for rush order throughput times. In his model the inter-operation time only consists of the pre-process waiting time as rush orders are transported preferentially and transportation times can therefore be neglected. In this case, the inter-operation time equals the mean remaining operation time of the previously processed order. Thus, the mean throughput time of rush orders is the sum of the mean remaining operation time of the preceding order and the rush order's operation time [1]:

$$\mathrm{TTP}_{m,rush} = \mathrm{TOP}_{m,rush} + \mathrm{TOP}_{m,rem,prec} \tag{3}$$

where $\mathrm{TTP}_{m,rush}$ is the mean throughput time of rush orders (SCD), $\mathrm{TOP}_{m,rush}$ the mean operation time of rush orders (SCD) and $\mathrm{TOP}_{m,rem,prec}$ the mean remaining operation time of the preceding order (SCD).

However, Eq. 3 is only valid if no other rush order is in the waiting queue of the workstation at the moment of arrival.

3 Modeling the Throughput Time of Rush Orders Due to Setup Cycles

3.1 Accelerating Rush Orders in Setup Cycles

A simple and often applied sequencing rule with sequence-dependent setup times in job shop production is class exhaustion [8]. Class exhaustion means that orders of a setup family (or setup class) are produced until no further order of this family is left in the queue. The decision, which family is processed next, can be fixed by a repetitive pattern similar to the levelling of assembly lines (e.g. setup family A – setup family B – setup family C). The aim of this strategy is to save as many major setup efforts as possible. Both output rate and sequence deviations reached by this sequencing rule can be determined [9, 10].

If a rush order arrives at a workstation with sequence-dependent setups, two general strategies may be distinguished. Strategy 1 is the *maximum acceleration* of the order. Independent from whether the workstation is currently setup for the rush order's family or not, this order is the next to be processed even though there are still orders of the currently processed family in queue. Afterwards, the setup cycle will be continued according to the fixed pattern. Strategy 2 is to *wait on the setup family* and only to accelerate rush orders within their families. Both strategies have different influences on throughput times, which will be explained in the following section. For an initial assessment, we focus on the maximum and minimum possible throughput time of rush orders caused by these strategies.

3.2 Modeling the Influence of Setup Cycles on the Throughput Time of Rush Orders

Setup cycles influence the throughput time of rush orders. Figure 2 shows the most important parameters. The following models are based on the assumption that both the mean setup cycle time and the mean operation time of setup families is known. Please see our preliminary studies for a deeper focus on their calculation [9]. Furthermore, we assume a negligible low probability of concurrency between rush orders as their percentage is below 30% [1].

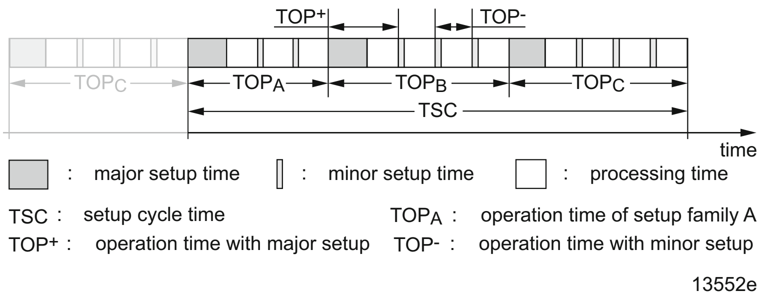


Fig. 2. Main parameters of building setup cycles

Independent from the sequencing rule, the minimum throughput time is determined by the operation time with minor setup effort when the workstation is already setup for the rush order's setup family and the preceding order has just been finished processing meaning the waiting time equals zero:

$$TTP_{min,rush} = TOP^{-} \tag{4}$$

where $TTP_{min,rush}$ is the minimum throughput time of rush orders (SCD) and TOP^{-} the operation time with minor setup (SCD).

The maximum possible throughput time differs for both strategies, as they influence the waiting time. If a rush order is maximally accelerated, the worst case scenario would be that the rush order will wait during the whole processing of the first order of a setup family requiring a major setup. If the preceding order has been of a different setup family, another major setup is required for the rush order. So for the strategy of a *maximum acceleration*, the maximum throughput time would equal twice the operation time with major setups:

$$TTP_{max,rush,ma} = 2 \cdot TOP^{+} \quad (5)$$

where $TTP_{max,rush,ma}$ is the maximum throughput time of rush orders when maximally accelerated (SCD) and TOP^{+} the operation time with major setup (SCD).

Simulation runs have shown that 98–99% of all rush orders had a lower throughput time than the prognosed possible maximum. Higher throughput times result if the unlikely event of two rush orders present in the waiting queue happens and these orders therefore concur for the resources.

When the rush order has to wait on its setup family, the worst case would be that it arrives when the workstation has just started processing the setup family following right after the rush order's family. Thus, the rush order has to wait until its own family is processed, which equals the length of a setup cycle time less the operation time of the rush order's family. As the rush order is prioritized within its setup family, it will be the first to be processed and therefore requires a major setup. The maximum throughput time of a rush order *waiting on the setup family* is:

$$TTP_{max,rush,ws} = TSC - TOP_i + TOP^{+} \quad (6)$$

where $TTP_{max,rush,ws}$ is the maximum throughput time of rush orders when waiting on their setup family (SCD), TOP_i the operation time of the rush order's setup family i (SCD) and TOP^{+} the operation time with major setup (SCD).

Simulation runs have shown that 95-100% of rush orders had a throughput time lower than the prognosed maximum. Obviously, the standard deviation of the throughput time is much higher when the rush order has to wait on its setup family compared to its maximum acceleration. Nevertheless, both strategies have advantages and disadvantages in terms of their influence on logistic objectives, which will be discussed in the following section.

3.3 Influence of Rush Order Acceleration in a Setup Cycle on Logistic Objectives

Maximum Acceleration. Figure 3(a) shows the results of a simulated workstation with sequence-dependent setup times and a maximum acceleration of rush orders. The box plots depict both rush and standard order throughput times for two different rush order percentages. When rush orders are maximally accelerated, the advantage is that their throughput time can be extremely lowered compared to standard orders. Nevertheless, the standard orders' throughput times are extremely scattering with a maximum of 48 or 190 SCD respectively. The 95th percentiles are also very high compared to the 75th percentile (15 and 29 SCD) and thereby support the findings.

With a high rush order percentage of 30%, the setup cycle is more often interrupted than with 5%, which means that a lower number of jobs is bundled. This leads to two different effects on the logistic objectives of the workstation: The first effect is that both

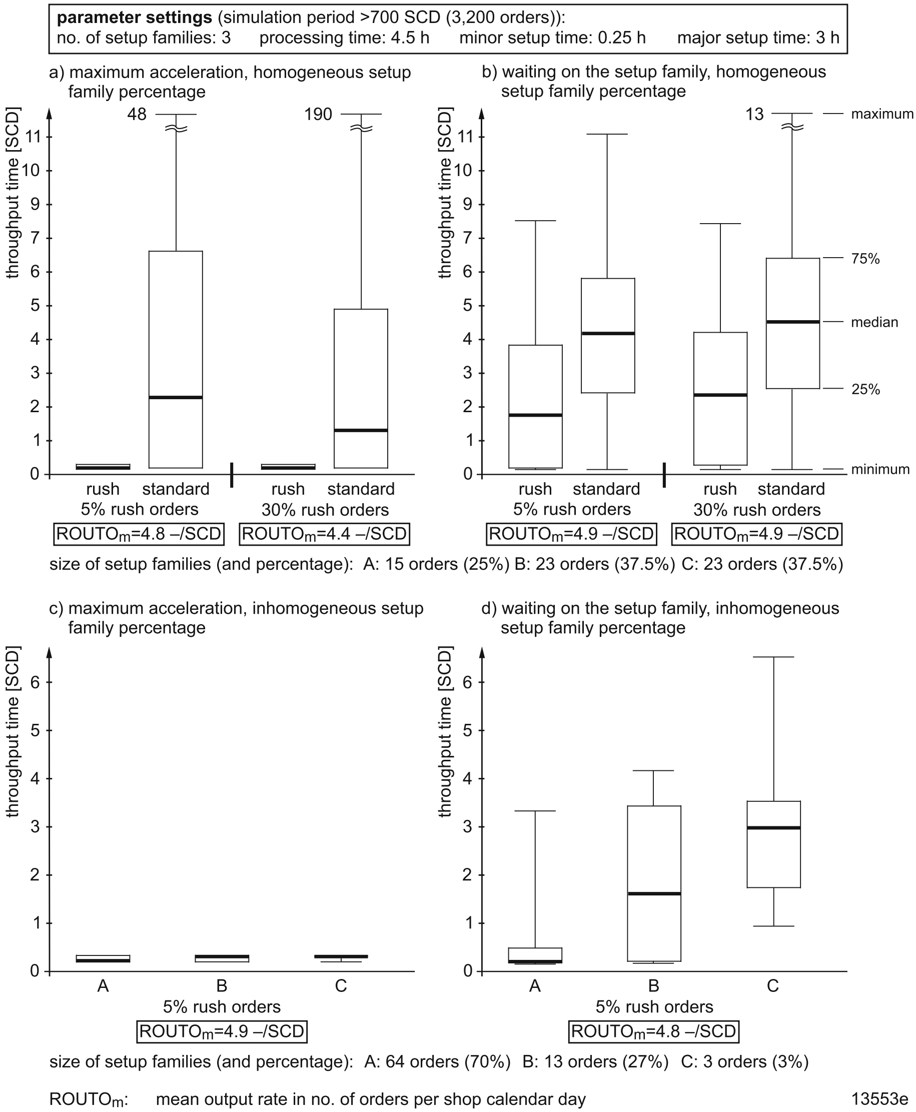


Fig. 3. Box plots of throughput time due to rush order acceleration in setup cycles

the median and the third quartile of the standard orders' throughput time is lower than with 5% rush orders since standard orders do not have to wait that long on their setup family. However, as the setup cycle is not fixed by a repetitive pattern but by the arrival of rush orders, the range of the upper 25% of throughput times is very wide. The second effect of a lower amount of bundled jobs is that less setup efforts are saved and thus, the output rate is reduced. In the simulation experiment a maximum acceleration with 30% rush orders leads to a loss of 8% output rate compared to the simulation with

5% rush orders. If this is not considered in capacity planning, this strategy would lead to a systematic backlog at the respective workstation.

Additional simulation experiments have been conducted to evaluate the influence of different setup family sizes on the throughput time of rush orders. Figure 3(c) shows the results for the strategy of a maximum acceleration. Although the three setup families can be differentiated in high (family A and B) and low volume (family C) families, their percentages do not influence the throughput time of rush orders. A rush order of setup family C can be accelerated to the same extent as a rush order of family A.

Waiting on the Setup Family. Figure 3(b) displays the simulation results of a workstation with sequence-dependent setup times and rush orders that are only accelerated within their families. Again, the box plots depict both the throughput times of rush and standard orders for two different rush order percentages. The main disadvantage of this acceleration strategy becomes apparent at first glance: rush orders are still accelerated but their throughput time scatters almost to the same extent as the standard order throughput time. Again, the 95^{th} percentile equals similar high values as the maximum throughput times (8 and 9 SCD). Nevertheless, the advantage of this strategy is that neither a systematic backlog is induced nor are the throughput times of standard orders that severely affected. As the rush order percentage has only little influence on the distribution of throughput times, another advantage of the strategy is its universal applicability.

Figure 3(d) shows the influence of this strategy on the throughput time of rush orders if setup family percentages are very inhomogeneous. A high setup family percentage leads to high setup family sizes and thus to high operation times. According to Eq. 6, the higher the operation time of a setup family is, the lower is the potential maximum throughput time of rush orders. Rush orders of setup family A receive the highest acceleration as the probability is very high that this family is currently processed when the rush order arrives. In contrast, rush orders of the low volume variant C have to wait for a long time until family C is processed. This causes a high median of throughput times and also high deviations from the mean.

Recommendations. The strategy of a maximum acceleration leads to very low throughput times of rush orders but highly scattering throughput times of standard orders. Furthermore, rush orders make a logistic positioning between a high output rate and a low sequence deviation almost impossible as they generate high turbulences in sequencing. An application of this strategy is only reasonable if the rush order percentage is low, if the acceleration of rush orders is a crucial logistic target and if there is enough capacity available to make up for additional setup efforts.

The strategy to wait on the setup family has the advantage of accelerating rush orders without affecting the throughput of standard orders. Furthermore, the productivity is not affected by rush orders which limits this strategy's applicability not to a low rush order percentage. If percentages of setup families are highly diverging, this strategy causes high mean and highly scattering throughput times for rush orders belonging to low volume families.

To sum up, if a workstation has sequence-dependent setup times companies should thoroughly weigh the rush order prioritization up against increasing productivity by setup-optimized sequencing.

4 Summary and Outlook

This paper explains the influence of setup cycles on the throughput time of rush orders. Two different strategies to accelerate rush orders within setup cycles have been investigated. The first strategy is to immediately change to a rush order's setup family after finishing the currently processed order. This strategy enables the highest acceleration while resulting in high setup efforts and scattering throughput times of standard orders. The second strategy is to wait on the rush order's setup family according to the regular setup cycle and to only accelerate orders within their family. The advantage of this strategy is that neither setup efforts nor throughput times of standard orders are crucially affected.

Companies should be aware of the target conflict between setup efforts and rush order throughput time when deciding how to accelerate rush orders with sequence-dependent setup times. Individual decisions depending on the importance of the respective rush order or a hybrid strategy with a minimum amount of bundled jobs in setup families before changing to the rush order's family are also possible but not yet investigated.

Future research will focus on the probability of the minimum and maximum throughput times modelled in this paper to enable companies to calculate reliable throughput times. Furthermore, for the strategy of an immediate changeover the probability of an interruption of the setup cycle depending on the rush order percentage shall be investigated to assess additional setup efforts. In the end, it is planned to propose a suitable acceleration strategy for rush orders depending on their percentage and setup times.

The authors would like to thank Deutsche Forschungsgemeinschaft (DFG) for funding the project "Development and implementation of a production planning and control for rush orders in the industrial application" (LO 858/16-1).

References

1. Trzyna, D.: Modellierung und Steuerung von Eilaufträgen in der Produktion. Dissertation Technische Universität Hamburg-Harburg (2015)
2. Trzyna, D., Lödding, H.: Modeling the probability of rush order concurrence. In: Proceedings of the 18th International Working Seminar on Production Economics, Innsbruck, 24–28 February, vol. 1, pp. 467–478 (2014)
3. Plossl, G.W.: Manufacturing Control – The Last Frontier for Profits. Reston Publishing, Reston (1973)
4. Conway, R.W., Maxwell, W.L., Miller, L.W.: Theory of Scheduling. Addison-Wesley, Reading (1967)
5. Lödding, H.: Handbook of Manufacturing Control. Springer, Heidelberg (2013). https://doi.org/10.1007/978-3-642-24458-2

6. Wiendahl, H.-P.: Fertigungsregelung. Logistische Beherrschung von Fertigungsabläufen auf Basis des Trichtermodells. Carl Hanser Verlag, Munich/Vienna (1997)
7. Nyhuis, P., Wiendahl, H.-P.: Fundamentals of Production Logistics. Theory, Tools and Applications. Springer, Berlin (2009). https://doi.org/10.1007/978-3-540-34211-3
8. Russell, G.R., Philipoom, P.R.: Sequencing rules and due date setting procedures in flow line cells with family setups. J. Oper. Manag. **10**(4), 524–545 (1991)
9. Engehausen, F., Lödding, H.: Produktionskennlinien für Arbeitssysteme mit Rüstzyklen. Wt Werkstattstechnik online **107**(4), 282–287 (2017)
10. Engehausen, F., Lödding, H.: Modeling lateness for workstations with setup cycles. In: Lödding, H., Riedel, R., Thoben, K.-D., von Cieminski, G., Kiritsis, D. (eds.) APMS 2017. IAICT, vol. 513, pp. 509–517. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-66923-6_60

A Flow Based Foundation for Capacity Dimensioning

Joakim Wikner(✉) and Lisa Hedvall

Jönköping University, Jönköping, Sweden
joakim.wikner@ju.se

Abstract. To proactively decide on the volume of capacity available in a period of time is referred to as capacity dimensioning. The actual dimensioning of capacity concerns both the regular capacity, to cater for systematic variations, and safety capacity, to handle the stochastic variations. Despite the critical impact of these two types of variations, the support in the literature is limited in terms of formal methods for resource management based on dimensioning of capacity in general, and of safety capacity in particular. Capacity is one aspect of resources' capabilities and as a point of departure for developing such methods, the two overarching challenges of form-place-time matching and capacity balancing are defined. These challenges are exploited to provide a holistic approach to the combination of capacity and the generic form, place and time transformations performed to create customer value. This approach requires alignment between these types of transformation to enable a homogenous perspective on different types of resources such as machines and stock shelves. Such transformations are performed over time and a discrete-time period-based approach requires that the intra-period transfers and inter-period variations are integrated. Finally, the preconditions for proactive and reactive control related to capacity required are outlined. A foundation for capacity dimensioning is then established based on capacity balancing, period transfers and flow control.

Keywords: Capacity dimensioning · Safety capacity · Inventory control

1 Introduction

Capacity is a property of resources and reflects their ability to fulfill requirements. Comparing capacity required with capacity available is at the core of resource management and in this context resources are usually associated with e.g. machines or operators (we adhere to the definitions by Apics [1] for the key terminology related to capacity). At the same time materials have traditionally been perceived as a complement to this type of capacity (machines etc.). In for example MRPII the priorities (materials) are planned and controlled in a first phase and then the resulting plans for materials are checked for feasibility in terms of capacity [2]. However, by applying a more generic perspective on resources it is possible to provide an integrative perspective on what in MRPII terminology is referred to as materials and capacity. The point of departure for this analysis is to shift focus from the actual materials in inventory to the resources holding the inventory. The resource in this case is e.g. the

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 384–391, 2018.
https://doi.org/10.1007/978-3-319-99704-9_47

shelf or the tank holding the inventory and then the materials in inventory represent the amount of the resource that is required, i.e. the capacity required of the resource. Inventory therefore share several characteristics with other types of resources where the materials in inventory represent capacity required and the constraints of the entity holding inventory represent the capacity available. As a consequence, there are also some interesting analogies between the traditional control of capacity and the control of inventory that may be identified and exploited.

The methods for inventory control and capacity control have developed in parallel but also diverged over the years [3]. Inventory control in general has emphasized the financial implications and customer service whereas capacity control mainly has focused on the physical properties of manufacturing resources and their load, and contraction or expansion. Both inventory and capacity are however related to the performance of transformation and this is the focal point for this research since transformation as the foci enables a generalization of the applicability of capacity control. In relation to resource management it is of particular interest to compare capacity required to capacity available and as a consequence also how to establish capacity available, i.e. capacity dimensioning. The decision on capacity dimensioning sets the preconditions for the analysis of load in terms of capacity required in relation to the capacity available. The capacity required originates in the demand for output and correspondingly the capacity available reflects the capability of the resources to provide supply that may fulfill that demand. This supply is a concept that covers both being able to perform the appropriate transformation, and having sufficient capacity to actually perform the transformation in line with demand. From a regular perspective this comparative analysis concerns expected development but to cater for uncertain events it is important to also dimension some additional safety capacity and this is particularly challenging due to the uncertainties. The purpose of this research is therefore to identify the key aspects of resource management to provide a foundation for capacity dimensioning in general and dimensioning of safety capacity in particular. The business value of a resource is its contribution to the value adding transformation and hence a flow perspective is employed with emphasis on the transformation performed by the resources.

This research emanates from empirical observations of capacity dimensioning in practice where informal methods prevail. Based on empirical observations and a review of the literature (not included here), it is concluded that the formal tools available in the literature for capacity dimensioning are limited. The development of such tools requires that the fundamental logic of resource management and the related capacity control is known since this provide the foundation for capacity dimensioning based on the three fundamental concepts of capacity balancing, period transfers and flow control.

2 Resources and Matching/Balancing

The significance of capacity available for resource management is highlighted by the challenges of capacity balancing where the capacity required is compared to the capacity available. The first step in outlining the key components of capacity dimensioning (which is the process to decide on the capacity available) is therefore to identify the characteristics of capacity balancing. Balancing may be analyzed from different perspectives but from a business management perspective the performed transformations are an important point of departure. A resource performing a transformation has certain capabilities related to the type of transformation it can perform and how much transformation it can perform.

The type of transformation is here assumed to be of three different types. Form transformation (F) is performed in manufacturing, through for example machining or assembly where the F characteristics are transformed. A typical example of F is machining of a metal part into a certain shape. Place transformation (P) is related to transportation and concerns when an entity is moved from one place to another. Examples of P are trains moving parts across a continent or a pipeline moving oil between an oil well and a refinery. Time transformation (T), finally, is created by enabling the separation in time of provisioning and consumption, which is the key function of inventory and here represented by warehousing. Replenishing inventory on Monday to cover for demand on Friday is an example of T, a part is produced at one point in time but can be consumed at a later point in time. The combination form-place-time (FPT) transformation reflects the type of transformation that can be performed but should not be confused the expectations from the market. FPT represents the mix capability of the resources in terms of the mix of transformation a resource can perform.

Besides having the capability to perform a specific type of transformation a resource must also be able to perform certain volume of transformations. This is here referred to as the volume capability of a resource in terms of how much transformation a resource can perform and this corresponds to the capacity available of a resource.

The mix capability and the volume capability represent two different types of resource capabilities. To make these capabilities operational it is necessary for each type (mix and volume) of capability required to be in line with the capability available. Required capability, in terms of mix and volume, is the capability that is required, to perform a specific transformation. Capability available, in terms of mix and volume, is instead a property of the resource performing the transformation.

In an operational context it is key for resource management to establish a competitive combination of the capability required and the capability available. For this, two fundamental challenges related to both mix capability and volume capability can be identified. For the mix capability the challenge is to identify the available FPT mix that can fulfil the required FPT mix and this is here referred to as FPT matching. In addition, the resource must be able to perform a certain volume of transformation and this is here referred to as capacity balancing. Both FPT matching and capacity balancing are positioned in Table 1. In short this boils down to a two-stage approach where the first step is to identify the right type of resource and the second step is to investigate if the resource has the capacity required to perform the transformation: First do the right things and then do the things right, i.e. first focus on effectiveness and then on efficiency [4]. FPT matching is the effectiveness dominated part of resource management in terms of being able to do the right things, i.e. the right type of transformation based on the mix of form; place; and time. Capacity balancing, on the other hand, is the efficiency dominated part of resource management in terms of doing things right, i.e. to have capacity available that is well balanced with the capacity required.

Table 1. Flow resources and capabilities.

	Capability required	Capability available
Mix capability (FPT)	FPT matching	
Volume capability (Capacity)	Capacity balancing	

In summary, the two key areas of resource management identified above are FPT matching focusing on identifying the right type of resources for the transformation to be performed and capacity balancing focusing on identifying how much of the transformation to be performed. FPT matching is fundamental in many aspects as it emphasizes that the type of transformation should be aligned but below it is assumed that the matching is already performed, i.e. the right type of resources is in place, and the remaining issue is to investigate the characteristics of capacity balancing.

3 Periods and Transfer

Capacity balancing is based on a relation between what is required and what is available. Such a ratio can be defined for each instant of time in a continuous-time fashion but in most cases the time horizon is divided into segments, here referred to as periods. Each period is a subset of the time horizon and three distinct parts of a period can be identified: the start of the period, the intra-period time-frame and finally the end of the period. The start and the end of a period are the interfaces to preceding and succeeding periods and are where a transfer is performed between periods, see e.g. [5]. From a capacity balancing perspective both demand for capacity (capacity required) and supply of capacity (capacity available) may be transferred [6]: Transferred demand is demand that is not fulfilled in a period and instead fulfilled in a succeeding period. Transferred supply is supply that is not used to fulfil demand in a period and instead used to fulfil demand in a succeeding period.

The amount transferred to the succeeding period may however deviate from what remains from the preceding period. In some cases, the whole volume persists and is transferred but in others the remains are transient and lost and therefore not possible to transfer to the succeeding period. Supply/demand can therefore be categorized as: Transient in the sense that remnant supply/demand is not transferred to the succeeding period or Persistent in the sense that remnant supply/demand is transferred to the succeeding period.

To summarize, it is possible to identify four categories of transferred supply/demand between periods, as shown in Table 2. The transfer of supply/demand constitute the preconditions for the intra-period flow control and requirements.

Table 2. Flow periods and transfer of supply/demand.

	Transient (Lost)	Persistent (Backordered)
Demand (Capacity required)	Lost requirements	Backordered requirements
Supply (Capacity available)	Lost availability	Backordered availability

4 Control and Capacity Required

The concept of period is significant from a flow control perspective as the period represents an entity of time that can be used for scheduling. Each period has a time extension and a series of consecutive periods constitute the time horizon. The exact timing of an event, such as a customer order received or a machine breakdown, in relation to periods is not known before the actual event occurs even if a forecast may be available in advance. If the event is related to a future period it is possible to be proactive in relation to the event but if the event is not known in advance of the present period the control can only be reactive. Flow control can therefore be divided into inter-period control based on expectations about events in future periods, i.e. *proactive control*, and intra-period control based on actual events in the "present" period, i.e. *reactive control*.

Proactive control can be based on for example forward scheduling or backwards scheduling in how different periods are managed in combination. During the proactive phase the expected capacity required is allocated to different periods providing an estimate of the requirements for regular capacity. In addition, the proactive control concerns the expected variations in the coming periods and this is covered by the safety capacity that is dimensioned based on the expected stochastic behavior.

The reactive control referred to here, concerns both capacity required and capacity available. For capacity required there can be both increasing capacity required (Addition) or decreasing capacity required (Reduction). The changes in capacity required may behave as a stochastic process, referred to as "Stochastic" in Table 3 or subject to influence of the decision maker, referred to as "Decided" in Table 3. Combining these two types of behavior it is possible to identify four types of reactive flow control. In addition, a similar pattern can be identified for a proactive approach to capacity available where capacity available is provided for unexpected events in future periods which provides requirements for safety capacity. The reactive control of capacity available can compensate for some uncertainties through for example flexible workforce or quick replenishment of inventory.

Table 3. Flow characteristics in terms of decided and stochastic variations.

	Decided reduction	Stochastic reduction
Decided addition	1. Decided-decided	2. Decided-stochastic
Stochastic addition	3. Stochastic-decided	4. Stochastic-stochastic

The combination of decided and stochastic variations shown in Table 3 provides a compilation of the alternatives related to reactive control but as such also represent the aspects to consider in proactive control. It is the combination of decided and stochastic variations that should be considered in dimensioning both regular capacity and safety capacity.

5 Control and Dimensioning of Capacity Available

Capacity balancing concerns the relation between capacity required and capacity available in time-periods. The capacity available in a period is modelled as an interval ranging from the minimum capacity available to the maximum capacity available. The maximum capacity available can be assumed to be infinite if the limit is ignored or finite if the limit is considered. In Fig. 1 the finite level is represented by “Maximum capacity available (MaCA)” of a resource. At the other end of the spectrum is the “Minimum capacity available (MiCA)” and in most cases, this is zero. However, a more general definition would be to set MiCA to a fraction of MaCA such that MiCA = $\gamma \cdot$ MaCA where $0 \leq \gamma \leq 1$. MiCA then represents the minimum amount of the capacity available that must be used. For instance, an inventory resource may not be allowed to be empty but rather have a minimum level that must be used such as for some liquids where a completely empty tank is not allowed. Both MiCA and MaCA are depicted in Fig. 1. Capacity available is one side of balancing and represents the boundary for capacity required that can be balanced. In general, all levels of capacity required between MiCA and MaCA can be catered for in the period. Challenges arise when the capacity required is less than MiCA or larger than MaCA, i.e. when the capacity required is outside the approved interval. In both cases a balance is not established.

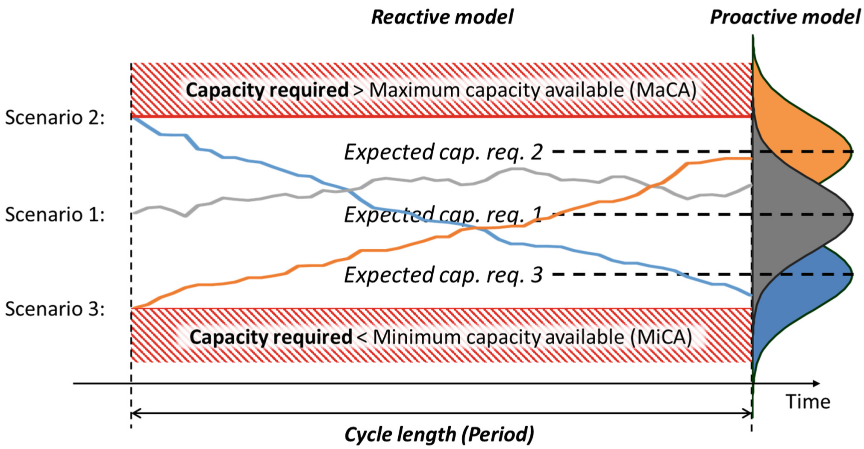


Fig. 1. Balancing, periods and control. (Color figure online)

The capacity balancing challenge depicted in Fig. 1 illustrates both proactive control and reactive control. For the purpose of proactive control, the future capacity required must be estimated to enable the dimensioning of capacity available in advance. Note that when proactive control is applied it is not known with certainty how the capacity required will develop during the future period concerned and since this development is difficult to estimate for each instant of time the focus is usually on estimating the aggregate capacity required for the whole of that period. The estimation is two-fold and for the regular capacity required, the expected capacity required is estimated as the most probable outcome for the period in total. In case of uncertainties the proactive control estimates how much additional safety capacity is required. In particular the investigation concerns the uncertainty of capacity required in relation to the limits MiCA and MaCA. In this context the capacity required is uncertain and can be modelled based on a probability distribution, such as the normal distribution. The scenarios with uncertain requirements are represented by the probability distribution for a complete period, could be valid for multiple periods, as illustrated in Fig. 1. The lower blue distribution on the right side represents the risk of capacity required under-shooting MiCA in the period (scenario 2 in Table 3) and the upper orange distribution on the right side represents the risk for capacity required over-shooting MaCA in the period (scenario 3 in Table 3). The middle grey distribution on the right side represents a situation where under-shoot and over-shot are equally likely in the period (scenario 1 in Table 3). The discussion so far has centered on the capacity required but as an extension it is also possible to include uncertainty in capacity available. This aspect is however not included here due to the limited space available.

The over-shoot (capacity required is greater than MaCA) is a possible scenario for all types of FPT-transformation and related to when the capacity available is insufficient such as when machine time is lacking (F-type) or means for transportation are insufficient (P-type). In e.g. process industry it could also reflect challenges related to limited storage capacity in tanks (T-type). The under-shoot is normally less of a problem as such but it represents that the capacity required is less than MiCA. For F and P transformation this basically concerns that the capacity is not used. For T transformation there is a more extensive interpretation since when all capacity is available it also reflects that the resource is empty, i.e. there is no materials in inventory. In terms of inventory this could also indicate the presence of backorders or lost sale. This symmetrical property of over-shoot and under-shoot enables the application of tools and methods for one issue to be applied on the other. For example, methods for dimensioning of safety inventory (where inventory is capacity required of the resource holding the inventory) may also be applied for dimensioning of safety capacity [6] in for example a manufacturing resource and as outlined above, the capacity may be related to manufacturing, transportation as well as warehousing (inventory). Finally, it is important to acknowledge the possible transfer of supply and/or demand between periods and in Fig. 1 it is assumed that either all capacity is available at the beginning of the period (Scenario 3), where the orange line represent the capacity required, or no capacity is available at the beginning (Scenario 2), where the blue line represents the capacity required. Both these scenarios mean that the state at the beginning of the period is independent of the state at the end of the preceding period and hence no transfer of supply can take place between periods. Consider for example the blue line that ends at the lower part close to MiCA. When the succeeding period begins it is assumed to be restored to the MaCA corresponding to the blue line on the left.

6 Conclusions

Capacity dimensioning concerns decisions of capacity available in future periods and this is an important challenge for managers in relation to manufacturing, transportation as well as warehousing since capacity available not only drives cost but is also important for responsiveness. To strike a competitive balance between cost efficiency and responsiveness requires a balance between capacity required and capacity available. The balance is traditionally focusing on manufacturing resources but the balance analysis is valid for not only F transformation but also P and T transformation. T is in particular conceptually interesting since availability is usually associated with the materials in inventory whereas this approach considers the inventory-holding entity as the resource and instead positions materials as representing capacity required. The capacity required is the result of transformations to perform, a combination of preconditions and decisions, whereas the capacity available is a management decision related to capacity dimensioning. Continuous-time dimensioning is rarely viable due to the sheer amount of decisions it implies and instead a discrete-time approach is usually employed where the time horizon is divided into periods. Proactive control enables capacity balancing in that dimensioning of capacity available sets the constraints of the flow in terms of capacity available per period. As events unfold over time the capacity is consumed and within each period a reactive control approach can be used. In summary, balancing, periods and control have been integrated to provide a foundation for capacity dimensioning with a generic approach embracing all three types of FPT transformation in a similar fashion and in particular provide a foundation for dimensioning of safety capacity. Dimensioning sets the stage for each period of the planning horizon with proactive control. Note, however, that also the reactive control applied in each period must be considered in dimensioning as it may influence the capacity required as well as the capacity available in each period but the implications of these aspects require further research. In addition, this integrative approach to resource management, involving the three types of transformation, also merits empirical validation.

Acknowledgement. This research was performed in collaboration with industry in the project KOPability (KKS-20160324), funded by the research environment SPARK at Jönköping University and The Knowledge Foundation.

References

1. Pittman, P., Atwater, J. (eds.): APICS Dictionary. APICS, Chicago (2016)
2. Wight, O.W.: MRP II: Unlocking America's Productivity Potential. Omneo (1981)
3. Jodlbauer, H., Altendorfer, K.: Trade-off between capacity invested and inventory needed. Eur. J. Oper. Res. **203**(1), 118–133 (2010)
4. Drucker, P.F.: The Effective Executive. HarperBusiness Essentials, London (1966)
5. Angelus, A., Porteus, E.L.: Simultaneous capacity and production management of short-life-cycle, produce-to-stock goods under stochastic demand. Manag. Sci. **48**(3), 399–413 (2002)
6. Wikner, J., Mattsson, S.: Safety capacity dimensioning based on inventory management methods. In: Proceedings of the 20th International Working Seminar on Production Economics, Innsbruck, Austria, 19–23 February 2018 (2018)

On Comparison of Multiple Non-linear Profiles for Process Selection

Chen-ju Lin(✉) and Pei-Ying Lin

Yuan Ze University, Taoyuan 32003, Taiwan
Chenju.lin@saturn.yzu.edu.tw

Abstract. A product can be produced by using alternative processes. The processes that can produce the product having consistent quality performance as the existing process are qualified alternative processes. Having several qualified alternative processes can relax the conditions for production scheduling and increase production capacity. This research focuses on analyzing the quality characteristic which is nonlinear profile. The quality characteristic, which is the response variable, has a non-linear functional relationship with the explanatory variable. The objective of this research is to select a subset of qualified alternative processes among I alternative processes, $I > 1$. A Step-up Test Procedure is proposed to compare the non-linear profile of each process with the existing process. Polynomial regression is used to estimate the non-linear profile models before applying the step-up sequential tests. The proposed method can effectively test the significance of the differences among processes, while controlling the overall error rate of testing I processes below α.

Keywords: Non-linear profile · Multiple comparisons · Sequential tests

1 Introduction

A product can be manufactured or assembled by using different processes. Having multiple alternative processes in production can increase utilization, reduce production time, or decrease production cost. However, the product quality under alternative processes may differ. Process Selection is a critical problem to production management. The objective of the problem is to select the qualified alternative processes that can produce the required specifications while having consistent quality performance as the existing process. This research aims as tackling the Process Selection problem under non-linear profile data, where there is a non-linear functional relationship between the response variable and the explanatory variable.

Most literature monitored profile data obtained from one manufacturing process. The monitoring process signals once the process is out-of-control [1–3]. However, the existing methods cannot be applied to solve the Process Selection problem where several processes are simultaneously compared with the existing process. The existing methods did not consider the overall error rate of conducting multiple comparisons. Consequently, we propose the Step-up Test Procedure to select the qualified alternative processes from I processes under non-linear profile data, $I > 1$. The proposed method

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 392–398, 2018.
https://doi.org/10.1007/978-3-319-99704-9_48

considers data variation from different alternative processes, and controls the overall error rate of conducting many-to-one comparisons below α.

The following paper is organized as follows. Section 2 reviews the related literature about profile monitoring. Section 3 introduces the proposed Step-up Test Procedure for the Process Selection problem. Section 4 presents the simulation results followed by the conclusions in Sect. 5.

2 Literature Review

Quality characteristics often appear to be non-linear profile data in industry [4, 5]. Polynomial regression models were commonly used to fit non-linear profile data [6, 7]. After model estimation, researchers used multiple control charts to monitor the coefficients and the variance of the estimated models. [8, 9] applied sine and hyperbolic tangent functions for data fitting before using the Hotelling's T^2 control chart for monitoring. Other researchers used wavelet to transform non-linear data [10, 11]. Their studies applied the T^2 or the Cumulative Sum (CUSUM) control charts for detecting mean shifts in non-linear profile data. The CUSUM control chart was shown to be more sensitive to small shifts than the T^2 chart.

To select a subset of qualified alternative processes, many-to-one comparisons need to be made. The aforementioned methods aim at monitoring one process, and signal when the process is out-of-control. The existing methods cannot be directly applied to solve the Process Selection problem which compares multiple processes. Consequently, we propose the Step-up Test Procedure to tackle the Process Selection problem under non-linear profile data. The method selects a subset of qualified alternative processes from I candidate processes, $I > 1$.

3 Methodology

The proposed method tests the discrepancy between the non-linear profiles of each alternative process and the existing process, indexed as 0. Let the quality characteristic (response variable) be a non-linear function of the explanatory variable, $y_{i,j} = f_i(x_{i,j}) + \varepsilon_{i,j}$. Let $x_{i,j}$, $y_{i,j}$, and $\varepsilon_{i,j}$ be the jth explanatory variable, response variable, and the error term of process i, respectively, $i = 0, \ldots, I$, $j = 1, \ldots, n$. Assume that $\varepsilon_{i,j}$ is normally distributed with a mean 0 and a standard deviation σ_i, $i = 0, \ldots, I$. The explanatory variable is bounded for practical usage, $a < x_{i,j} < b$. The proposed method contains three steps: parameters estimation, test statistics calculation, and the step-up procedure, which are explained in the following subsections.

3.1 Parameters Estimation

Collect n samples from each process, $(x_{i,j}, y_{i,j})$, $i = 0, \ldots, I, j = 1, \ldots, n$. The non-linear profile data are fitted by using polynomial regression models, $y_{i,j} = \beta_{i,0} + \beta_{i,1}\ x_{i,j} + \ldots + \beta_{i,p}\ (x_{i,j})^p + \varepsilon_{i,j}$, $i = 0, \ldots, I, j = 1, \ldots, n$. The estimator of $\beta_i = [\beta_{i,0}, \beta_{i,1}, \ldots, \beta_{i,p}]^T$ is calculated as $\hat{\beta}_i = \left(X_i^T X_i\right)^{-1} X_i^T y_i$ by using the least squares method, where

$$X_i = \begin{bmatrix} 1 & x_{i,1} & \cdots & x_{i,1}^p \\ \vdots & \vdots & \cdots & \vdots \\ 1 & x_{i,n} & \cdots & x_{i,n}^p \end{bmatrix} \quad (1)$$

and $y_i = [y_{i,1}, \ldots, y_{i,n}]^T$, $i = 0, \ldots, I$. The mean squared error is used to estimate variance

$$\hat{\sigma}_i^2 = \frac{\left(y_i - X_i\hat{\beta}_i\right)^T\left(y_i - X_i\hat{\beta}_i\right)}{n-p-1}, i = 0 \cdots I. \quad (2)$$

Since the highest power term of the polynomial regression model is unknown, we fit the data under $p = 0, \ldots, P$, where P is a sufficiently large number. The Akaike's information criterion (AIC) is used for model selection. The model with the smallest AIC value is considered as the best polynomial regression model for each process. Let p_i^* be the highest power term of the best model for process i, $i = 0, \ldots, I$. The best estimated polynomial regression model for process i is

$$\hat{y}_{i,j} = \hat{\beta}_{i,0} + \hat{\beta}_{i,1}x_{i,j} + \ldots + \hat{\beta}_{i,p_i^*}(x_{i,j})^{p_i^*}, i = 0, \ldots, I, j = 1, \ldots, n \quad (3)$$

3.2 Test Statistics Calculation

To test the discrepancy between process g and process 0, the hypotheses are set as follows: the null hypothesis H_{0g}: process i has consistent performance as process 0, versus the alternative hypothesis H_{1g}: process i has inconsistent performance as process 0, $g = 1, \ldots, I$. We propose the S_g test statistic that sums up the absolute standardized differences of the response variable at m evenly spaced values between a and b for the explanatory variable.

$$S_g = \sum_{j=1}^{m} \frac{\left|\hat{y}_{0,j} - \hat{y}_{g,j}\right|}{\sqrt{\hat{\sigma}_0^2 + \hat{\sigma}_g^2}}, g = 1, \ldots I \quad (4)$$

3.3 The Step-Up Procedure

The I test statistics are arranged in an ascending order before applying the sequential tests. Let $S_{(1)} \leq S_{(2)} \leq \ldots \leq S_{(I)}$ and $\{H_{0(g)}, H_{a(g)}\}$, $g = 1, \ldots, I$, be the ordered statistics and their matching hypotheses, respectively. $H_{0(g)}$ is the null hypothesis that process (g) has consistent performance as process 0; $H_{a(g)}$ is the alternative hypothesis that process (g) has inconsistent performance as process 0, $g = 1, \ldots, I$. For example, if $S_3 < S_1 < S_2$, processes (1), (2), and (3) refer to processes 3, 1, 2, respectively. The main concept of the step-up procedure is to test sequentially from the least significant hypothesis, and stop testing once rejecting a hypothesis. The test procedure starts with testing $\{H_{0(1)}, H_{a(1)}\}$, $H_{0(1)}$ is rejected if $S_{(1)}$ is greater than the critical value. Then, reject all of the un-tested hypotheses and stop the test procedure. Otherwise, accept $H_{0(1)}$ and continue testing $\{H_{0(2)}, H_{a(2)}\}$ until $\{H_{0(I)}, H_{a(I)}\}$ (Fig. 1). The processes being rejected are claimed to have different quality performance from process 0. The processes being accepted are claimed to have consistent quality performance as process 0.

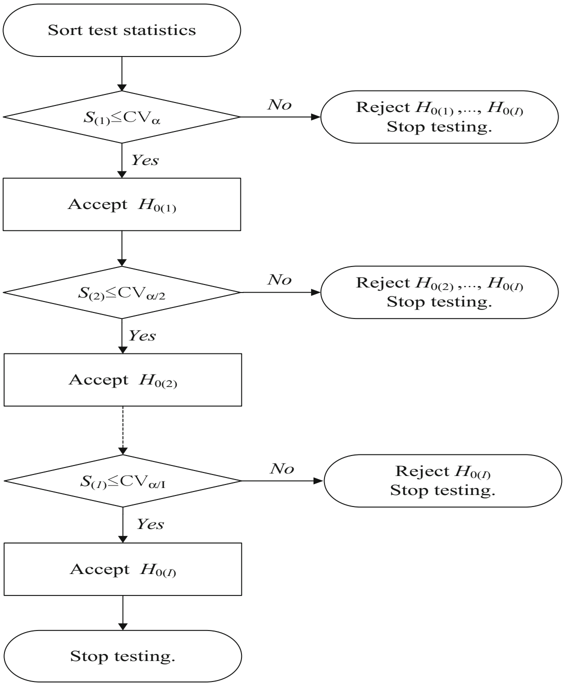
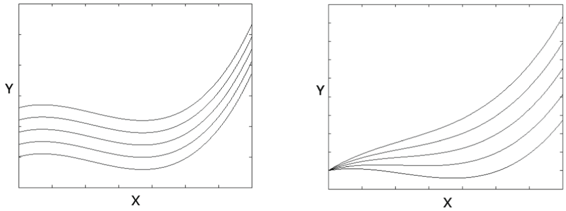


Fig. 1. The step-up test procedure.

The critical value, (CV_α, $CV_{\alpha/2}$, $CV_{\alpha/I}$) is calculated by simulation. Two series of non-linear profile data from the estimated polynomial regression model of process 0 is generated under the null hypothesis. Then, calculate the test statistic S_g. Repeat for R times and sort R of the test statistics. The critical value, $CV_{\alpha/(g-1)}$, is the $\alpha/g*100\%$ percentile of the sorted test statistics, $g = 1, \ldots, I$. Based on the prove in [12], the step-up test scheme can control the overall error rate of no greater than α by modifying the significance level of each sequential test to α/g, $g = 1, \ldots, I$.

4 Simulation Analysis

The power is the probability of rejecting the null hypotheses given that the alternative hypotheses are true. That is the probability of correctly rejecting the processes with inconsistent quality performance as process 0. To evaluate the performance of the proposed method, we analyze the power by simulation at $I = 2, 4, 6$. The underlying model of process 0 is set to $Y_{0,j} = 15 + 3X_{0,j} - 5(X_{0,j})^2 + 1.5(X_{0,j})^3 + \varepsilon_{i,j}$, $\varepsilon_{i,j} \sim N(0,1)$. Two shift patterns for alternative processes are investigated: (a) $E[Y_i|X] = (15 + i\ \delta_0) + 3X - 5X^2 + 1.5X^3$, (b) $E[Y_i|X] = 15 + (3X + i\ \delta_1) - 5X^2 + 1.5X^3$, $i = 1, \ldots, I$ (Fig. 2). The value for the explanatory variable is within $a = 0$ and $b = 4$. The shift magnitude is set as $\delta_0 = \delta_1 = 0.2, 0.4, \ldots, 2$. $n = 10$ samples are collected for data fitting. The difference between profiles are calculated at $m = 10$ equally spaced x values between 0 and 4. The overall error rate is set to $\alpha = 0.05$. $R = 10^5$ simulation runs are performed under the null hypothesis to calculate the critical values (Table 1). A large number of simulation runs is applied to get stable critical values.

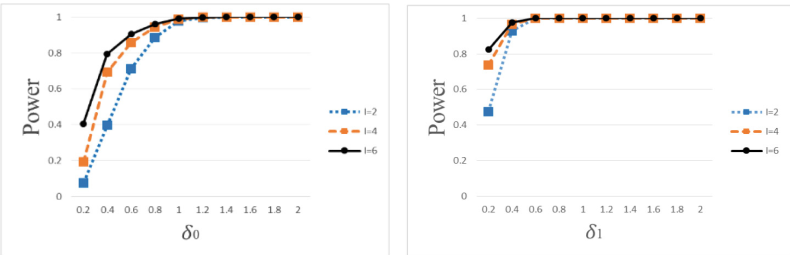


(a) (b)

Fig. 2. The illustrations of the simulated mean shifts in (a) β_0 and (b) β_1 with $I = 4$.

Table 1. The critical values $CV_{0.05/g}$ for testing $I = 2, 4, 6$ processes, $g = 1, \ldots, I$.

$I \backslash g$	1	2	3	4	5	6
2	5.1632	5.7967				
4	5.1632	5.7967	6.1763	6.4703		
6	5.1632	5.7967	6.1763	6.4703	6.6859	6.8511



(a) (b)

Fig. 3. The power curves under $I = 2, 4, 6$ with shifts in case (a) and (b).

The power is calculated as the average percentage of the processes being rejected among I different processes in 10^5 simulation runs. The power curves in Fig. 3 show that the power increases as the shift magnitude increases, which is reasonable. The power increases by *I*. This phenomenon is because that the simulation sets different nonlinear profile models for all of the alternative processes to be different from the existing process. The shift magnitude also increases by *I*. The analysis result suggests that the proposed method is effective in differentiating non-linear profiles for Process Selection.

5 Conclusion

Process Selection is a critical task in production management. Selecting and using multiple qualified alternative processes can increase production flexibility and capacity, while maintaining quality. This research tackle the Process Selection problem by proposing the Step-up Test Procedure. By modifying the significance level of each sequential test along with using the step-up procedure, the proposed method controls the overall error rate to be no more than α. The proposed method effectively differentiate the non-linear profile of each alternative process from the existing process. Manufacturers can then use the selected processes along with the existing process to retain product quality in production. To relax the normality assumption, future research will investigate nonparametric methods for data fitting.

Acknowledgments. The authors would like to thank the reviewers for their valuable comments which greatly improve the quality of the paper.

References

1. Woodall, W.H., Montgomery, D.C.: Some current directions in the theory and application of statistical process monitoring. J. Qual. Technol. **46**(1), 78–94 (2014)
2. Woodall, W.H.: Bridging the gap between theory and practice in basic statistical process monitoring. Qual. Eng. **29**(1), 2–15 (2017)
3. Gomaa, A.S., Birch, J.B.: A semiparametric nonlinear mixed model approach to phase I profile monitoring. In: Communications in Statistics-Simulation and Computation, pp. 1–17 (2018)
4. Wang, F.K., Guo, Y.C.: Measuring process yield for nonlinear profiles. Qual. Reliab. Eng. Int. **30**(8), 1333–1339 (2014)
5. Chen, Y.J., Birch, J.B., Woodall, W.H.: A phase I cluster-based method for analyzing nonparametric profiles. Qual. Reliab. Eng. Int. **31**(8), 1675–1689 (2015)
6. Qiu, K., Wang, R., Peng, C., Lu, X., Wang, N.: Polynomial regression and interpolation of thermodynamic data in Al–Si–Mg–Fe system. Calphad **48**, 175–183 (2015)
7. Xu, M., Pinson, P., Lu, Z., Qiao, Y., Min, Y.: Adaptive robust polynomial regression for power curve modeling with application to wind power forecasting. Wind Energy **19**(12), 2321–2336 (2016)
8. Fan, S.K., Chang, Y.J., Aidara, N.F.: Nonlinear profile monitoring of reflow process data based on the sum of sine functions. Qual. Reliab. Eng. Int. **29**(5), 743–758 (2013)
9. Fan, S.K., Lee, T.Y.: Using hyperbolic tangent function for nonlinear profile monitoring. In: Lin, Y.K., Tsao, Y.C., Lin, S.W. (eds.) Proceedings of the Institute of Industrial Engineers Asian Conference 2013, pp. 457–463. Springer, Singapore (2013). https://doi.org/10.1007/978-981-4451-98-7_55

10. Lee, J.S., Hur, Y.M., Kim, S.H., Wilson, J.R.: Monitoring nonlinear profiles using a wavelet-based distribution-free CUSUM chart. Int. J. Prod. Res. **50**(22), 6574–6594 (2012)
11. Wang, H.Z., Kim, S.H., Huo, X.M., Hur, Y.M., Wilson, J.R.: Monitoring nonlinear profiles adaptively with a wavelet-based distribution-free CUSUM chart. Int. J. Prod. Res. **53**(15), 4648–4667 (2015)
12. Hochberg, Y., Tamhane, A.C.: Multiple Comparison Procedures. Wiley, New York (1987)

Combinatorial Benders' Cut for the Admission Control Decision in Flow Shop Scheduling Problems with Queue Time Constraints

Rudi Nurdiansyah[1,2] and I-Hsuan Hong[1](✉)

[1] Institute of Industrial Engineering, National Taiwan University, Taipei 10617, Taiwan
ihong@ntu.edu.tw
[2] Department of Industrial Engineering, Universitas Negeri Malang, Malang 65145, Indonesia

Abstract. This paper presents the mixed-integer linear programming (MILP) based model to approach the admission control in flow shop scheduling problem with queue time constraints, where there are various upper bounds limit in each queue. The scheduling proposed in this paper iteratively retrieves the real-time status of a production system such as machine failures and recoveries, and job arrivals in each step and generate the most updated scheduling result at each decision time. Our objective function is to minimize the occurrence of queue time violation. We solve the MILP using combinatorial Benders' cut (CBC), where the MILP model is decomposed into two independent parts: the binary variables as a master problem and the continuous variables as a slave problem. We compare the CBC with the results gained from the CPLEX. The numerical results indicate that the CBC indeed effectively and efficiently reaches the good feasible solution within a reasonable timeframe in the context of timely updating scheduling problem.

Keywords: Flow shop · Queue time constraint · Combinatorial Benders' cut

1 Introduction

Flow shop production is a common system in a manufacturing system, where there are several steps and each step has multiple machines. A current mega factory may have a hundred of steps and machines with thousands of jobs; hence, the flow shop scheduling is a challenge nowadays. Furthermore, each step in a flow shop typically has queue time constraints, which prescribes an upper bound of waiting time between two consecutive steps. Such constraints are commonly observed in the semiconductor manufacturing [1, 2], food industries [3], and steel-making industries [4]. A typical queue time constraint occurs after the furnace tube operations in a semi-conductor wafer fabrication process since the queue time constraint can avoid the ab-sorption of the particulates in air [5].

Due to the stochastic nature, several studies apply Markov decision processes to flow shop scheduling problems with queue time constraints such as [6, 7]. [8] investigates a two-step model to determine the admission control of jobs in a flow shop

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 399–405, 2018.
https://doi.org/10.1007/978-3-319-99704-9_49

scheduling with queue time constraints while it may not return the decision as the problem size increases due to *curse of dimensionality* [9]. Moreover, the communication with industries reveals that statistical distribution information may be unavailable in the real-world production system or the front line manager may not believe that the statistical model from historical data precisely describes the future stochastic process in the manufacturing line.

Another approach for flow shop scheduling problem with queue time constraints is heuristics [10–12]. [10] uses the ant colony optimization algorithm (ACO) to propose a feasible solution of admission control problems. [11] determines a threshold to decide whether the job is admissible to each step. [12] investigates production scheduling with queue time constraints in semiconductor manufacturing by using several heuristics methods. Although heuristics methods are able to look for a feasible (or near optimal) solution within a reasonable time, the heuristics solutions may perform poorly if it falls into a pitfall of local optimum. The lack of flexibility to the change in heuristics model settings is another disadvantage.

We present a mixed integer linear programming (MILP) based model to approach the admission control decision in a flow shop with queue time constraints by frequently revising uncertain parameters such as machine failures and job arrival processes in each step in the model. Due to the fast development of Industry 4.0, the vast deployment of monitoring sensors enables frequently updating uncertain parameters in a stochastic nature production system to enhance the accuracy of a deterministic model approaching a stochastic nature system.

We further use combinatorial Benders' cuts (CBC) to promptly solve the MILP model when uncertain parameters are frequently revised according to the most updated information from deployed sensors in a production system. With the CBC, the proposed MILP is decomposed into two independent parts: integer and continuously parts. The decomposition technique allows us to accelerate the computational time and combines the if-then rule to reduce redundant constraints with the big-M method.

CBC is a relatively new method to solve MILP problems containing "big-M" [13]. Successful applications of CBC for solving integer programming models have been shown by [14, 15]. [14] used CBC to solve quayside operations problem at container terminals and reported that their approach is more efficient than the branch and cut algorithm. [15] solved assembly line balancing problem and notified that the CBC is capable to solve small to medium instances. [16] proposed a modification of CBC for solving a vaccine allocation problem. Their computational results confirm that these cuts extensively reduce solution times and the number of nodes explored in the branch-and-bound tree for their problem.

The CBC will be applied to solve the admission control decision in a flow shop scheduling problem with queue time constraints. The comparison between our proposed method with the commercial optimization package ILOG CPLEX solver (IBM ILOG 2014) shows that our method has better performance than the results gained from the CPLEX. The remainder of the paper is organized as follows. Section 1 describes the problem and mathematically formulates the proposed MILP model. Section 2 introduces the solution methodology of CBC and the computation results. Section 3 concludes of the research.

2 The Model

The proposed model considers a multi-step manufacturing process where each step has multiple identically machines with a common queue. In each consecutive step, only one machine can process one job at most in each time, and one job can only be processed by one machine in each step. Various upper bounds limit the waiting times in each queue. If the queue time is longer than the upper bound of the queue time constraints, the job cannot be further processed and becomes scrapped.

A real-world production system involves with several uncertainties including machine failures and recovery, and job arrival processes in each step. Unexpected uncertain events typically cause the scheduled production plan infeasible to a real-world production system and lead to a substantial loss due to scraped jobs. We explore such stochastic-nature flow shop scheduling problems with queue time constraints by frequently revising uncertain parameters in a production system and solving the mixed integer linear programming model (MILP) for admission control decisions of jobs. Following the similar concept, the scheduling proposed in this paper iteratively retrieves the real-time status of a production system such as machine failures and recoveries, and job arrivals in each step and generate the most updated scheduling result at each decision time. The parameters and decision variables of the model are described in Table 1. Equations (1)–(10) are the objective functions and the constraints.

Table 1. Parameters and decision variables

Parameters		Decision variables	
S	total number of steps in the production loop	$s_{q,i}^{f}$	starting time of job i in queue q at future step f
M^f	number of machines at step f	$c_{q,i}^{f}$	ending time of job i in queue q at future step f
Ω_q	set of jobs in queue q	$e_{q,i}^{f}$	queue time violation of job i in queue q at future step f
p_j^f	processing time of machine j at step f	$k_{q,m,p,n}^{f}$	0-1 variable that is equal to 1 if job m in queue q at future step f is produced before job n in queue p, 0 otherwise
qT^f	queue time limit of step f	$y_{q,i,j}^{f}$	0-1 variable that is equal to 1 if job i in queue q will be processed in machine j in future step f, 0 otherwise
a_j^f	earliest time of machine j can process at step f		
T	current time decision		

$$\min_{s,e} \sum_{q=1}^{S} \sum_{i=1}^{|\Omega_q|} \sum_{f=q}^{S} \left(s_{q,i}^{f} + \frac{\alpha}{S-f} . e_{q,i}^{f} \right) \tag{1}$$

subject to

$$\sum_{j=1}^{M^f} y_{q,i,j}^f = 1,\ \forall q \in \{1, \ldots, S\},\ \forall i \in \Omega_q,\ \forall f \in \{q, \ldots, S\}, \tag{2}$$

$$s_{q,i}^f + \sum_{j=1}^{M^f} p_j^f \cdot y_{q,i,j}^f = c_{q,i}^f,\ \forall q \in \{1, \ldots, S\}, \forall i \in \Omega_q, \forall f \in \{q, \ldots, S\} \tag{3}$$

$$s_{q,i}^f \geq \sum_{j=1}^{M^f} a_j^f \cdot y_{q,i,j}^f,\ \forall q \in \{1, \ldots, S\},\ \forall i \in \Omega_q,\ \forall f \in \{q, \ldots, S\} \tag{4}$$

$$s_{q,i}^f \geq c_{q,i}^{f-1}, \forall q \in \{2, \ldots, S\},\ \forall i \in \Omega_q,\ \forall f \in \{q, \ldots, S\} \tag{5}$$

$$s_{1,i}^1 \geq T,\ \forall i \in \Omega_1 \tag{6}$$

$$s_{q,i}^f - c_{q,i}^{f-1} - qT^f \leq e_{q,i}^f,\ \forall q \in \{2, \ldots, S\},\ \forall i \in \Omega_q,\ \forall f \in \{q, \ldots, S\} \tag{7}$$

$$\begin{gathered} s_{q,m}^f + \mathrm{M}\left(2 + k_{q,m,q',n}^f - y_{q,m,j}^f - y_{q',n,j}^f\right) \geq c_{q',n}^f \\ \forall q \in \{1, \ldots, S\},\ \forall i \in \Omega_q,\ \forall f \in \{q, \ldots, S\} \end{gathered} \tag{8}$$

$$\begin{gathered} s_{q',n}^f + \mathrm{M}\left(3 - k_{q,m,q',n}^f - y_{q,m,j}^f - y_{q',n,j}^f\right) \geq c_{q,m}^f \\ \forall q \in \{1, \ldots, S\}, \forall i \in \Omega_q, \forall f \in \{q, \ldots, S\} \end{gathered} \tag{9}$$

$$\begin{gathered} s_{f,1}^f \leq \cdots \leq s_{f,\left|\Omega_f\right|}^f \leq s_{f-1,1}^f \leq \cdots \leq s_{f-1,\left|\Omega_{f-1}\right|}^f \leq \ldots \leq s_{1,|\Omega_1|}^f \\ \forall f \in \{1, \ldots, S\} \end{gathered} \tag{10}$$

The objective function as shown in (1) is to minimize the starting time of all jobs at each step and to minimize the occurrence of queue time violation. α is a weight value, how much the price must be paid if there is situation that exceeds the queue time limit. The denominator $S - f$ is used to indicate that the downstream site does not want to exceed the queue time limit.

Constraint (2) shows that every job must be processed to one of the machines at each step. Constraint (3) determines the ending time of job i, by adding the starting time of job i with processing time of machine j that processes job i. Starting time of job i processed by machine j must be greater than or equal to the allowable time as described in constraint (4). Constraint (5) means job i starts to be processed at step f if job i has been completed in the previous step. Starting time of the first step must be larger than or equal the time when the decision is made as shown in constraint (6).

Constraint (7) is set as inequality. When the value calculated on the left is negative, variable $e_{q,i}^f$ can be any positive number. But with the goal of minimum variable $e_{q,i}^f$, this variable automatically controls zero as the best solution. When the value calculated on the left is positive, variable $e_{q,i}^f$ is also controlled to be equal to this positive number.

This study discusses flow shop scheduling problem with parallel machines. Constraints (8) and (9) indicate that when two jobs are allocated to the same machines at the same time, successive relations must be considered. This is the most complicated to modeling the Big M method. When $y_{q,m,j}^f$ and $y_{q',n,j}^f$ are both 1, the job m and n are assigned to the machine j at step f at the same time. At this point, we have to use the decision variable $k^f_{q,m,q',n}$ to control the sequence. If $k^f_{q,m,q',n}$ is 1, job m has priority than job n to be processed. Constraint (8) will be a redundant constraint. Constraint (9) will restrict the starting time of job n after the completion time of job m. On the contrary, if $k^f_{q,m,q',n}$ is 0, job n has priority to be processed. The last constraints means all job in this model follow FIFO rules as shown in (10).

3 Solution Approach and Numerical Results

We apply the CBC to solve the proposed MILP model, where the model is decomposed into two sub problems: the binary variables $y^f_{q,i,j}$, $k^f_{q,m,q',n}$ as master problem and the continuous variables $s^f_{q,i}$, $c^f_{q,i}$, $e^f_{q,i}$ as slave problem. The first phase is to solve the master problem and to find a set of feasible solution Y^*. The master problem is integer programming, so the variables are binary variables. The result simply involves every set of feasible solutions. Furthermore, we take the result from the first phase into the slave problem. All constraints in the slave problem are continuous variables. Consequently, the slave problem turns into a linear programming. Now, we can promptly obtain the solution to the problem. The master problem and slave problem is stated as follows:

Master problem:

$$\min Y^*$$

s.t. constraints (2), (8), and (9)

Slave problem:

$$\min_{s,e} \sum_{q=1}^{S} \sum_{i=1}^{|\Omega_q|} \sum_{f=q}^{S} \left(s^f_{q,i} + \frac{\alpha}{S-f} . e^f_{q,i} \right)$$

s.t. constraints (3), (4), (5), (6), (7), and (10)

We compare the CBC on our proposed model for a six-step flow shop production system with queue time constraints with the results obtained from the CPLEX. The columns of MILP and CBC in Table 2 summarizes the returned objective function values within 180 s obtained from the CPLEX and CBC, respectively for the various problem sizes.

As the number of jobs in the system remains in 20, the CPLEX and CBC return the same quality solution. However, the CBC outperforms the CPLEX when the number of jobs in the system increases to 40. The CPLEX even cannot obtain the initial feasible solution within 180 s when the problem size reaches 60, 80, and 100. The numerical results demonstrate that the CBC indeed effectively and efficiently reaches the good feasible solution within a reasonable timeframe in the context of timely updating scheduling problem.

Table 2. The comparison of CBC and CPLEX results

Number of jobs	Return solution		Performance improvement (%)
	MILP	CBC	$\frac{\text{MILP} - \text{CBC}}{\text{MILP}}$
20	35,340	35,340	0.00
40	150,467,395	4,436,735	97.05
60	No solution	3,315,546,045	N/A
80	No solution	12,972,160,360	N/A
100	No solution	26,535,369,685	N/A

4 Conclusions

In this paper, we propose the Mixed Integer Linear Programming (MILP) based model to approach flow shop scheduling problems with queue time constraints. We devise the model with queue time constraints by the big-M method. The model updates the machine failures and recoveries, and job arrival processes in each step at each decision time.

The model is decomposed into two independent parts, the binary variables as a master problem and the continuous variables as a slave problem in order to create the combinatorial Benders' cut. The numerical results of the CBC are compared with the results obtained from the CPLEX. The algorithms is tested on a six-step flow shop production system with queue time constraints. The results show that the CBC has an effectively and efficiently the good feasible solution. The CPLEX even has no solution when the problem size reaches 60, 80 and 100 jobs within 180 s.

References

1. Scholl, W., Domaschke, J.: Implementation of modeling and simulation in semiconductor wafer fabrication with time constraints between wet etch and furnace operations. IEEE Trans. Semicond. Manuf. **13**(3), 273–277 (2000)
2. Robinson, J.K., Giglio, R.: Capacity planning for semiconductor wafer fabrication with time constraints between operations. In: Proceedings of the 31st Conference on Winter Simulation, Arizona, USA, pp. 880–887. ACM (1999)
3. Akkerman, R., Van Donk, D.P., Gaalman, G.: Influence of capacity and time-constrained intermediate storage in two-stage food production systems. Int. J. Prod. Res. **45**(13), 2955–2973 (2007)
4. Harjunkoski, I., Grossmann, I.E.: A decomposition approach for the scheduling of a steel plant production. Comput. Chem. Eng. **25**(11–12), 1647–1660 (2001)
5. Su, L.H.: A hybrid two-stage flow shop with limited waiting time constraints. Comput. Ind. Eng. **44**, 409–424 (2003)
6. Wu, C.H., Lin, J.T., Chien, W.C.: Dynamic production control in a serial line with process queue time constraint. Int. J. Prod. Res. **48**(13), 3823–3843 (2010)
7. Wu, C.H., Lin, J.T., Chien, W.C.: Dynamic production control in parallel processing systems under process queue time constraints. Comput. Ind. Eng. **63**(1), 192–203 (2012)

8. Wu, C.H., Chien, W.C., Chuang, Y.T., Cheng, Y.C.: Multiple product admission control in semiconductor manufacturing systems with process queue time (PQT) constraints. Comput. Ind. Eng. **99**, 347–363 (2016)
9. Bellman, R.: Dynamic Programming. Courier Dover Publications, New York (2003)
10. Guo, C., Zhibin, J., Zhang, H., Li, N.: Decomposition-based classified ant colony optimization algorithm for scheduling semiconductor wafer fabrication system. Comput. Ind. Eng. **62**(1), 141–151 (2012)
11. Wu, K., Zhao, N., Gao, L., Lee, C.K.M.: Production control policy for tandem workstations with constant service times and queue time constraints. Int. J. Prod. Res. **54**(21), 6302–6316 (2016)
12. Kim, Y.D., Joo, B.J., Choi, S.Y.: Scheduling wafer lots on diffusion machines in a semiconductor wafer fabrication facility. IEEE Trans. Semicond. Manuf. **23**(2), 246–254 (2010)
13. Codato, G., Fischetti, M.: Combinatorial benders' cuts for mixed-integer linear programming. Oper. Res. **54**(4), 756–766 (2006)
14. Chen, J.H., Lee, D.H., Cao, J.X.: A combinatorial benders' cuts algorithm for the quayside operation problem at container terminals. Transp. Res. Part E: Logist. Transp. Rev. **48**(1), 266–275 (2012)
15. Akpinar, S., Elmi, A., Bektaş, T.: Combinatorial Benders cuts for assembly line balancing problems with setups. Eur. J. Oper. Res. **259**(2), 527–537 (2017)
16. Tanner, M.W., Ntaimo, L.: IIS branch-and-cut for joint chance-constrained stochastic programs and application to optimal vaccine allocation. Eur. J. Oper. Res. **207**(1), 290–296 (2010)

Simulation Analysis for Demonstrating the Economic Competitiveness of Busan Port in the Northeast Asia

Ilkyeong Moon[1(✉)], Qian-Ru Shen[2], and Xuehao Feng[3]

[1] Department of Industrial Engineering, Seoul National University, Seoul, Korea
[2] Beijing CaoZiTou Aesthetic Co. Ltd., Beijing, China
[3] Ocean College, Zhejiang University, Zhoushan, China

Abstract. Container traffic between Busan and Japan is continuously blooming as the global economy grows impressively. It is interesting to see that Busan in Korea has great potential to be considered as a transit port for container export/import in Japan instead of Japanese domestic transit ports, due to the special geographic location and economical container handling cost. This paper attempts to demonstrate the economic competitiveness of Busan port for container transshipment. It describes models for analyzing the container transportation time and cost by transshipment mode, specifically, transferring via the ports of Japan vs. via Busan. A simulation programming method is developed to build the models. A case study which considers twenty Japanese regional cities has been presented. According to the comparison of simulation results and sensitivity analysis, the paper concludes with a discussion and suggestions for the container transportation transshipment network design of Japan.

Keywords: Simulation · Container · Transshipment · Network design

1 Introduction

With the continuous growth of the international trade cooperation of the world, containerization becomes progressively popular for commodity transportation. Japan, as one of the most important trade nations in Asia, has a very large import and export trade volume. Currently, the five major ports (Tokyo, Nagoya, Osaka, Yokohama, and Kobe) are assuming the role of handling most of the container traffic in Japan. Containers are firstly transferred by trucking from regional cities to major ports. Then the mode shifts from trucking to shipping, and the containers are transported by Ultra Large Containerships (ULCS) from the major ports to destinations. However, for some routes of container transportation in Japan, the handling cost and inland transportation cost in Japan is relatively high, and the recent financial crisis and ensuing worldwide economic recession have meant that enterprises are trimming their transportation budget. A more economic, competitive way of container transportation may be considered.

The purpose of our research is to find the best container transportation routes for regional cities in Japan and establish the economic competitiveness of Busan port and

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 406–414, 2018.
https://doi.org/10.1007/978-3-319-99704-9_50

the benefits that can be obtained when Busan is used for transshipment. The study focuses on the time and cost comparison of two types of intermodal container transportation. Few previous investigations of container transportation simulation models have been found by us, besides that of Cortes *et al*. [4], who presented a simulation model of freight traffic in the Seville inland port. For most of the other existing research, simulation has been used to visualize the process inside container ports, e.g. container terminal planning (Kim and Kim [5]), layout planning (Bruzzone and Singnorile [6]), planning of maritime traffic (Kose *et al*. [7], Hayuth *et al*. [8]).

2 The Container Transportation Model

2.1 Candidate Ports and Cities

Twenty regional cities and twenty regional ports having a one-to-one relationship are considered in this study, which means that the containers of each regional city will be transported to the nearest regional port. Five domestic ports of Japan and Busan are the transit ports; the main variations in this simulation comparison arise from the transit process. In addition, one destination ports are considered, all of which are in North America. Detailed information on the cities and ports is displayed in Table 1. As there are two optional regional ports for Yamaguchi city to transit, we marked them as Yamaguchi_1 and Yamaguchi_2 to distinguish.

2.2 Model Logic

The simulation model compares the total cost and time between two transshipment modes: via Busan and via Japan.

Mode via Busan

(1) Containers are transported by truck from a regional city to a regional port in Japan.
(2) A feeder ship is used for transporting containers from the regional port in Japan to Busan.
(3) Containers are transferred to ULCS at Busan port and transported to North America.

Mode via Japan

(1) Containers are transported by inland transportation (truck) from a regional Japanese city to a major port in Japan.
(2) As with the case of Busan, maritime transportation by ULCS transfers the containers to North America.

Table 1. Candidate ports and cities

Regional city	Regional port	Transit port	Destination
Sapporo	Tomakomai	Busan	Long Beach
Aomori	Hachinohe		
Akita	Akita		
Sendai	Sendai	Tokyo	
Niigata	Niigata		
Toyama	Toyama		
Kanazawa	Kanazawa	Yokohama	
Shizuoka	Shimizu		
Tsu	Yokkaichi		
Okayama	Mizushima	Nagoya	
Hiroshima	Hiroshima		Rotterdam
Yamaguchi_1	Tokuyama		
Yamaguchi_2	Shimonoseki	Kobe	
Matsuyama	Matsuyama		
Kitakyushu	Kitakyushu		
Hukuoka	Hakata		
Saga	Imari	Osaka	
Oita	Oita		
Kagoshima	Shibushi		
Naha	Naha		

2.3 Assumptions

(1) We only consider the transportation of 20ft container in this simulation model, as the specification of container truck in Japan is 20ft [9].
(2) Only one TEU container is considered for transportation from regional cities to North America, which means after one TEU container has been transferred to the destination, the next container arrives. There is no container aggregation in this model.
(3) Containers may wait in the port due to the mismatch between the arrival time and departure schedule. During the waiting time, the loading and unloading service for the container can be completed, that is, the service time of container loading and unloading is not considered.

3 Simulation Approach

3.1 Data Analysis

Processed Data. Usually, input data collection represented a significant portion that 30% of total project effort and time [10]. Thus, firstly we collected raw data from

Japanese publications, and processed them before using them as the simulation input data [11–13]. For a shipping route that may be served by more than one shipping company, we selected the shortest transportation time. In case there was a direct route, obviously, the direct route was chosen ahead of the transshipment route. If there was no direct route, the transshipment time was selected. We also collected the shipping time schedule of each candidate port. The phenomenon of scheduling mismatches can be accurately simulated by ARENA. Table 2 show the information on shipping lines from the transit ports to North America. We chose Long Beach to represent the ports of North America. Table 3 displays the information on the times of shipping lines from regional Japanese ports to Busan port.

Table 2. Information on the time from Busan and major Japanese ports to Long Beach (Unit: days)

Transit port	Average waiting time (days)	Transportation time (days)			Frequency (time/week)	Pattern
		Min	Mean	Max		
Busan	1.214	10.0	10.3	11.0	3	Direct
Tokyo	2.071	7.2	9.0	10.8	2	Direct
Osaka	3.500	8.0	10.0	12.0	1	Transshipment
Yokohama	3.500	9	9.5	10	1	Transshipment
Kobe	3.500	8.8	11.0	13.2	1	Transshipment
Nagoya	3.500	8.0	10.0	12.0	1	Transshipment

We assume that the transportation speed is 50 km/hour; thus, the transportation time can be obtained by dividing the distance by speed. The handling cost of each port is presented in Table 4, and we assume that the handling costs of Japanese transit ports are all the same.

Stochastic Parameters. Except the waiting time, all the parameters in this simulation are stochastic. For most of the regional cities, we can obtain the maximum, mean and minimum values of transportation time. Since triangular distribution is recommended to be used in Monte Carlo simulation modeling when the underlying distribution is unknown, but a minimal value, some maximal value and a most likely value are available [14], we assume all the transportation time follow triangular distribution.

However, some transportation time just have mean value (only one service route), we need to estimate maximum, mean and minimum values of these parameters. Therefore, we calculated the minimum and maximum values by adding a multiplier $\alpha\%$. The value of α is estimated according to the correlation of existing maximum, mean and minimum values. Here α equals to 20.

During the data collection, we got only mean values of transportation cost, so triangular distribution is not suitable for the simulation. As the fluctuation rate of cost is equally likely to be observed, we obtained uniform distribution to the transportation cost. All the values of cost can be multiplied by fluctuation rate $\beta\%$. The value of β is observed by logistics expert [9]. In this paper, β equals to 10.

Table 3. Information on the time from regional Japanese ports to Busan (Unit: days)

Regional port	Average waiting time (days)	Transportation time (days)			Frequency (time/week)	Pattern
		Min	Mean	Max		
Hakata	0.929	0.5	0.8	1.0	9	Direct
Tomakomai	3.500	2.4	3.0	3.6	1	Direct
Niigata	0.786	3.0	4.0	5.0	6	Transshipment
Hiroshima	2.643	0.8	1.0	1.2	2	Direct
Naha	3.500	2.4	3.0	3.6	1	Direct
Shimizu	1.071	3.0	4.0	5.0	7	Transshipment
Akita	2.071	1.6	2.0	2.4	3	Direct
Shibushi	3.500	0.8	1.0	1.2	1	Direct
Sendai	1.500	3.0	3.3	4.0	3	Transshipment
Shimonoseki	0.643	1.0	1.3	2.0	6	Transshipment
Kitakyushu	0.643	0.5	0.9	1.0	13	Direct
Matsuyama	3.500	0.8	1.0	1.2	1	Direct
Oita	3.500	0.8	1.0	1.2	1	Direct
Yokkaichi	3.500	2.4	3.0	3.6	1	Direct
Mizushima	2.643	0.8	1.0	1.2	2	Direct
Hachinohe	2.071	2.4	3.0	3.6	2	Transshipment
Toyama	1.786	1.0	1.5	2.0	2	Direct
Tokuyama	2.643	0.8	1.0	1.2	2	Direct
Kanazawa	1.214	2.0	2.8	5.0	4	Transshipment
Imari	2.643	2.0	2.5	3.0	2	Transshipment

Table 4. Handling cost of each port (Unit: Yen/TEU)

Port	Handling cost	Port	Handling cost
Hakata	14,580	Matsuyama	10,605
Tomakomai	10,605	Oita	10,605
Niigata	14,580	Yokkaichi	17,100
Hiroshima	14,580	Mizushima	20,000
Naha	10,605	Hachinohe	10,605
Shimizu	10,605	Toyama	10,605
Akita	10,605	Tokuyama	10,605
Shibushi	10,605	Kanazawa	10,605
Sendai	10,605	Imari	14,580
Shimonoseki	14,580	*Busan	114.6
Kitakyushu	14,580	Port of East Japan	28,300

*The unit of handling cost in Busan is USD

3.2 The ARENA Simulation

We firstly conducted Monte Carlo simulation by using an Excel spreadsheet to study this problem. We randomly generate every parameter to examine the total cost and time of one replication and aggregate the simulation result after 100 replications. However, Monte Carlo simulation is not very well suited for the simulation of dynamic models even though it is quite popular for static models [15]. For this reason, we developed an ARENA version 10.0 simulation model. The aim of this ARENA simulation study is to measure the waiting time at the port and visualize the dynamics of the process [16]. Meanwhile, the result of ARENA simulation can be compared with that of Monte Carlo simulation for examining the validity.

4 Comparison of Simulation Results

4.1 Candidate Ports

Twenty regional cities and twenty regional ports of Japan have been selected for this case study. For the mode via Japan, we chose the transit major port that is the closest to the regional city (Table 5).

Table 5. Corresponding Japanese major ports

Regional city	Regional port	Closest major port in Japan	Regional city	Regional port	Closest major port in Japan
Sapporo	Tomakomai	Tokyo	Hiroshima	Hiroshima	Kobe
Aomori	Hachinohe	Tokyo	Yamaguchi_1	Tokuyama	Kobe
Akita	Akita	Tokyo	Yamaguchi_2	Shimonoseki	Kobe
Sendai	Sendai	Tokyo	Matsuyama	Matsuyama	Kobe
Niigata	Niigata	Tokyo	Kitakyushu	Kitakyushu	Kobe
Toyama	Toyama	Nagoya	Hukuoka	Hakata	Kobe
Kanazawa	Kanazawa	Nagoya	Saga	Imari	Kobe
Shizuoka	Shimizu	Yokohama	Oita	Oita	Kobe
Tsu	Yokkaichi	Nagoya	Kagoshima	Shibushi	Kobe
Okayama	Mizushima	Kobe	Naha	Naha	Kobe

4.2 The Case of the North America Route

The results show that most of the twenty regional cities – with the exception of Tsu, Okayama, Hiroshima, and Shizuoka (For Shizuoka, both Busan and Japan major port is acceptable) - enjoy cost advantages when using Busan for transshipment (See Table 6). On the other hand, Busan is also superior in terms of shipping time when a container is transported from Yamaguchi_2, Kitakyushu or Hukuoka city to Long Beach. The reason why the costs of transiting via Japan are largely higher is that the maritime transportation cost and handling cost are greater. Besides, the inland transportation cost in Japan is much higher than the maritime transportation cost between the regional Japanese port and Busan.

Table 6. Results of the comparison (Long Beach)

Results of the comparison (Long Beach)					
Regional city	Regional port	Cost (USD)		Time (days)	
		Busan	Japan	Busan	Japan
Sapporo	Tomakomai	2427.7	3625.5	18.2	12.0
Aomori	Hachinohe	2407.3	2999.6	16.9	11.5
Akita	Akita	2148.0	2888.3	15.7	11.7
Sendai	Sendai	2142.8	2445.7	16.6	11.4
Niigata	Niigata	2145.5	2418.4	16.5	11.4
Toyama	Toyama	2013.1	2282.7	15.0	14.0
Kanazawa	Kanazawa	2010.7	2132.7	16.1	13.8
Shizuoka	Shimizu	2046.5	2041.6	16.5	13.2
Tsu	Yokkaichi	2136.1	1708.9	18.2	13.6
Okayama	Mizushima	2228.7	1928.9	15.2	14.4
Hiroshima	Hiroshima	2180.9	2104.0	15.3	14.7
Yamaguchi_1	Tokuyama	2126.9	2521.0	15.3	14.8
Yamaguchi_2	Shimonoseki	2299.2	2528.5	13.8	14.6
Matsuyama	Matsuyama	1967.3	2190.2	16.1	14.5
Kitakyushu	Kitakyushu	2001.5	2664.9	13.1	14.8
Hukuoka	Hakata	2014.6	2690.3	13.4	14.9
Saga	Imari	2272.0	2817.7	16.8	15.0
Oita	Oita	2154.8	2778.9	16.2	15.3
Kagoshima	Shibushi	2004.8	3170.1	16.3	15.3
Naha	Naha	2022.9	3497.5	18.2	15.8

Table 7 provides the recommended target transshipment ports for regional Japanese cities. The regional cities Yamaguchi, Kitakyushu, and Hukuoka are located close to Busan; they enjoy advantages in both time and cost when Busan is used as the transshipment port. Thus, Busan can be a good option for the transshipment port for them. The results of Case I prove that Busan has strong competitive strength for transshipment.

Table 7. Target transit port (Long Beach)

Transit port (Long Beach)		
Regional city	Cost	Time
	Transit port	
Sapporo	Busan	Tokyo
Aomori	Busan	Tokyo
Akita	Busan	Tokyo
Sendai	Busan	Tokyo
Niigata	Busan	Tokyo
Toyama	Busan	Nagoya
Kanazawa	Busan	Nagoya
Shizuoka	Yokohama/Busan	Yokohama
Tsu	Nagoya	Nagoya
Okayama	Kobe	Kobe
Hiroshima	Kobe	Kobe
Yamaguchi_1	Busan	Kobe
Yamaguchi_2	Busan	Busan
Matsuyama	Busan	Kobe
Kitakyushu	Busan	Busan
Hukuoka	Busan	Busan
Saga	Busan	Kobe
Oita	Busan	Kobe
Kagoshima	Busan	Kobe
Naha	Busan	Kobe

5 Conclusion

This paper has proposed simulation models of the container transportation network in the Busan-West Japan region in order to compare the transportation time and cost via two different transit ports and establish that Busan is more economical than other options as a transit port. An ARENA simulation model was firstly presented. Then, we conducted simulation experiments by using actual shipping data. Finally, we recommended the target cities/ports in West Japan after an analysis of the experiment results. From the analysis of the results of this paper, we can conclude that Busan is a highly competitive transit port for container transportation for the cities that are located on the western coast of Japan. However, currently there are a few shipping routes between these two regions. To obtain benefits for Busan and regional cities in West Japan, more cooperation should be established between both sides.

References

1. Wikipedia. http://www.wikipedia.org/. Accessed 2010
2. Busan Port Authority. http://www.busanpa.com/. Accessed 2010
3. Kim, H.T.: Construction of cooperative relationship between the port of Busan and Donghae coast ports of Japan. In: 2008 International Symposium on Maritime and Port Logistics, Busan, Korea, pp. 21–3528 (2008)
4. Cortes, P., Munuzuri, J., Ibanez, J.N., Guadix, J.: Simulation of freight traffic in the Seville inland port. Simul. Model. Pract. Theory **15**, 256–271 (2007)
5. Kim, K.H., Kim, H.B.: Segregating space allocation models for container inventories in port container terminals. Int. J. Prod. Econ. **59**(1–3), 415–423 (1999)
6. Bruzzone, A., Signorile, R.: Simulation and genetic algorithms for ship planning and ship yard layout. Simulation **71**(2), 74–83 (1998)
7. Kose, E., Basar, E., Demirci, E., Gunerglu, A., Erkebay, S.: Simulation of marine traffic in Istanbul Strait. Simul. Model. Pract. Theory **11**, 597–608 (2003)
8. Hayuth, Y., Pollatschek, M.A., Roll, Y.: Building a port simulator. Simulation **63**(3), 179–189 (1994)
9. Kang, I.D.: Logitech, Hi, Personal Communication, September 2009
10. Williams, E.J., Khoubyari, S.: Modeling issues in a shipping system. In: Proceedings of 1996 Winter Simulation Conference, pp. 1353–1358 (1996)
11. Main Cost of Transportation & Warehouse, 30th edn, Sanbi Printing Co., Ltd., Japan (2008)
12. Transportation Cost of Suit Product. Transportation Books Publication, Japan (1999)
13. Kenji, N., Akira, N.: International Transportation Handbook. 2009 version. Ocean Commerce Ltd., Japan (2009)
14. Kotz, S., Van Dorp, J.R.: Beyond Beta: Other Continuous Families of distributions with Bounded Support and Applications. World Scientific Publishing Co. Pte. Ltd., Singapore (2004)
15. Kelton, W.D., Sadowski, R.P., Sturrock, D.T.: Simulation with ARENA, 4th edn. McGRAW Hill, New York (2007)
16. Bapat, V., Swets, N.: The ARENA product family: enterprise modeling solutions. In: Proceedings of 2000 Winter Simulation Conference, pp. 163–169 (2000)

Causes of Delivery-Time Variance in Maritime-Equipment Manufacturing Supply-Chains: An Empirical Study

Olumide E. Oluyisola(✉), Tuomo E. Salmi, and Jan O. Strandhagen

Department of Mechanical and Industrial Engineering, NTNU – Norwegian University of Science and Technology, Trondheim, Norway
{olumide.e.oluyisola, ola.strandhagen}@ntnu.no, tesalmi@stud.ntnu.no

Abstract. The overall performance of manufacturing companies has become increasingly dependent on their ability to coordinate a network of suppliers effectively. For manufacturers of customized equipment, it is even more important to coordinate several such network relationships concurrently to achieve service level objectives while minimizing inventory- and quality-related costs. In this paper, we investigate the causes of delivery variance in an engineer-to-order supply chain. Using four case companies within the global supply chain of a customized maritime-equipment manufacturer, we discuss these causes of delivery-time variance and suggestions for managing them.

Keywords: Performance management · Supplier development
Global manufacturing network

1 Introduction

The overall performance of manufacturing companies – and especially, the 'on-time' delivery of products to customers – is increasingly dependent on their ability to coordinate a network of suppliers effectively. For manufacturers of customized equipment such as thruster systems used in large ships, purchased components and sub-assemblies can represent up to eighty percent of the total contract value [1, 2]. Hence, manufacturers of complex, customized-equipment (also referred to as engineer-to-order or ETO) often need to coordinate several such networks of suppliers concurrently to deliver products on time, at minimum cost and at the right quality [2]. Consequently, the delivery performance of suppliers plays a vital role in the overall delivery performance of ETO manufacturers [1, 2].

Supplier delivery performance is often measured using two performance indicators: *delivery lead-time,* which is an indication of how soon an order can be fulfilled; and *delivery reliability,* an indication of the variance or the deviation from the expected or promised 'delivery window' [3]. All deliveries outside the expected delivery window are considered as not being delivered on-time, since they always lead to additional costs [4] in the form inventory handling costs or disruptions to planned allocation of

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 415–421, 2018.
https://doi.org/10.1007/978-3-319-99704-9_51

manufacturing resources. It could also be in the form of penalties from the end-customer for late order delivery.

This paper presents empirical findings (Sect. 4) from an investigation of the causes of demand variance in a ship building supply chain. The study comprises four suppliers and a focal company, which manufactures several critical subsystems for ship builders in Asia and Europe. The management team of the focal company in this study identified long delivery lead-time and high delivery variability as key issues hampering the competitiveness of its Asian operations, which is the target of this study. Thus, this study was commissioned to investigate the factors affecting the delivery performance of the four tier-2 suppliers – tier-2 because the focal company is itself a 'tier-1' supplier for ship-builders. One important objective of the study, therefore, was to enable management adequately price the cost of this variance into supply chain transactions and to serve as a motivation for improvements by its members. To address this objective, we briefly considered the theoretical background (Sect. 2) for supply performance in ETO supply chains. Thereafter, a description of the data collection methodology and a case description follows (Sect. 3). The findings are presented in a structured format (Sect. 4), and discussed in final section.

2 Theoretical Background

2.1 Market and Supply Characteristics of ETO Supply Chains

A central challenge in ETO markets is high demand fluctuation, which is generally higher than that witnessed in, say, mass production cases, and is almost impossible to forecast [1, 2, 5]. This condition creates a big challenge for manufacturers and at the same time, a business opportunity for companies that are able to deliver in short lead time and within the promised delivery window [6]. In addition to delivery performance, other sources of competitiveness are: design or engineering competences, price and responsiveness [1]. High degree of responsiveness is particularly important in the tendering phase. Caron and Fiore [7] and Gosling and Naim [8] have also identified flexibility in the order fulfillment process as a crucial for order-winning by ETO companies. Surveys [9] have further revealed that seventy percent of project-based cost overruns are due to delivery untimeliness, and that on-time delivery is a good indicator for projects that want to achieve minimize such costs.

Because of such demand characteristics, combined with the fact that each produced unit is a large proportion of the production capacity, a major source of risk for ETO companies is, therefore, that supplier relationships can vary significantly [1, 6]. One reason for this variation is the demand uncertainty, which limits cooperative long-term supply chain relations [1]. To cope with this uncertainty, a large portion of production is outsourced – sometimes up to eighty percent [1, 2]. In order to reduce supply uncertainty many ETO companies use multi-sourcing [6] which is characterized by mutual mistrust and "win-lose" transactions [1]. Furthermore, ETO companies recognize that there are benefits in developing suppliers for long-term collaboration [1]. For those long-term collaborations, the delivery variance must be minimized or eradicated where possible.

2.2 Causes of Delivery Variance in Supply Chains

The difficulty in controlling ETO delivery timeliness arises from the poor coordination of the interface between engineering and production, and especially in coordinating multiple organizations, not coordination in single organization [10]. Furthermore, the trend of outsourcing production to low-labour cost countries and retaining engineering as a core expertise has resulted in an even larger gap between engineering and production leading to more delays in delivery. Several other causes have been documented in the literature [10, 11] namely:

a. Procurement phase delayed due to missing designs and poor quality of documentation;
b. High number of quality problems at the supplier; information flow not integrated between supplier and buyer;
c. Poor visibility of business processes by decision makers and workers;
d. Excessive optimism in business partner's skills;
e. Poor delivery documentation;
f. Long-lead times, which increases the chance of occurrence of unpredicted events (e.g. strikes, new trade regulations etc.); and
g. Changes in technical requirements after production starts.

Some of causes originate from process and product uncertainty, while others originate from the people-related and organizational factors.

2.3 Management of Delivery Variance in Supply Chains

According to Guiffrida and Jaber [12], supply chain managers can use delivery-variance reduction in order to improve delivery performance in a similar way that quality managers historically used the reduction of process variation to improve product quality. In their model, the delivery variance (v) is traded-off against investment in continuous improvement of on-time delivery (cost). Defining the variables G(v), total cost supplier untimeliness; Y(v), the expected cost (penalty) of untimely delivery; C(v), investment cost for delivery variance reduction; and v, delivery variance, Guiffrida and Jaber [12] obtained the following (Fig. 1):

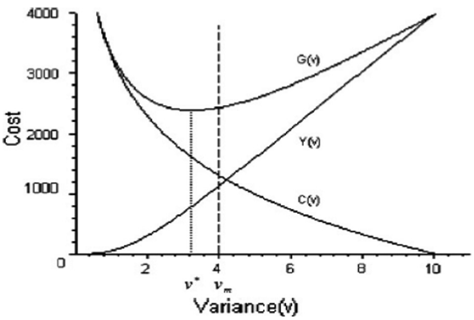


Fig. 1. Optimal delivery variance model [12]

The model suggests that there is a variance level, $v*$, at which total cost of untimeliness is minimized. This indicates that a trade-off must be regarding (a) how much to invest in efforts to reduce the cost of untimely delivery and (b) how much penalty is expected due to untimely delivery. Several ways to control this variance have been reported namely: the supplier gaining tighter control over process flow times; enhanced coordination of freight transport; more efficient material handling of outbound stock by the supplier and inbound stock by the buyer; and improved communications between both parties [12, 13].

3 Methodology and Case Description

3.1 Data Collection Method

This paper uses a case study design with five units of analysis – the four tier-2 suppliers, serving a common customer which will be referred to as Company S – not real name. Company S is a customized-equipment manufacturer serving the ship building industry. Data is collected using semi-formal interviews based on an interview guide, in addition to factory tours at Company S and the four tier-2 suppliers. The interviews were conducted with the supply chain management staff of Company S by the second author using an interview guide, with follow-up phone calls and meetings with the four suppliers for clarification and verification.

The objective of the interview was to identify the critical processes and procedures that contribute to poor supplier delivery performance at the four tier-2 suppliers. The interview guide was designed to elicit the causes for poor delivery performance, the implications of poor supplier delivery performance, and the current supplier delivery performance practices. Followed-up meetings aimed to elicit managers' recommendations about how the delivery performance could be improved.

3.2 Case Selection and Description

The four suppliers operate in China and Europe, while Company S has its headquarters in Europe and a production subsidiary in China. Out of several suppliers, these four suppliers (of Company S) were selected based on following criteria:

a. The supplier has underperformed the expectations and targets set by Company S during the past two or more years;
b. The suppliers deliver different kind of components which have a significant impact on the operational performance of Company S.

Supplier A is a European company producing slip ring units, which are one of the most critical outsourced subassemblies in Company S products. Design and production of main components are carried out in Europe, after which those components are shipped to China for other production activities. Customers, such as Company S, place orders through the main office in Europe.

Supplier B manufactures larger casted main components for Company S. The production process has two phases – casting and machining. These phases are carried out in separate sections within the same plant in China and shipped to Company S. The components are partly made-to-stock in the casting phase and made-to-order in the machining phase.

Supplier C is responsible for machining several key components. For this study, three most valuable components are considered. Supplier C ships components directly to Company S after the production. All components are made-to-order.

Supplier D delivers numerous types of hydraulic systems components such as hoses, couplings and connectors from its facilities in Northern Europe from where all orders are fulfilled and shipped to Company S in China. The hoses are made-to-order while the rest of the components are standard and directly shipped from the stock.

4 Causes of Delivery-Time Variance

In this section, the causes for high delivery-time by the case suppliers are presented - see Table 1. Poor delivery performance by these suppliers to Company S typically disrupts its production plans in two ways. Firstly, since the production planning at Company S is scheduled based on the available production slots and delivery dates promised to the customer, delivering earlier than agreed is generally disadvantageous. This due to increased inventory levels and capital tie-downs.

Table 1. Summary of observations at the case companies

	Supplier A	Supplier B	Supplier C	Supplier D
Primary source of untimely delivery	Poor coordination between design departments of Co. S and Sup-A	Defective output from the casting process	Lack of process standardization	Long transport time; inflexibility in order fulfilment process
Where/when does it happen?	Design phase, due to need for customer and 3rd party approval	Casting process facility	Entire operation relating to this supply chain	Rush orders
Other observations	Internal planning and control problems leading to missing parts	Poor coordination within the two sites; high inventory after casting process	Need to have large time buffers for delivery of orders	Internal planning and control, leading use of large buffers

Meanwhile, the second issue – of late deliveries from supplier – is adjudged by Company S to be of greater criticality. Such delays lead to production stoppages, waiting, overtime work, risk of high penalty and reputational damage from the shipyards. These then lead to increased costs in project execution and reduced profitability. To manage its own consequent order fulfillment process variability, which is relatively high, Company S uses internal buffers.

5 Discussion and Conclusions

The purpose of this paper was to investigate the causes of delivery variance in a global, engineer-to-order maritime-equipment supply chain. Furthermore, we wanted to observe how those causes are managed in an empirical setting – the focal company of this study and four of its main suppliers. We found that the most significant causes for delays were poor communication and coordination at Supplier A, process inefficiency at Supplier B, lack of process standardization at Supplier C, and a long transport distance in addition to inflexibility in the order-fulfilment process at Supplier D. The lack of transparency in suppliers' order fulfillment process made it difficult for Company S to coordinate and manage suppliers. Very often, problems are discovered much later in the production process. As a result, it is highly problematic to trace the sequence of events that led to the issue precisely, and thus develop solutions to avoid such issues in the future. This is especially true with supplier A and B, who produce long lead-time components.

One reason for this is that process times are not measured at the suppliers, making it very difficult to trace the sources of process variability. Therefore, one key outcome of this study was the proposal that Company S and its suppliers begin to monitor actual process times or order fulfillment times, especially for orders involving long lead-time items. Another suggestion is to introduce delivery-time windows (or period) in purchase orders, thus allowing suppliers more flexibility in planning their own production to accommodate other operational constraints. In cultures where there is punishment for revealing issues, a management policy that rewards openness – maybe in the form of a continuous improvement programme – will lead to improvements.

Culture also plays a role – both within the focal company and at the suppliers. We observed that workers at the suppliers were afraid of being caught to have made mistakes, and for issues to be traced back to them. For the same reason, supplier development is also difficult because the local supply chain team (i.e., in Asia as opposed to Europe-based headquarters) of the focal company prefers that problems are not traceable. This way, those knotty issues can easily be ascribed (and this is often the case) to the differences between the European and Asian business environment.

Future research will extend the preliminary findings of this study by investigating how the use of penalties and rewards will work in this setting. In the next phase of this study, the use of a systematically determined penalty for untimely delivery from suppliers will be explored within this supply chain, as this is currently not in use. The penalty can be based on a revised and agreed delivery-time window, so that suppliers know the customer requirements, and are motivated to improve delivery-time performance. In the same vein, manufacturers such as Company S could also explore the possibility of rewarding suppliers who consistently exceed the performance targets either by publicizing this or by awarding a rank score which will influence future contract awards.

References

1. McGovern, T., Hicks, C., Earl, C.F.: Modelling supply chain management processes in engineer-to-order companies. Int. J. Logist.: Res. Appl. **2**(2), 147–159 (1999)
2. Mello, M.H., Strandhagen, J.O.: Supply chain management in the shipbuilding industry: challenges and perspectives. Proc. Inst. Mech. Eng. Part M: J. of Eng. Marit. Environ. **225**(3), 261–270 (2011)
3. Milgate, M.: Supply chain complexity and delivery performance: an international exploratory study. Supply Chain Manag.: Int. J. **6**(3), 106–118 (2001)
4. Gunasekaran, A., Patel, C., Tirtiroglu, E.: Performance measures and metrics in a supply chain environment. Int. J. Oper. Prod. Manag. **21**(1/2), 71–87 (2001)
5. Bertrand, J., Muntslag, D.: Production control in engineer-to-order firms. Int. J. Prod. Econ. **30**(1), 3–22 (1993)
6. Hicks, C., McGovern, T., Earl, C.F.: Supply chain management: a strategic issue in engineer to order manufacturing. Int. J. Prod. Econ. **65**(2), 179–190 (2000)
7. Caron, F., Fiore, A.: 'Engineer to order' companies: how to integrate manufacturing and innovative processes. Int. J. Proj. Manage. **13**(5), 313–319 (1995)
8. Gosling, J., Naim, M.M.: Engineer-to-order supply chain management: a literature review and research agenda. Int. J. Prod. Econ. **122**(2), 741–754 (2009)
9. Assaf, S.A., Al-Hejji, S.: Causes of delay in large construction projects. Int. J. Proj. Manag. **24**(4), 349–357 (2006)
10. Mello, M.H., Strandhagen, J.O., Alfnes, E.: The role of coordination in avoiding project delays in an engineer-to-order supply chain. J. Manuf. Technol. Manag. **26**(3), 429–454 (2015)
11. Zorzini, M., Corti, D., Pozzetti, A.: Due date (DD) quotation and capacity planning in make-to-order companies: results from an empirical analysis. Int. J. Prod. Econ. **112**(2), 919–933 (2008)
12. Guiffrida, A.L., Jaber, M.Y.: Managerial and economic impacts of reducing delivery variance in the supply chain. Appl. Math. Model. **32**(10), 2149–2161 (2008)
13. Guiffrida, A.L., Nagi, R.: Economics of managerial neglect in supply chain delivery performance. Eng. Econ. **51**(1), 1–17 (2006)

Knowledge Based Production Planning and Control

Discrete Event Simulation – A New Approach to Multi-level Capacitated Planning?

Ernst-August Stehr[1(✉)], Jan Reschke[1], and Günther Schuh[2]

[1] F.I.R. e.V. an der RWTH Aachen, Campus Boulevard 55, 52074 Aachen, Germany
{ernst-august.stehr, jan.reschke}@fir.rwth-aachen.de
[2] Werkzeugmaschinenlabor WZL der Rheinisch-Westfälischen Technischen Hochschule (RWTH) Aachen, Campus-Boulevard 30, 52074 Aachen, Germany
guenther.schuh@fir.rwth-aachen.de

Abstract. Discrete Event Simulation (DES) is a well-known approach to simulate production environments. However it was rarely used for operative planning processes and to our knowledge never in terms of multiple disposition levels. In this paper we develop the necessary adjustments to use DES for this purpose and show some theoretical advantages.

Keywords: Discrete Event Simulation · Advanced planning
Production optimization · Multi-level production

1 Introduction

Companies strive for competitive advantages. With the proliferation of modern machinery the focus has changed to a higher relative importance of time-to-delivery, a reliable order promising and high utilization of expensive assets as quality and product features become more and more standard [1]. All these factors are highly influenced by the production planning. IT systems were developed and deployed in order to improve these functions. This started from material requirements planning (MRP) systems which do not consider capacities and recently advanced planning systems (APS) which do.

The acceptance of such software packages is somewhat limited as often companies experienced so called ERP-nervousness [2]. This term implies that the planning results – most importantly promised delivery dates – vary from planning run to planning run and leave customers and companies puzzled for a reliable deadline. On the other hand, Discrete Event Simulation (DES) – or more generally simulation – has been used for a long time to model uncertainties and provide reliable insights under stochastic conditions.

Before a literature survey is given, the next chapter will outline the problem and some generally applicable principles. In the literature survey we will consider briefly alternative solution approaches and their shortcomings before focusing on DES and its current lack of support for multi-level production planning. In the remainder we will present the solution approaches.

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 425–432, 2018.
https://doi.org/10.1007/978-3-319-99704-9_52

2 Problem Description

This paper focuses on job shops. The machines are grouped by their technological characteristics and not by the sequence of the jobs on hand as these might differ significantly. The production is described by a set of production orders, each consisting of a sequence of operations. Every operation requires a machine and an operator for a specific time. The operators are qualified only for some machines and not for others. Furthermore some operations have a bill-of-material which describes the required components.

The existence of significant setup times mandates the production of larger lot sizes which in turn mean that one production order might fulfill multiple demands. Therefore n:m relationships between component manufacturing orders and assembly orders might exist and this is repeated over different levels of production. E.g. a set of hundreds of pistons is manufactured which in turn is used to produce different engines which are then used for multiple cars. We will refer to this as order networks, describing the component flow between different orders, and multi-level production.

The objective of any production planning algorithm must be to time the execution of the operations in such a way, that (a) machines are utilized as much as possible (b) stocks are kept to a minimum and therefore produced as late as possible (c) deadlines for deliveries are met for the overall products.

While these objectives should be fulfilled in the best possible way the restrictions have to be taken into account: (a) Material availability (no production can be scheduled before the components are ready) (b) machine and personal capacity has to be available and (c) may not be double-booked. Obviously deviations from the plan will happen and must therefore be buffered against which increases stock levels and reduces overall efficiency.

3 Literature Survey

3.1 Classical Approaches Without Simulation

Many companies use an MRP like system [3]. These systems generate assembly orders for the customer orders and derive secondary demands from the bill-of-material information. In order to do so, they sort all materials by their disposition level and calculate for each level the demand. In terms of timing they assume a fixed lead time per material or operation. This approach however does not take the actual capacity into account and therefore generates invalid plans [4]. Additionally small changes in available quantities have significant impact on the deadlines [5].

Another approach is to use linear optimization programs that depict the capacity as a set of equations where the sum of all processing times in a period may not exceed a threshold [6]. These systems are computationally complex and therefore often have to be very simplified models of reality.

A well utilized approach is job-based-sequencing [7, 8]. In this approach the final orders are sorted by their creation date. The algorithm works its way backwards from the last to the first operation and finds a slot in the Gantt-chart of a machine where to plan the order. If components are needed, they are scheduled in the same way. However, this approach has multiple draw-backs:

- As the free slots get smaller and smaller, large operations cannot be scheduled in and require the system to find a slot with long lead times
- For the same reason a minor disruption needs to find a new slot which might differ significantly from the previously assigned slot, so small changes result in disproportionally large shifts of overall planned deliveries.
- Once the system comes into the past it switches to a forward calculation, but usually it does not change the already scheduled sub-components which are therefore delivered too early.

3.2 Priority Based (Simulation) Approaches

Another approach is based on priority rules. In every situation the sequence is built by ordering the operations according to a simple rule. These approaches are often used for "Leitstand"-type systems which only plan short term operations but take the earliest start and latest end date per order from another (MRP)-system.

A number of works starting in the 1960 have analyzed the effect of priority rules on certain target objectives. An excellent overview is given by Ramasesh [9]. In this paper among others the coordination of multiple components in an assembly job is proposed via means of different rules which assign priorities based on the question whether an order is on a critical path or not. However, this implicitly assumes that the assignment of component orders to the assembly order is fixed and known in advance. In contrast classical approaches are able to reassign material reservations and thus use an additional degree of freedom to optimize performance.

A specific implementation of this is discrete event simulation that uses priority rules to simulate the passage of time [10, 11]. There at every time step the most urgent job is scheduled on a machine. The end of a job or a shift is an event which triggers the selection of the next job from the queue. This might include Kanban-like material systems, in which the event "out-of-stock" generates a new production order. This does not include the handling of "push"-type orders for which no regular stock is held as is the case in manufacturing-to-order environments. The name is unfortunate, because it mixes the algorithm (prioritized queues, event based processing) with the purpose simulation. However, the algorithms yields dates for each operation and therefore the same result as classical day-to-day planning approaches.

Yet, these systems are focused very much on high-level capacity and strategy analysis instead of a productive scheduling [12]. The few exceptions were generally in the semi-conductor field [13, 14] where very complex routings have to be faced, yet material availability and therefore order networks are not needed.

Some approaches have tried to combine simulation approaches with other systems. Some authors use simulation results considering capacity to adopt the lead times of MRP-like systems [15, 16]. Graves and Milne propose a way to schedule the order release based on previous simulation results by allowing a maximum threshold of time in the system [17]. Again other works combine DES with optimization approaches, typically meta-heuristics as genetic algorithms or simulated annealing. None of these use the DES as a full production planning program in its own right [11, 14, 15].

3.3 Summary of Literature Survey

A vast body of literature exists on a number of classical, non-simulation based planning solutions. But small deviations lead to massive changes in the planning result (Nervousness). On the other hand Discrete Event Simulation has been used successfully in highly uncertain environments as strategic planning and factory design. However, it was mostly limited to that role. Again there are many such papers (Table 1).

Table 1. Comparison of approaches in literature

Criteria	DES	Classical	This paper
Calculates dates on operation level	Yes	Yes	Yes
Reduces nervousness	Yes	No	Yes
Used for day-to-day planning	Rarely	Yes	Yes
Copes with multiple disposition levels as stand-alone tool	No	Yes	Yes

There are far fewer papers for the usage of DES in day-to-day production planning, but these fall in two categories: (a) Scheduling single-level productions or (b) the combination of DES with other systems, e.g. genetic algorithms or simulated annealing or MRP systems. Both approaches follow the hierarchical planning paradigm in which capacity and material are planned separately.

This paper shall develop a system based on DES, which uses the inherent stability, but extends it towards the requirements for a day-to-day planning in multiple disposition levels. This is not trivial for reasons given in the solution part.

4 Solution Approach

In this article a system based on a discrete event simulation was developed to work on multi-level-order networks. The implementation was done in Java. The data model consists of orders which (with the exception of customer orders) deliver a material to stock and contain a number of operations. These operations require a machine for a certain processing time and a minimum time between operations for transport. The machine itself needs a qualified person from a pool. The operators have a set of shifts in which they can work. The start and end of a shift as well as the start and end of the processing of an operation are depicted as events in the DES. Additionally the end of an order triggers the start of succeeding operations of other orders. Some of the additional, novel aspects needed for an operative planning are described in the following part.

4.1 The Due Date Problem

The due dates are calculated by a fixed lead time which is calculated backwards from customer orders to its components. The resulting deadline might be in the past as it is only used for the priority rules, not the actual calculation of planned dates. While conventional due dates consist of just one date, the operative planning required a split between the wish of the customer (often unrealistic, but the earliest allowed delivery time) and the order promise date which results from the first capacitated planning run. Therefore an internal synthetic date is used as due date. This is calculated as follows: As long as the (simulation) time is before the promised date (calculated backward from the last to the first operation with fixed lead time), the wished date is used. However, once the promised date is before the simulation time, so that the order is getting urgent, than the promised date is used minus a large surcharge (e.g. 10 years) to make sure that promised orders have higher priorities than a mere wish. This additionally allows having different surcharges for different customers, yet keeping the capacity available unless the due date is really in danger.

4.2 The Order Release Problem

As a DES is a forward calculating system the order release is a major problem. Without such a mechanism it would flush all orders immediately into the (simulated) production. However, it became clear in first experiments that low priority orders finish their operations more or less regardless when they are released. This happens because the relative order of the due dates and the capacity constraints just lead to a longer waiting time. Therefore the date results (last Plan = LP) from one planning run are used to determine the order release as a fixed lead time before the next run. Therefore only a fixed advancement for the LP is allowed. Experiments show very little deviations between the planning runs despite vastly different order release times. In the second planning run orders are often released weeks after the results from the first run. Consecutively they finish the first operations much faster, but at the bottleneck (and one operation is always the bottleneck) and after the difference mostly is down to a few minutes.

While this logic discusses only the order release based on bottlenecks in later operations and has little advantages over CONWIP (constant level of Work-in-progress) or other mechanisms here, it can be extended to order networks. In this case a late assembly (e.g. because of a late purchase order) allows the manufacturing of components only a fixed lead time in advance of the calculated planned date. In other words: In a first simulation run all orders are released quite early (only restricted by the wish-date). A late purchase order or a capacity bottleneck results in a late delivery (despite potentially a high priority). This information is used to withhold the order release in the second run for a fixed lead time of the date calculated in the first run. This second run takes place immediately after the first run and together they form a production plan. As discussed analysis shows that despite large differences in order release times the final outcome does virtually not change.

4.3 The Material Availability

At the core of the system is the ability to account for material not yet on stock or in other words the capacitated, simultaneous planning of multiple disposition levels. The actual check for the availability is quite simple: The bill of material for an operation is known and its start is only allowed once all requirements are fulfilled.

Also the assignment of material to one of multiple, competing demands can just be handled in the same way as any other priority rule for capacities. However the priorisation of production orders becomes much more complex and is subject to ongoing experiments.

In a discrete event simulation the speed of the processing of an order depends on the priority an order has. This priority in turn depends on the usage. So a production order which is only delivered to stock will have a lower priority and hence slower progress than an order used for an urgent customer order. Thus unwanted and hard to solve feedback loops are happening where changes in the assignment of material reservations have impact on the planned dates and therefore the database of the assignment. We will report hopefully in the near future on progress on this topic.

5 Evaluation

The developed system is used by an industrial company in a real-world example since 2016. Before the introduction of the new DES-based system a Job-based-sequencing (JBS) was used. The company has roughly 400 employees, thereof 100 in direct manufacturing. The monthly revenue is ca. 5 million €, the total order book contains 4000 customer orders with 20 million € worth. Every day 30.000 manufacturing operations are planned within less than a minute (JBS needed hours). The planning results in terms of revenue, utilization etc. are approximately comparable between JBS and DES and obviously depend strongly on the production environment.

After the rollout of the new system the actual delivery performance (# of orders delivered on time) increased from 75% to 85%.

To separate the real-world influences from planning performance the planning results for two consecutive days were compared. 3.488 identical customer orders were planned on both days. After this one day DES had 136 delayed orders (3.9%) compared to the previous planning run. However, only 46 (1.32%) were delayed by more than one day so that a small change had a disproportionate effect. The respective figures for the JBS were 22% and 5% and therefore worse by a factor of 4-5.

6 Conclusion and Outlook

Production planning and scheduling remain important, yet not fully satisfactory solved problems. One of the most pressing one is the nervousness, defined as a permanent change of planned delivery times from planning run to planning run despite only modest changes of the input. Existing systems tend to increase this problem while discrete event simulation from its base in simulation under highly unreliable and stochastic data promises a better performance in this way. However the usage of multiple production echelons requires many changes to the original idea of a DES.

The separate train of thoughts of simulation experts and operative planners has so far inhibited the development of such extensions to the algorithms. While our solution is not yet fully finished we have some very promising indications. This includes apparently a much more robust planning result especially compared to job based sequencing. The outlook is therefore twofold:

- To fully develop a system to improve the material reservation in a multi-level production environment. This has to focus on the priorisation of component orders and the (re)-assignment of demand material reservations under the framework of a DES.
- Further evaluation of the complete system against a set of performance criteria, namely the quality of the plan (measured in utilization and output, tardiness, stock levels and so forth) and the stability of the plan (measured in the change of planned delivery dates under defined levels of changed input).

References

1. Schuh, G., Stich, V.: Produktion am Standort Deutschland. VDMA (2013)
2. Hauptvogel, A.: Bewertung und Gestaltung von cyber-physischer Feinplanung. Zugl. Aachen, Technische Hochschule, Diss. 2015, 1st edn. Ergebnisse aus der Produktionstechnik Produktionssystematik, vol. 2015, p. 6. Apprimus-Verlag, Aachen (2015)
3. Orlicky, J.: Material Requirements Planning: The New Way of Life in Production and Inventory Management. McGraw-Hill, New York (1975)
4. Tempelmeier, H.: Material-Logistik: Modelle und Algorithmen für die Produktionsplanung und -steuerung in Advanced Planning-Systemen, 6th edn. Springer, Berlin (2006)
5. van Donselaar, K.: The use of MRP and LRP in a stochastic environment. Prod. Plan. Control **3**, 239–246 (1992)
6. Helber, S.: Operations-Management-Tutorial. (ein Anfänger-Lehrbuch zum Operations-Management für alle, die auch gerne Formeln mögen). Helber, Hildesheim (2014)
7. Dickersbach, J.T., Keller, G.: Produktionsplanung und -steuerung mit SAP ERP. (umfassendes Handbuch zur Diskreten Fertigung mit SAP; Prozesse und Customizing von PP verständlich erklärt; mit Informationen zu Sonderbeschaffungsformen und der Integration mit SAP APO), 3rd edn. SAP Press. Galileo Press, Bonn (2012)
8. Hoppe, M.: Bestandsoptimierung mit SAP. (Mit SAP ERP und SAP SCM Bestände optimieren und Bestandskosten senken; Prognosegenauigkeit und Planung verbessern; mit zahlreichen Praxisbeispielen), 3rd edn. SAP betriebswirtschaftlich. Galileo Press, Bonn (2012)
9. Ramasesh, R.: Dynamic job shop scheduling: a survey of simulation research. Omega **18**, 43–57 (1990)
10. Bangsow, S.: Praxishandbuch Plant Simulation und SimTalk. Anwendung und Programmierung in über 150 Beispiel-Modellen. Hanser Verlag, München (2011)
11. Dangelmaier, W., Laroque, C., Klaas, A. (eds.): Simulation in Produktion und Logistik 2013. (Entscheidungsunterstützung von der Planung bis zur Steuerung; 15. ASIM Fachtagung); Paderborn, 09–11 Oktober 2013. ASIM-Mitteilung, vol. 147. Heinz-Nixdorf-Institute, University of Paderborn, Paderborn (2013)

12. Simini, et al.: Proceedings of the 38th conference on Winter simulation. In: Winter Simulation Conference, s. l (2006)
13. Klemmt, A.: Ablaufplanung in der Halbleiter- und Elektronikproduktion. Hybride Optimierungsverfahren und Dekompositionstechniken. Zugl. Aachen, Technische Hochschule, Diss. 2011. Vieweg+Teubner Verlag, Wiesbaden (2012)
14. März, L., Krug, W., Rose, O., Weigert, G.: Simulation und Optimierung in Produktion und Logistik. Springer, Heidelberg (2011). https://doi.org/10.1007/978-3-642-14536-0
15. Leypold, et al.: Integrierte Materialflusssimulation zur dynamischen Produktionsplanung und -steuerung (IsiPS). Abschlussbericht AiF-Vorhaben KF 0444 601 KSS2 (2003)
16. Moon, Y.B., Phatak, D.: Enhancing ERP system's functionality with discrete event simulation. Ind. Manag. Data Syst. **105**, 1206–1224 (2005)
17. Graves, R.J., Milne, R.J.: A new method for order release. Prod. Plann. Control **8**, 332–342 (1997)

Procurement Decisions in Multi-period Supply Chain

Izabela Nielsen and Subrata Saha(✉)

Department of Materials and Production, Aalborg University, 9220 Aalborg, DK, Denmark
izabela@mp.aau.dk, subrata.scm@gmail.com

Abstract. Pricing and ordering decision in multi-period supply chain environments is not explored comprehensively. We consider three pragmatic procurement scenarios where the retailer can procure products (i) by maintaining strategic inventory, (ii) in bulk in first-period and distribute them in forthcoming selling period, and (iii) without maintaining any inventory. The results suggest that conventional single period planning exhibit sub-optimal characteristics. Build-up strategic inventory is not always profitable for the retailer. The retailer can also earn more profits by employing a bulk procurement strategy.

Keywords: Multi-period supply chain · Inventory · Game theory

1 Introduction

Efficient inventory management is one of the key issues in retailing. Retailers maintain inventory to reduce transportation cost, take advantage of quantity discounts, ensure continuity of selling activities, evade variations in wholesale price and demand etc. [4,5,9,10]. However, Anand et al. [1] reported that retailer's decision to maintain inventory in multi-period supply chain interactions under manufacturer-stackelberg game can reduce the degree of double marginalization. They found that the retailer can force the manufacturer to reduce the wholesale price of forthcoming periods by maintaining surplus order quantities as strategic inventory. Arya and Mittendorf [3] proved that the manufacturer can curtail advantage of the retailer in building strategic inventory by introducing consumer rebate. Consumer rebate prevents the retailer to maintain high amounts of SI. Arya et al. [2] extended this enticing stream of research and compare the effect of SI in the presence of multiple retail outlets. Hartwig et al. [6] conducted empirical investment to explore the effect of SI and found that the retailer can immensely induce differentiated wholesale pricing behaviour by building up SI. Mantin and Jiang [7] explored the impact of the product quality deterioration in the presence of SI. Moon et al. [8] analyzed the impact of SI in perspective of supply

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 433–442, 2018.
https://doi.org/10.1007/978-3-319-99704-9_53

chain coordination. They found that the optimal supply chain profit cannot be achieved by implementing quadratic quantity discount contract mechanism. All the above cited contributions consider multi-period interaction among supply chain member to explore the consequences of SI.

In the existing literature on supply chain models, it is assumed that the retailer procures products to satisfy demand in each selling period. However, in practice, the retailer maintains SI to satisfy future demand. But, to the best of the authors' knowledge, the advantage of SI is not fully explored in current state. We consider three procurement decision for the retailer and explore the pricing and ordering behaviour under five consecutive selling period. It is found that the pricing behaviour is correlated with procurement decision. The single-period procurement decision always leads to suboptimal solution. The supply chain members can receive higher profit if the retailer maintains SI or procures in bulk.

2 Problem Description

We explore the interaction in a serial supply chain with one retailer and one supplier under price-sensitive demand in a fifth-period game. The retailer in the supply chain has a downstream retail monopoly and rely solely on the upstream supplier for the retailed good. Three procurement strategies are considered. In first procurement strategy (WSI), the retailer may maintain SI in between two-consecutive selling period. In Second procurement strategy (BP), the retailer procures in bulk for the first selling period and distribute those in forthcoming periods. Third procurement strategy (BM) is similar to the conventional literature, where the retailer procures products to satisfy demand for each period. We consider linear price sensitive demand and derive optimal solution. For feasibility of the optimal solution, it is assumed that the retail (p_t) and wholesale prices (w_t) at each period satisfy the following relations $p_t > w_t > 0$, $\forall t = 1, \ldots, 5$. The unit holding cost for the retailer is h. All the parameters related to market demand are common knowledge between supply chain members [6].

2.1 Optimal Decision in the Presence of SI

At the beginning of each period ($t = 1, \cdots, 5$), the supplier determines a wholesale price (w_t^{wsi}). The retailer then procures (Q_t^{wsi}) amounts of product and sets retail price (p_t^{wsi}) to satisfy market demand ($q_t^{wsi} = a - bp_t^{wsi}$). If the procured quantity at each period is larger than the quantity sold in the that period (i.e., if $Q_t^{wsi} > q_t^{wsi}$), then the retailer builds up SI ($I_t^{wsi} = Q_t^{wsi} - q_t^{wsi}$) to be sold in the immediate period and invests hI_t^{wsi} as holding cost. The profit functions for the supplier and retailer are obtained as follows:

$$\pi_{r5}^{wsi} = p_5^{wsi}(a - bp_5^{wsi}) - w_5^{wsi}(a - bp_5^{wsi} - I_4^{wsi})$$
$$\pi_{m5}^{wsi} = w_5^{wsi}(a - bp_5^{wsi} - I_4^{wsi})$$
$$\pi_{r4}^{wsi} = p_4^{wsi}(a - bp_4^{wsi}) - w_4^{wsi}(a - bp_4^{wsi} + I_4^{wsi} - I_3^{wsi}) - hI_4^{wsi} + \pi_{r5}^{wsi}$$
$$\pi_{m4}^{wsi} = w_4^{wsi}(a - bp_4^{wsi} + I_4^{wsi} - I_3^{wsi}) + \pi_{m5}^{wsi}$$
$$\pi_{r3}^{wsi} = p_3^{wsi}(a - bp_3^{wsi}) - w_3^{wsi}(a - bp_3^{wsi} + I_3^{wsi} - I_2^{wsi}) - hI_3^{wsi} + \pi_{r4}^{wsi}$$
$$\pi_{m3}^{wsi} = w_3^{wsi}(a - bp_3^{wsi} + I_3^{wsi} - I2^{wsi}) + \pi_{m4}^{wsi}$$
$$\pi_{r2}^{wsi} = p_2^{wsi}(a - bp_2^{wsi}) - w_2^{wsi}(a - bp_2^{wsi} - I_1^{wsi} + I_2^{wsi}) + \pi_{r3}^{wsi} - hI_2^{wsi}$$
$$\pi_{m2}^{wsi} = w_2^{wsi}(a - bp_2^{wsi} - I_1^{wsi} + I_2^{wsi}) + \pi_{m3}^{wsi}$$
$$\pi_{r1}^{wsi} = p_1^{wsi}(a - bp_1^{wsi}) - w_1^{wsi}(a - bp_1^{wsi} + I_1^{wsi}) - hI_1^{wsi} + \pi_{r2}^{wsi}$$
$$\pi_{m1}^{wsi} = w_1^{wsi}(a - bp_1^{wsi} + I_1^{wsi}) + \pi_{m2}^{wsi}$$

The optimal solution for the retailer fifth-period optimization problem presented in the first equation is obtained by solving $\frac{d\pi_{r5}^{wsi}}{dp_5^{wsi}} = 0$. On simplification, we have $p_5^{wsi} = \frac{a+bw_5^{wsi}}{2b}$. The optimal solution for the supplier fifth-period optimization problem presented in the second equation is obtained by solving $\frac{\partial\pi_{m5}^{wsi}}{\partial w_5^{wsi}} = 0$. On simplification, one can obtain $w_5^{wsi} = \frac{a-2I_4^{wsi}}{2b}$. The profit function for the retailer and supplier in fifth-period is concave because $\frac{d^2\pi_{r5}^{wsi}}{dp_5^{wsi^2}} = -2b < 0$ and $\frac{d^2\pi_{m5}^{wsi}}{dw_5^{wsi^2}} = -b < 0$, respectively.

Substituting the optimal response obtained in fifth-period, profit function for the retailer in fourth-period is obtained as follows:

$$\pi_{r4}^{wsi} = \frac{a^2 + 12aI_4^{wsi} - 12I_4^{wsi^2}}{16b} + p_4^{wsi}(a - bp_4^{wsi}) - (a - I_3^{wsi} - bp_4^{wsi})w_4^{wsi} - hI_4^{wsi}$$

The optimal solution for the above problem is obtained by solving $\frac{\partial\pi_{r4}^{wsi}}{\partial p_4^{wsi}} = 0$ and $\frac{\partial\pi_{r4}^{wsi}}{\partial I_4^{wsi}} = 0$. On simplification, $p_4^{wsi} = \frac{a+bw_4^{wsi}}{2b}$ and $I_4^{wsi} = \frac{3a-4b(h+w_4^{wsi}))}{6}$. Substituting optimal response, the profit function for the supplier is obtained as $\pi_{m4}^{wsi} = (a-I_3^{wsi})w_4^{wsi} + \frac{b(4h^2-4hw_4^{wsi}-17w_4^{wsi^2})}{18}$. After solving first order condition, the wholesale price for the fourth period is obtained as $w_4^{wsi} = \frac{9a-2bh-9I_3^{wsi}}{17b}$.

Because $\frac{\partial^2\pi_{r4}^{wsi}}{\partial p_4^{wsi^2}} = -2b < 0$ and $\frac{\partial^2\pi_{r4}^{wsi}}{\partial p_4^{wsi^2}}\frac{\partial^2\pi_{r4}^{wsi}}{\partial I_4^{wsi^2}} - \left(\frac{\partial^2\pi_{r4}^{wsi}}{\partial I_4^{wsi}\partial p_4^{wsi}}\right)^2 = 3 > 0$; and $\frac{\partial^2\pi_{m4}^{wsi}}{\partial w_4^{wsi^2}} = -\frac{17b}{9} < 0$, the profit function of the retailer and supplier are concave. Similarly, the profit function for the retailer in third-period is obtained as follows:

$$\pi_{r3}^{wsi} = \frac{155a^2 - 118abh + 304b^2h^2 + 846aI_3^{wsi} - 460bhI_3^{wsi} - 423I_3^{wsi^2}}{1156b}$$
$$+p_3^{wsi}(a - bp_3^{wsi}) - (a - I_2^{wsi} + I_3^{wsi} - bp_3^{wsi})w_3^{wsi} - hI_3^{wsi}$$

Corresponding optimal retail price and SI are $p_3^{wsi} = \frac{a+bw_3^{wsi}}{2b}$ and $I_3^{wsi} = \frac{423a-2b(404h+289w_3^{wsi})}{423}$, respectively. Substituting optimal response for the retailer, profit function for the supplier in third-period is obtained as follows:

$$\pi_{m3}^{wsi} = \frac{3aw_3^{wsi} - 2I_2^{wsi}w_3^{wsi}}{2} + \frac{b(38824h^2 - 27400hw_3^{wsi} - 54561{w_3^{wsi}}^2)}{39762}$$

and corresponding wholesale price is $w_3^{wsi} = \frac{59643a-27400bh-39762I_2^{wsi}}{109122b}$. Note the the third-period optimization problem for the retailer and supplier are concave because $\frac{\partial^2\pi_{r3}^{wsi}}{\partial {p_3^{wsi}}^2} = -2b < 0$ and $\frac{\partial^2\pi_{r3}^{wsi}}{\partial {p_3^{wsi}}^2}\frac{\partial^2\pi_{r3}^{wsi}}{\partial {I_3^{wsi}}^2} - \left(\frac{\partial^2\pi_{r3}^{wsi}}{\partial I_3^{wsi}\partial p_3^{wsi}}\right)^2 = \frac{423}{289} > 0$; and $\frac{\partial^2\pi_{m3}^{wsi}}{\partial {w_3^{wsi}}^2} = -\frac{18187b}{6627} < 0$. The second-period profit function for the retailer is obtained as follows:

$$\pi_{r2}^{wsi} = p_2^{wsi}(a - bp_2^{wsi}) - (a - I_1^{wsi} + I_2^{wsi} - bp_2^{wsi})w_2^{wsi} - hI_2^{wsi} + \frac{0.208932a^2 - 0.335467abh + 1.17731b^2h^2 + 0.721424aI_2^{wsi} - 0.776356bhI_2^{wsi} - 0.240475{I_2^{wsi}}^2}{b}$$

Corresponding optimal retail price and SI are $p_2^{wsi} = \frac{a+bw_2^{wsi}}{2b}$ and $I_2^{wsi} = \frac{3a}{2} - \frac{2b(5288037907h+2976902721w_2^{wsi})}{2863480311}$, respectively. Substituting optimal response, the profit function for the supplier in second-period is obtained as $\pi_{m2}^{wsi} = 2aw_2^{wsi} - I_1^{wsi}w_2^{wsi} + b(2.62087h^2 - 1.41726hw_2^{wsi} - 1.79158{w_2^{wsi}}^2)$, and corresponding wholesale price is $w_2^{wsi} = \frac{0.558166a-0.395535bh-0.279083I_1^{wsi}}{b}$. Note the second-period optimization problem for the retailer and supplier are concave because $\frac{\partial^2\pi_{r2}^{wsi}}{\partial {p_2^{wsi}}^2} = -2b < 0$ and $\frac{\partial^2\pi_{r2}^{wsi}}{\partial {p_2^{wsi}}^2}\frac{\partial^2\pi_{r2}^{wsi}}{\partial {I_2^{wsi}}^2} - \left(\frac{\partial^2\pi_{r2}^{wsi}}{\partial I_2^{wsi}\partial p_2^{wsi}}\right)^2 = 0.961899 > 0$; and $\frac{\partial^2\pi_{m2}^{wsi}}{\partial {w_2^{wsi}}^2} = -3.58316b < 0$, respectively. Finally, the first-period profit function for the retailer is obtained as follows:

$$\pi_{r1}^{wsi} = \frac{1}{b}[0.285445a^2 - bI_1^{wsi}(2.1416h + w_1^{wsi}) + ab(p_1^{wsi} - w_1^{wsi} - 0.716806h) + 0.714555aI_1^{wsi} - 0.178639{I_1^{wsi}}^2 + b^2(3.19862h^2 - p_1^{wsi}(p_1^{wsi} - w_1^{wsi}))]$$

Correspondingly optimal retail price and SI are $p_1^{wsi} = \frac{a+bw_1^{wsi}}{2b}$ and $I_1^{wsi} = 2a - 5.99421bh - 2.79895bw_1^{wsi}$. Substituting the optimal response for the retailer, the profit function for the supplier in first-period is obtained as follows:

$$\pi_{m1}^{wsi} = 2.5aw_1^{wsi} + b(5.54404h^2 - 2.41898hw_1^{wsi} - 2.20576{w_1^{wsi}}^2)$$

and corresponding wholesale price is $w_1^{wsi} = \frac{0.566697a-0.548333bh}{b}$. Note that the first-period optimization problem for the retailer and supplier are concave as $\frac{\partial^2\pi_{r1}^{wsi}}{\partial {p_1^{wsi}}^2} = -2b < 0$ and $\frac{\partial^2\pi_{r1}^{wsi}}{\partial {p_1^{wsi}}^2}\frac{\partial^2\pi_{r1}^{wsi}}{\partial {I_1^{wsi}}^2} - \left(\frac{\partial^2\pi_{r1}^{wsi}}{\partial I_1^{wsi}\partial p_1^{wsi}}\right)^2 = 0.714555 > 0$; and $\frac{\partial^2\pi_{m1}^{wsi}}{\partial {w_1^{wsi}}^2} = -4.41153b < 0$, respectively. By using back substitution, one can obtain the following optimal solutions:

$$w_1^{wsi} = \frac{0.783349a - 0.274166bh}{b} \quad w_2^{wsi} = \frac{0.442669a + 0.849025bh}{b} \quad w_3^{wsi} = \frac{0.335378a + 1.73797bh}{b}$$
$$w_4^{wsi} = \frac{0.242614a + 2.15087bh}{b} \quad w_5^{wsi} = \frac{0.161743a + 2.10058bh}{b}$$
$$p_1^{wsi} = \frac{0.783349a - 0.274166bh}{b} \quad p_2^{wsi} = \frac{0.721334a + 0.424512bh}{b} \quad p_3^{wsi} = \frac{0.667689a + 0.868984bh}{b}$$
$$p_4^{wsi} = \frac{0.621307a + 1.07544bh}{b} \quad p_5^{wsi} = \frac{0.580871a + 1.05029bh}{b}$$
$$I_1^{wsi} = 0.413846a - 4.45946bh \quad I_2^{wsi} = 0.579595a - 5.45874bh$$
$$I_3^{wsi} = 0.541729a - 4.28498bh \quad I_4^{wsi} = 0.338257a - 2.10058bh$$
$$\pi_{r5}^{wsi} = \frac{0.230379a^2 - 0.509631abh - 3.30933b^2h^2}{b^2} \quad \pi_{m5}^{wsi} = \frac{2.20622(0.0769991a + bh)^2}{b^2}$$
$$\pi_{r4}^{wsi} = \frac{0.423153a^2 - 1.75473abh - 4.75054b^2h^2}{b^2} \quad \pi_{m4}^{wsi} = \frac{0.0555915a^2 + 0.985682abh + 4.59145b^2h^2}{b^2}$$
$$\pi_{r3}^{wsi} = \frac{0.546283a^2 - 3.20185abh - 1.7504b^2h^2}{b^2} \quad \pi_{m3}^{wsi} = \frac{0.154342a^2 + 1.59964abh + 5.12115b^2h^2}{b^2}$$
$$\pi_{r2}^{wsi} = \frac{0.550566a^2 - 3.71641abh + 4.73697b^2h^2}{b^2} \quad \pi_{m2}^{wsi} = \frac{0.35107a^2 + 1.34668abh + 3.91231b^2h^2}{b^2}$$
$$\pi_{r1}^{wsi} = \frac{0.362978a^2 - 1.25738abh + 6.82633b^2h^2}{b^2} \quad \pi_{m1}^{wsi} = \frac{0.708371a^2 - 1.37083abh + 6.20725b^2h^2}{b^2}.$$

2.2 Optimal Decisions in Scenario BP

At the beginning of first period, the supplier determines a wholesale price (w_1^{bp}) and then the retailer procures $a - bp_1^{bp} + \sum_{t=1}^{4} I_t^{bp}$ unit of products and sets the retail price (p_1^{bp}). In next four selling period, the supplier determines wholesale price (w_t^{bp}) and then the retailer procures ($q_t^{bp} = a - bp_t^{bp} - I_{t-1}^{bp})(t = 2, \cdots, 5)$ units of product and sets retail price (p_t^{bp}) to satisfy market demand. The profit functions of the supplier and retailer for five consecutive selling periods are obtained as follows:

$$\pi_{r5}^{bp} = p_5^{bp}(a - bp_5^{bp}) - w_5^{bp}(a - bp_5^{bp} - I_4^{bp})$$
$$\pi_{m5}^{bp} = w_5^{bp}(a - bp_5^{bp} - I_4^{bp})$$
$$\pi_{r4}^{bp} = p_4^{bp}(a - bp_4^{bp}) - w_4^{bp}(a - bp_4^{bp} - I_3^{bp}) - hI_4^{bp} + \pi_{r5}^{bp}$$
$$\pi_{m4}^{bp} = w_4^{bp}(a - bp_4^{bp} - I_3^{bp}) + \pi_{m5}^{bp}$$
$$\pi_{r3}^{bp} = p_3^{bp}(a - bp_3^{bp}) - w_3^{bp}(a - bp_3^{bp} - I_2^{bp}) - h(I_3^{bp} + I_4^{bp}) + \pi_{r4}^{bp}$$
$$\pi_{m3}^{bp} = w_3^{bp}(a - bp_3^{bp} - I_2^{bp}) + \pi_{m4}^{bp}$$
$$\pi_{r2}^{bp} = p_2^{bp}(a - bp_2^{bp}) - w_2^{bp}(a - bp_2^{bp} - I_1^{bp}) - h\sum_{t=2}^{4} I_t^{bp} + \pi_{r3}^{bp}$$
$$\pi_{m2}^{bp} = w_2^{bp}(a - bp_2^{bp} - I_1^{bp}) + \pi_{m3}^{bp}$$
$$\pi_{r1}^{bp} = p_1^{bp}(a - bp_1^{bp}) - w_1^{bp}(a - bp_1^{bp} + \sum_{t=1}^{4} I_t^{bp}) - \sum_{t=1}^{4} I_t^{bp} + \pi_{r2}^{bp}$$
$$\pi_{m1}^{bp} = w_1^{bp}(a - bp_1^{bp} + \sum_{t=1}^{4} I_t^{bp}) + \pi_{m2}^{bp}$$

The optimal solution for the retailer fifth-period optimization problem is obtained by solving $\frac{d\pi_{r5}^{bp}}{dp_5^{bp}} = 0$. On simplification, we have $p_5^{bp} = \frac{a+bw_5^{bp}}{2b}$. The optimal solution for the supplier fifth-period optimization problem is obtained by solving $\frac{\partial \pi_{m5}^{bp}}{\partial w_5^{bp}} = 0$. On simplification, one can obtain $w_5^{bp} = \frac{a-2I_4^{bp}}{2b}$. The profit function for the retailer and supplier in fifth-period are concave because $\frac{d^2\pi_{r5}^{si}}{dp_5^{bp^2}} = -2b < 0$ and $\frac{d^2\pi_{m5}^{bp}}{dw_5^{bp^2}} = -b < 0$, respectively. Similar to previous subsection, the profit function for the retailer in first-period is obtained as follows:

$$\pi_{r1}^{bp} = \frac{a^2 - 3I_1^{bp^2} + 3a(I_1^{bp} + I_2^{bp} + I_3^{bp} + I_4^{bp}) - 4bh(I_2^{bp} + 2I_3^{bp} + 3I_4^{bp}) - 3(I_2^{bp^2} + I_3^{bp^2} + I_4^{bp^2})}{4b}$$
$$+(p_1^{bp} - w_1^{bp})(a - bp_1^{bp}) - (I_1^{bp} + I_2^{bp} + I_3^{bp} + I_4^{bp})w_1^{bp} - h(I_1^{bp} + I_2^{bp} + I_3^{bp} + I_4^{bp})$$

Optimal solution for the retailer first-period optimization problem is obtained by solving $\frac{\partial \pi_{r1}^{bp}}{\partial p_1^{bp}} = 0$; $\frac{\partial \pi_{r1}^{bp}}{\partial I_1^{bp}} = 0$; $\frac{\partial \pi_{r1}^{bp}}{\partial I_2^{bp}} = 0$; $\frac{\partial \pi_{r1}^{bp}}{\partial I_3^{bp}} = 0$ and $\frac{\partial \pi_{r1}^{bp}}{\partial I_4^{bp}} = 0$, simultaneously. After solving, following solution is obtained: $p_1^{bp} = \frac{a+bw_1^{bp}}{2b}$; $I_1^{bp} = \frac{3a-4b(h+w_1^{bp})}{6}$; $I_2^{bp} = \frac{3a-4b(2h+w_1^{bp})}{6}$; $I_3^{bp} = \frac{3a-4b(3h+w_1^{bp})}{6}$; $I_4^{bp} = \frac{3a-4b(4h+w_1^{bp})}{6}$.
We compute the following Hessian matrix to check concavity:

$$H^{bp} = \begin{pmatrix} \frac{\partial^2 \pi_{r1}^{bp}}{\partial p_1^{bp^2}} & \frac{\partial^2 \pi_{r1bp}^{bp}}{\partial p_1^{bp}\partial I_1^{bp}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial p_1^{bp}\partial I_2^{bp}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial p_1^{bp}\partial I_3^{bp}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial p_1^{bp}\partial I_4^{bp}} \\ \frac{\partial^2 \pi_{r1}^{bp}}{\partial p_1^{bp}\partial I_1^{bp}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial I_1^{bp^2}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial I_1^{bp}\partial I_2^{bp}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial I_1^{bp}\partial I_3^{bp}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial I_1^{bp}\partial I_4^{bp}} \\ \frac{\partial^2 \pi_{r1}^{bp}}{\partial p_1^{bp}\partial I_2^{bp}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial I_1^{bp}\partial I_2^{bp}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial I_2^{bp^2}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial I_2^{bp}\partial I_3^{bp}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial I_2^{bp}\partial I_4^{bp}} \\ \frac{\partial^2 \pi_{r1}^{bp}}{\partial p_1^{bp}\partial I_3^{bp}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial I_1^{bp}\partial I_3^{bp}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial I_2^{bp}\partial I_3^{bp}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial I_3^{bp^2}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial I_3^{bp}\partial I_4^{bp}} \\ \frac{\partial^2 \pi_{r1}^{bp}}{\partial p_1^{bp}\partial I_4^{bp}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial I_1^{bp}\partial I_4^{bp}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial I_2^{bp}\partial I_4^{bp}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial I_3^{bp}\partial I_4^{bp}} & \frac{\partial^2 \pi_{r1}^{bp}}{\partial I_4^{bp^2}} \end{pmatrix} == \begin{pmatrix} -2b & 0 & 0 & 0 & 0 \\ 0 & -\frac{3}{2b} & 0 & 0 & 0 \\ 0 & 0 & -\frac{3}{2b} & 0 & 0 \\ 0 & 0 & 0 & -\frac{3}{2b} & 0 \\ 0 & 0 & 0 & 0 & -\frac{3}{2b} \end{pmatrix}$$

The values of principal minors are $\Delta_1 = -2b < 0$; $\Delta_2 = 3 > 0$; $\Delta_3 = -\frac{9}{2b} < 0$; $\Delta_4 = \frac{27}{4b^2} > 0$ and $\Delta_5 = -\frac{81}{8b^3} < 0$, i.e. profit function for the retailer is concave. Substituting the optimal response for the retailer, the profit function for the supplier in first-period is obtained as $\pi_{m1}^{bp} = \frac{45aw_1^{bp}+b(120h^2-40hw_1^{bp}-41w_1^{bp^2})}{18}$ and the corresponding wholesale price is $w_1^{bp} = \frac{5(9a-8bh)}{82b}$. By using back substitution, one can obtain the following optimal solutions:

$$w_2^{bp} = \frac{15a + 14bh}{41b} \quad w_3^{bp} = \frac{45a + 124bh}{123b} \quad w_4^{bp} = \frac{45ab + 206bh}{123b} \quad w_5^{bp} = \frac{3(5a + 32bh)}{41b}$$
$$p_1^{bp} = \frac{127a - 40bh}{164b} \quad p_2^{bp} = \frac{7(4a + bh)}{41b} \quad p_3^{bp} = \frac{2(42a + 31bh)}{123b} \quad p_4^{bp} = \frac{84a + 103bh}{123} \quad p_5^{bp} = \frac{4(7a + 12bh)}{41b}$$
$$I_1^{bp} = \frac{11a - 28bh}{82b} \quad I_2^{bp} = \frac{33a - 248bh}{246} \quad I_3^{bp} = \frac{33a - 412bh}{246} \quad I_4^{bp} = \frac{11a - 192bh}{82}$$
$$\pi_{r5}^{bp} = \frac{503a^2 - 4320abh - 13824b^2h^2}{3362b} \quad \pi_{m5}^{bp} = \frac{2(6a + 29bh)^2}{1089b}$$
$$\pi_{r4}^{bp} = \frac{3018a^2 - 23583abh - 39074b^2h^2}{10086b} \quad \pi_{m4}^{bp} = \frac{5(405a^2 + 4446abh + 12538b^2h^2)}{15129b}$$
$$\pi_{r3}^{bp} = \frac{4527a^2 - 31869abh - 6254b^2h^2}{10086b} \quad \pi_{m3}^{bp} = \frac{6075a^2 + 55620abh + 140756b^2h^2}{30258b}$$
$$\pi_{r2}^{bp} = \frac{3018a^2 - 18909abh + 21770b^2h^2}{5043b} \quad \pi_{m2}^{bp} = \frac{10(405a^2 + 2970abh + 7126b^2h^2)}{15129b}$$
$$\pi_{r1}^{bp} = \frac{5(5727a^2 - 15648abh + 114976b^2h^2)}{80688b} \quad \pi_{m1}^{bp} = \frac{5(405a^2 - 720abh + 4256b^2h^2)}{2952}$$

2.3 Benchmark Model

In Scenario BM, the retailer does not maintain SI or procure products in bulk. The profit functions for the retailer and supplier in each selling period are $\pi_r^{bm} = (p^{bm} - w^{bm})(a - bp^{bm})$ and $\pi_m^{bm} = w^{bm}(a - bp^{bm})$, respectively. One may obtain the optimal response function of the retailer by solving first order condition of optimization as $p(w^{bm}) = \frac{a+bw^{bm}}{2}$. Substituting optimal response, the supplier's profit function is obtained as follows, $\pi_m = \frac{w^{bm}(a-bw^{bm})}{2}$ and the corresponding optimal wholesale price is $w^{bm} = \frac{a}{2b}$. Based on the optimal decisions, the closed form profit functions can be obtained as, $\pi_r^{bm} = \frac{a^2}{16b}$ and $\pi_m^{bm} = \frac{a^2}{8b}$. Note that in absence of additional inventory, wholesale and retail prices remain uniform in each period.

3 Managerial Implications

Proposition 1. In procurement scenario BP,

(i) the retailer and supplier sets maximum retail and wholesale price in first selling period, respectively.
(ii) the retail and wholesale prices increases from the second selling period.
(iii) the amount of products distributed by the retailer decreases as the selling period progress.

Proof. The retail and wholesale prices, and SI in Scenario BP satisfy the following relations:

$$p_1^{bp} - p_2^{bp} = \frac{15a - 68bh}{164b} > 0 \quad \text{and} \quad p_2^{bp} - p_3^{bp} = p_3^{bp} - p_4^{bp} = p_4^{bp} - p_5^{bp} = -\frac{h}{3} < 0$$
$$w_1^{bp} - w_2^{bp} = \frac{15a - 68bh}{82b} > 0 \quad \text{and} \quad w_2^{bp} - w_2^{bp} = w_3^{bp} - w_4^{bp} = w_4^{bp} - w_5^{bp} = -\frac{2h}{3} < 0$$
$$I_1^{bp} - I_2^{bp} = I_2^{bp} - I_3^{bp} = \frac{2bh}{3} > 0$$

The above inequalities ensures proof.

Proposition 2. In procurement scenario WSI,

(i) the retailer and supplier sets maximum retail and wholesale price in first selling period, respectively.
(ii) the retail and wholesale prices decreases from the second selling period.

Proof. The retail and wholesale prices, and SI in Scenario WSI:

$$p_1^{wsi} - p_2^{wsi} = \frac{0.0620142a - 0.6986787bh}{b} > 0, \quad p_2^{wsi} - p_3^{wsi} = \frac{0.053645a - 0.444472bh}{b} > 0,$$
$$p_3^{wsi} - p_4^{wsi} = \frac{0.046382a - 0.206451bh}{b} > 0, \quad p_4^{wsi} - p_5^{wsi} = \frac{0.04044a + 0.02515h}{b} > 0$$
$$w_1^{wsi} - w_2^{wsi} = \frac{0.12402847a - 1.397357bh}{b} > 0, \quad w_2^{wsi} - w_3^{wsi} = \frac{0.1072902a - 0.888943bh}{b} > 0$$
$$w_3^{wsi} - w_4^{wsi} = \frac{0.092764a - 0.41290bh}{b} > 0, \quad w_4^{wsi} - w_5^{wsi} = \frac{0.080871a + 0.05029bh}{b} > 0$$

The above inequalities ensures proof.

Proposition 3.

(i) The retailer decision to maintain SI always outperforms the single period procurement decision if $h \in \left[\frac{0.0591229a}{b}, \frac{0.125072a}{b}\right]$

(ii) Supply chain member receives higher profits in procurement scenarios under BP compared to BM.

Proof. The following relations ensure that the average profits of the supplier always greater compere to the profit earns by the supplier in Scenario BM:

$$\pi_{m1}^{wsi}/5 - \pi_m^{bm} = \frac{0.016674272a^2 - 0.27416633ahb + 1.2414495b^2h^2}{b} > 0$$

$$\pi_{m1}^{bp}/5 - \pi_m^{bm} = \frac{9a^2 - 180ahb + 1064b^2h^2}{738b} = \frac{9(a - 10bh)^2 + 164b^2h^2}{738b} > 0$$

Similarly, the difference of average profits obtain under different scenarios with profits obtain in Scenario BM are

$$\pi_{r1}^{wsi}/5 - \pi_r^{bm} = \frac{0.0100956a^2 - 0.251475abh + 1.36527b^2h^2}{b} \quad \text{if} \quad h \in \left[\frac{0.0591229a}{b}, \frac{0.125072a}{b}\right]$$

$$\pi_{r1}^{bp}/5 - \pi_r^{bm} = \frac{171a^2 - 3912abh + 28744b^2h^2}{20172b} > 0$$

The above inequalities ensures proof.

The graphical representation of the profit functions of the retailer and supplier are shown in Figs. 1a and b.

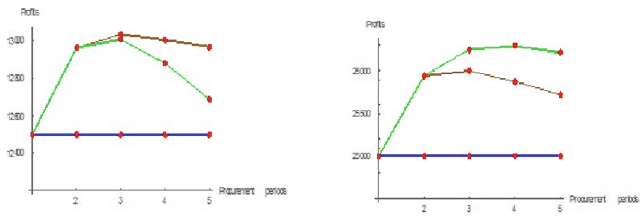


Fig. 1. a. Average Profits of the retailer b. Average profits of the manufacturer a = 200, b = 0.2, h = 50 Scenario BP (green), WSI (Brown), and BM (Blue) (Color figure online)

Figures 1a and b demonstrate the profits of the supply chain members if the retailer makes procurement planning for five consecutive cycle. It is found that Scenario BM is always outperformed by both scenarios BP and SI. It is found that the profit functions of the retailer does not demonstrate a cumulatively pattern. Due to additional procurement in the first selling period, the profit functions demonstrate that nature. However, one can not conclude with regards to the optimality of the procurement planning of the retailer.

Price elasticity and product holding cost are two extremely important factors affecting procurement decision and overall profitability. Price-elasticity is a critical factor [11,12] influencing the demand. Therefore, more analytical investigations are required to obtain concrete conclusion.

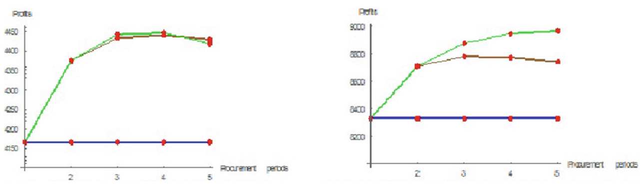


Fig. 2. a. Average Profits of the retailer b. Average profits of the manufacturer a = 200, b = 0.6, h = 10 Scenario BP (green), WSI (Brown), and BM (Blue) (Color figure online)

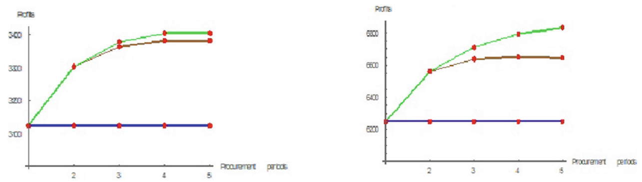


Fig. 3. a. Average Profits of the retailer b. Average profits of the manufacturer a = 200, b = 0.8, h = 5 Scenario BP (green), WSI (Brown), and BM (Blue) (Color figure online)

4 Conclusion

The pricing and procurement decisions in a supplier-retailer five-period supply chain is explored in this study. Under price sensitive demand, impact of three procurement decisions are analyzed and corresponding Stackelberg equilibriums are compared. The comparison among equilibrium outcomes in perspective of profits of each supply chain members demonstrate how the procurement decision is influencing the overall preference of the supply chain members. In contrast to Anand et al. [1], it is found that the build-up SI is not always profitable for the retailer, and manufacturer also. Price-elasticity and holding cost of the retailer are critical factors effecting procurement decision.

The present analysis can be extended to include several important features. For the analytical tractability, we consider five consecutive selling period. In future, one can extend the generalized version of the proposed model. One can also consider the effect of product deterioration or imperfect quality item.

References

1. Anand, K., Anupindi, R., Bassok, Y.: Strategic inventories in vertical contracts. Manag. Sci. **54**(10), 1792–1804 (2018)
2. Arya, A., Frimor, H., Mittendorf, B.: Decentralized procurement in light of strategic inventories. Manag. Sci. **61**(3), 578–585 (2014)
3. Arya, A., Mittendorf, B.: Managing strategic inventories via manufacturer-to-consumer rebates. Manag. Sci. **59**(4), 813–818 (2013)

4. Nielsen, P., Nielsen, I., Steger-Jensen, K.: Analyzing and evaluating product demand interdependencies. Comput. Ind. **61**(9), 869–876 (2010)
5. Eriksen, P.S., Nielsen, P.: Order quantity distributions: estimating an adequate aggregation horizon. Manage. Prod. Eng. Rev. **7**(3), 39–48 (2016)
6. Hartwig, R., Inderfurth, K., Sadrieh, A., Voigt, G.: Strategic inventory and supply chain behavior. Prod. Oper. Manag. **24**(8), 1329–1345 (2015)
7. Mantin, B., Jiang, L.: Strategic inventories with quality deterioration. Eur. J. Oper. Res. **258**(1), 155–164 (2017)
8. Moon, I., Dey, K., Saha, S.: Strategic inventory: manufacturer vs. retailer investment. Transp. Res. Part E: Logist. Transp. Rev. **109**(C), 63–82 (2018)
9. Michna, Z., Nielsen, P., Nielsen, I.E.: The impact of stochastic lead times on the bullwhip effect - a theoretical insight. Prod. Manuf. Res. (2018). https://doi.org/10.1080/21693277.2018.1484822
10. Sitek, P., Wikarek, J., Nielsen, P.: A constraint-driven approach to food supply chain management. Ind. Manag. Data Syst. **117**(9), 2115–2138 (2017)
11. Walters, R., Bommer, W.: Measuring the impact of product and promotion-related factors on product category price elasticities. J. Bus. Res. **36**(3), 203–216 (1996)
12. Huang, A., Dawes, J., Lockshin, L., Greenacre, L.: Consumer response to price changes in higher-priced brands. J. Retail. Consum. Serv. **39**, 1–10 (2017)

Due-Date Based Multi-period Part Selection for Flexible Manufacturing Systems with Controllable Processing Times

Issa B. Zeid, Hyoung-Ho Doh, Jeong-Hoon Shin, and Dong-Ho Lee(✉)

Department of Industrial Engineering, Hanyang University, Seoul, Korea
leman@hanyang.ac.kr

Abstract. This study addresses a multi-period part selection problem for flexible manufacturing systems in which processing times are controllable. The problem is to determine the set of parts and their processing times while satisfying the processing time and the tool magazine capacities in each period of a planning horizon. The objective is to minimize the sum of processing, earliness/tardiness, subcontracting and tool costs. Practical considerations such as available tool copies and tool lives are also considered. An integer programming model is developed, and two-phase heuristics are proposed in which an initial solution is obtained by a greedy heuristic under initial processing times and then it is improved using local search methods while adjusting processing times. Computational experiments were done on a number of test instances, and the results are reported.

Keywords: Flexible manufacturing systems · Controllable processing times
Part selection · Heuristics

1 Introduction

Flexible manufacturing system (FMS) is an automated manufacturing system that consists of numerical control machines and an automated material handling/storage system, which are controlled by a computer control system. Each machine has an automatic tool changer that can interchange cutting tools automatically, which allows consecutive operations to be performed with negligible setup times. Therefore, an FMS is capable of processing various part types simultaneously with higher utilization.

Part selection, alternatively called batching in the literature, is the problem of selecting the parts to be produced during the upcoming planning period. Most previous studies on FMS part selection propose single-period models that determine a set of parts to be produced simultaneously during an upcoming period. See Hwang and Shogan [1], Kim and Yano [2] and Bilge et al. [3] for examples. To obtain better solutions over the planning horizon with multiple periods, some articles extend the single-period models to multi-period ones. See Stecke and Toczylowski [4] and Lee and Kim [5] for examples.

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 443–449, 2018.
https://doi.org/10.1007/978-3-319-99704-9_54

This study focuses on a multi-period part selection problem with controllable processing times, which is the problem of determining a set of parts and their processing times in each period of a planning horizon. The controllable processing times imply that part processing times are not given, but can be changed to cope with system requirements such as energy consumption, scheduling performances, and so on. See Nowicki and Zdrzalka [6] for the detail of the controllable processing time concept.

To represent the problem mathematically, an integer programming model is developed. Then, due to the complexity of the problem, two-phase heuristics are proposed in which an initial solution is obtained by a greedy heuristic under initial processing times and then it is improved using local search methods while adjusting part processing times. Computational experiments were done, and the results are reported.

2 Problem Description

The FMS considered in this study consists of one or more numerical control machines, each of which has a tool magazine of a limited tool slot capacity. The machines can process different parts with negligible setup times if tooled differently in the tool magazines. To produce a part, several tools are required and each tool requires one or more slots in the tool magazine, where each tool has multiple copies with a limited life. Also, processing times of parts are controllable with different processing costs.

The problem is to determine the set of parts to be produced in each period of a planning horizon and their processing times while satisfying the constraints on processing time capacity, tool magazine capacity, tool copies and tool lives. The objective is to minimize the sum of part processing, earliness/tardiness, subcontracting and tool costs. The problem can be represented as the following integer programming model. The notations used are summarized below.

Parameters

d_i due-date of part i

cp_i^j processing cost of part i under the jth available processing time

cd_{ih} earliness or tardiness cost of part i incurred when it is assigned to period h, i.e.

$$cd_{ih} = \begin{cases} \epsilon_i \cdot (d_i - h), \text{ } if\ h \le d_i \\ \tau_i \cdot (h - d_i), \text{ } if\ h \ge d_i, \end{cases}$$

where ϵ_i and τ_i are per-period earliness and tardiness cost of part i, respectively

cs_i subcontracting cost of part i

ct_t cost of tool type t

p_i^j jth available processing time of part i

$$\left(p_i^1 \le p_i^2 \le \cdots \le p_i^{J_i} \text{ and } cp_i^1 \ge cp_i^2 \ge \cdots \ge cp_i^{J_i} \text{ for all } i.\right)$$

TC_t number of available copies of tool type t

TL_t life of tool type t

s_t number of slots required by tool type t
Φ_t set of parts that require tool type t
L aggregated processing time capacity in period h
S aggregated tool magazine capacity in period h

Decision variables
x_{ih}^j = 1 if part i is assigned to period h with the jth available processing time, and 0 otherwise
y_{th} number of copies for tool type t used in period h

Now, the integer programming model is given below. The detailed explanation is skipped here due to the space limitation. The problem [P] is NP-hard because the problem with fixed part processing times can be reduced to the generalized assignment problem that is known to be NP-hard [7].

$$[\mathbf{P}]\text{Minimize } \sum_{i=1}^{I}\sum_{j=1}^{J_i}\sum_{h=1}^{H} cp_i^j \cdot x_{ih}^j + \sum_{i=1}^{I}\sum_{j=1}^{J_i}\sum_{h=1}^{H} cd_{ih} \cdot x_{ih}^j + \sum_{i=1}^{I} cs_i \cdot \left(1 - \sum_{j=1}^{J_i}\sum_{h=1}^{H} x_{ih}^j\right) + \sum_{t=1}^{T}\sum_{h=1}^{H} ct_{th} \cdot y_{th}$$

subject to

$$\sum_{j=1}^{J_i}\sum_{h=1}^{H} x_{ih}^j \le 1 \qquad \text{for all } i \tag{1}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J_i} p_i^j \cdot x_{ih}^j \le L \qquad \text{for all } h \tag{2}$$

$$\sum_{t=1}^{T} s_t \cdot y_{th} \le S \qquad \text{for all } h \tag{3}$$

$$\sum_{h=1}^{H} y_{th} \le TC_t \qquad \text{for all } t \tag{4}$$

$$\sum_{i\in\Phi_t}\sum_{j=1}^{J_i} p_i^j \cdot x_{ih}^j \le TL_t \cdot y_{th} \qquad \text{for all } t \text{ and } h \tag{5}$$

$$x_{ih}^j \in \{0,1\} \qquad \text{for all } i, j \text{ and } h \tag{6}$$

$$y_{th} \ge 0 \text{ and integer} \qquad \text{for all } t \text{ and } h \tag{7}$$

3 Solution Approach

3.1 Phase I: Obtaining an Initial Solution

An initial solution is obtained by sorting the parts in the non-increasing order of subcontracting costs and allocating each part in the sorted list to the period with the smallest earliness/tardiness cost while satisfying the constraints.

3.2 Phase II: Improvement

Before explaining the improvement methods, the processing time adjustment method when a part cannot be moved to a period due to the time capacity is explained.

Adjusting Part Processing Times. If a part cannot be allocated to a period due to the processing time capacity, it is checked if the part can be allocated to the period after adjusting the processing times of the part as well as the parts allocated already to the period. Specifically, it is checked if a part to be moved can be allocated to a period while improving the current solution after its processing time is reduced. If it is not possible, the processing times of the parts allocated already to the period are changed one-by-one and check the possibility of moving the part to the period. For this purpose, the following rules to select the part to be moved are tested. In the following, $j(i)$ denotes the index for the processing time selected for part i.

CTR (cost/time ratio): select part i^* such that

$$i^* = \text{argmin}_{i \in X_h} \left\{ \left(cp_i^{j(i)-1} - cp_i^{j(i)} \right) \Big/ \left(p_i^{j(i)} - p_i^{j(i)-1} \right) \right\}$$

MCI (minimum cost increase): select part i^* such that $i^* = \text{argmin}_{i \in X_h} \left\{ cp_i^{j(i)} - cp_i^{j(i)-1} \right\}$

MTD (maximum time decrease): select part i^* such that $i^* = \text{argmax}_{i \in X_h} \left\{ p_i^{j(i)} - p_i^{j(i)-1} \right\}$

Improvement. The improvement method consists of interchange, insertion, perturbation and reallocations of subcontracted parts in sequence. For the current solution, let P_T and P_E denote the set of tardy and early parts, respectively.

Interchange Method. The parts in P_T (P_E) are sorted in the non-increasing order of the tardiness (earliness) costs. Then, according to the sorted list, each part is interchanged with the ones in the periods with less earliness (tardiness) costs than that of the part considered while adjusting the processing times of the parts to be interchanged and included in the periods that the parts are to be inserted and the best one is selected.

Insertion Method. Each part in P_T and P_E is removed from its original period and then it is inserted to another feasible period that reduces the total cost. To reduce the search space, we consider the periods with less earliness or tardiness costs than that of the part to be moved for the parts in P_T and P_E. The following two methods are tested.

BI (best improvement): The parts in P_T (P_E) are sorted in the non-increasing order of their tardiness (earliness) costs. Then, from the first part in the sorted list, it is removed from its original period and then allocated to the first feasible period that improves the current solution while adjusting the part processing times.

HI (hybrid improvement): From the first part, the first and the best periods that improve the current solution are found and then the better one is selected.

Perturbation Method. Each of the parts allocated to its due-date period is moved to the period with the minimum increase in cost and then the part with the largest earliness or tardiness cost is moved from the original period to the due-date period.

Reallocation Method. The subcontracted parts are sorted in the non-increasing order of subcontracting costs. Then, from the first to the last part in the sorted list, it is inserted to the first feasible period that improves the current solution while adjusting the processing times of relevant parts, where the insertions are done from the due-date to other periods in the non-decreasing order of earliness and tardiness cost.

4 Computational Results

Computational experiments were done to identify the best one among the 6 combinations of 3 processing time adjustment methods (CTR, MCI and MTD) and 2 variations of the improvement methods (BI and HI). The algorithms were coded in C++ and the tests were done on a PC with Intel Core i7 CPU at 3.40 GHz.

The first test was done for small-sized test instances and reports the percentage gaps from the optimal solution values, i.e. $100 \cdot \left(C_a - C_{opt}\right)/C_{opt}$, where C_a is the objective value obtained from combination a and C_{opt} is the optimal values obtained from the CPLEX with a time limit of 3600 s. For this test, 60 instances with 5 periods were generated randomly, i.e. 10 instances for each of the 6 combinations of 3 levels for the number of parts (20, 30 and 50) and 2 levels of the number of tools (tight and loose). The detailed data generation method is skipped due to the space limitation.

Test results are summarized in Table 1 that shows the number of instances that the CPLEX gave optimal solutions within 3600 s and the average percentage gaps. Although no one dominates the others, CTR-HI works better than the others and its overall average gap was 1.80. Finally, the CPU seconds of the two-phase heuristics are not reported since all the test instances were solved within 3 s.

Table 1. Test results for small-sized test instances

Number of parts	Number of periods	Tooling tightness	N^{a}_{opt}/ CPU^{b}_{opt}	CTR[c]		MCI[c]		MTD[c]	
				BI	HI	BI	HI	BI	HI
20	5	Tight	10/28.9	3.70/0.6[d]	3.70/0.8	2.56/0.6	2.56/0.7	2.84/0.7	2.84/0.8
		Loose	10/602.2	3.80/1.5	3.53/3.3	4.37/0.9	4.49/1.0	4.00/1.0	4.35/1.1
30	5	Tight	10/81.6	0.87/1.7	0.83/2.3	1.26/2.2	1.26/2.6	1.37/2.1	1.37/2.4
		Loose	8/162.1	1.06/1.8	1.14/2.4	1.45/2.3	1.45/2.6	1.04/2.3	1.26/2.5
50	5	Tight	9/963.7	1.06/2.9	0.84/3.4	0.78/3.0	0.78/3.2	1.10/2.8	1.11/2.5
		Loose	8/1206.5	0.65/4.2	0.75/5.0	0.75/3.7	0.69/3.6	0.59/3.4	0.59/3.8
Average				1.86	1.80	1.86	1.87	1.82	1.92

[a]Number of instances that the CPLEX gave the optimal solutions (out of 10 instances)
[b]Average CPU seconds of the CPLEX (for the instances that the optimal solutions were obtained)
[c]Processing time adjustment methods: CTR (cost/time ratio), MCI (minimum cost increase), MTD (maximum time decrease)
[d]Average percentage gap/CPU second out of 10 instances

The second test was done on large-sized instances. Because the optimal solutions could not be obtained, we compared them using the relative performance ratio, i.e.

$$100 \cdot (C_a - C_{best})/C_{best},$$

where C_{best} is the best objective value among those obtained by all combinations. Table 2 shows the test results that are similar to those for the small-sized instances.

Table 2. Test results for large-sized test instances

Number of parts	Number of periods	Tightness of tooling	CTR		MCI		MTD	
			BI	HI	BI	HI	BI	HI
30	10	Tight	2.49/2.2[a]	2.44/2.7	1.94/2.2	1.18/2.5	3.19/2.3	3.19/2.6
		Loose	0.85/2.6	0.85/2.9	2.96/2.4	2.54/2.8	3.07/2.7	3.18/2.8
	15	Tight	2.85/2.5	2.85/2.8	2.98/2.6	3.18/3.1	4.55/2.7	4.55/3.1
		Loose	1.92/2.8	1.92/3.1	3.76/2.8	3.76/3.6	0.48/2.8	0.48/3.3
50	10	Tight	1.33/4.9	1.33/5.4	2.85/4.7	2.85/5.5	0.82/5.3	0.85/5.8
		Loose	1.18/5.0	1.10/5.6	0.78/5.6	0.78/6.0	1.58/5.1	1.49/5.6
	15	Tight	1.43/5.8	1.68/6.3	2.14/5.9	2.14/7.0	1.26/5.9	1.90/6.8
		Loose	1.81/7.4	1.77/8.4	1.80/6.7	1.80/7.8	2.56/7.1	2.22/8.1
100	10	Tight	0.55/21.2	0.38/24.0	1.13/18.9	1.14/24.9	0.63/15.1	0.44/26.8
		Loose	0.51/18.5	0.50/18.9	0.56/18.6	0.69/21.7	0.30/16.0	0.30/15.3
	15	Tight	0.57/19.1	0.57/20.8	1.78/15.4	1.70/17.9	0.74/15.1	0.74/19.9
		Loose	1.03/14.4	1.03/16.3	0.62/15.3	0.74/17.9	0.86/13.1	0.86/16.9
Average			1.49	1.46	2.22	2.15	1.89	1.90

[a]Average relative performance ratio/CPU second out of 10 instances

5 Concluding Remarks

We considered multi-period part selection for FMSs with controllable processing times. The problem is to determine the set of parts and their processing times that satisfy the processing time and the tool magazine capacities in each period of a planning horizon for the objective of minimizing the sum of part processing, earliness/tardiness, subcontracting and tool costs. The number of available tool copies, tool life restrictions and tool sharing were also considered. An integer programming model was developed, and then two-phase heuristics were proposed in which an initial solution is obtained by a greedy algorithm under initial processing times and then it is improved using two local search methods. Computational experiments were done on a number of test instances, and the best ones were reported.

For further research, it is needed to develop meta-heuristics that can improve the solution quality especially for large-sized instances. Also, the problem can be integrated with other problems such as loading and scheduling.

Acknowledgement. This work was supported by the Technology Innovation Program funded by the Ministry of Trade, industry & Energy, Korea Government. (Grant code: 10052978-2015-

4, Title: Development of a jig-center class 5-axis horizontal machining system capable of over 24 h continuous operation).

References

1. Hwang, S., Shogan, A.W.: Modelling and solving an FMS part-type selection problem. Int. J. Prod. Res. **27**(8), 1349–1366 (1989)
2. Kim, Y.-D., Yano, C.A.: A due date-based approach to part type selection in flexible manufacturing systems. Int. J. Prod. Res. **32**(5), 1027–1043 (1994)
3. Bilge, Ü., Albey, E., Beşikci, U., Erbaur, K.: Mathematical models for FMS loading and part type selection with flexible process plans. Eur. J. Ind. Eng. **9**(2), 171–194 (2015)
4. Stecke, K.E., Toczylowski, E.: Profit-based FMS dynamic part type selection over time for mid-term production planning. Eur. J. Oper. Res. **63**(1), 54–65 (1992)
5. Lee, D.-H., Kim, Y.-D.: A multi-period order selection problem in flexible manufacturing systems. J. Oper. Res. Soc. **49**(3), 278–286 (1998)
6. Nowicki, E., Zdrzalka, S.: A survey of results for sequencing problems with controllable processing times. Discret. Appl. Math. **26**(2–3), 271–287 (1990)
7. Garey, M.R., Johnson, D.S.: Computers and Intractability. Freeman, New York (1979)

Inventory Model with the Consideration of Pricing, Product Substitution and Value Deterioration

Felix T. S. Chan[1(✉)], J. H. Ruan[1,2,3], A. H. Tai[4], S. H. Chung[1], and A. E. E. Eltoukhy[1]

[1] Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hung Hom, Hong Kong
{f.chan, junhu.ruan, nick.sh.chung}@polyu.edu.hk, elsayed.abdelrahman@connect.polyu.hk
[2] College of Economics and Management, Northwest A & F University, Yangling, China
[3] Institute of Systems Engineering, Dalian University of Technology, Dalian, China
[4] Department of Applied Mathematics, The Hong Kong Polytechnic University, Hung Hum, Hong Kong
allen.tai@polyu.edu.hk

Abstract. Nowadays, due to the radical development for the e-commerce means, it becomes a trend to buy the products, especially the electronic products, directly from the manufacturers instead of retailers. It is commonly known that each entity in the market has the autonomy to deciding both the production/inventory plan and the pricing plan. Nevertheless, the existing research focuses either on the production planning or pricing. Using such approach can generate optimal solution for production and pricing, but the global optimal solution for integrated production planning and pricing is not guaranteed. Investigating the literature reveals that there are two literature review studies indicate that it is of great important to study the integrated model in production and inventory control problem with perishable and substitutable product. Therefore, this study aims to discuss the aforementioned problem by solving an inventory model with the consideration of pricing, product substitution and value deterioration. For this purpose, we propose a Mixed Integer Linear Programming model to represent our inventory model and develop a method to find out the best pricing strategy and its corresponding production plan. To demonstrate the validity of the proposed model, we present an example, the results reveal that our model can efficiently handle the proposed problem.

Keywords: Production planning · Inventory control · Product substitution Product pricing

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 450–456, 2018.
https://doi.org/10.1007/978-3-319-99704-9_55

1 Introduction

The process of launching new electronic models to the market happens frequently, owing to the advance technology development. Indeed, this process is a strategy for companies in order to keep up with the customers' changing needs. By doing so, both the new and old models of the product are available in the market. This results in a value deterioration for old models, and hence leads to price reduction of old models to attract customers who were not willing to buy this product with its original price. This situation is quite complex for companies, as it is difficult to set optimal price for both models while considering the customer preference. This difficulty stems from the fact that large price difference might lead in demand drop for new model, whereas small price difference might cause in a slow inventory consumption for old model. This problem has received much attention from researchers. For example, Zhou et al. [1] discussed how to find out the optimal pricing for fashion product by considering the inventory cost. The challenge faced by companies is not only the price but also the demand of the product, which is affected by the customer preference. For example, with respect to the price sensitive customers, large price difference motivates them to buy the old models, whereas for quality sensitive customers, they tend to buy the new models.

Although the production plan and its corresponding cost account for a large portion of the total company cost, they are seldom considered. Indeed, reasonable production plan or strategy can significantly reduce the inventory cost and production cost as well. Investigating the literature reveal that scholars focused on either the inventory cost with pricing strategy, or production strategy alone. Towards the goal of approaching the reality, it is of great importance to investigate the joint optimization for the production and pricing strategies and see how they are affected by the customer preference. In addition, this study considers one-way substitution, as it is commonly used in practice. Note that substitution reflects the action of using one model in order to substitute another one in order to satisfy the demand.

The above-mentioned problem is handled as follows. First, we model this problem as a multi period dynamic lot size problem, while considering the one-way substitution and value deterioration. Second, we propose a MILP model for this problem and develop a response surface method to derive the optimal production quantity for each period and its corresponding prices. The main objective is to maximize the overall profit, by subtracting the production, inventory and conversion costs from the revenue sales.

The rest of this paper is proceeds as follows. In Sect. 2, relevant literature review is discussed. Section 3 presents the used notations and assumptions. Then, the mathematical model is presented in Sect. 4. Numerical experiments are included in Sect. 5. Finally, the conclusions are given in Sect. 6.

2 Literature Review

This section mainly discusses the research work pertaining to production and inventory control: substitution, deterioration, pricing and customer preference modeling. Indeed, production and inventory control have been extensively discussed in the literature, resulting in models such as Economic Production Quantity (EPQ) and Economical Order Quantity and Dynamic Lot Sizing (DLS). Friedman and Hoch [2] was the first author to introduce DLS while considering the deterioration rate of perishable products. Later, Hsu et al. [3] integrated the DLS and products substitution. On the focus of models that consider deteriorating product, Bakker et al. [4] provided a review paper, which indicated that modeling the substitution and deterioration together is significant and could contribute to the existing research. This point is also confirmed by another review paper by Shin et al. [5]. On the other hand, the integration of pricing decision with inventory problems has received much attention in the literature. For example, Dong et al. [6] studied the dynamic pricing on substitutable products by adoption of stochastic dynamic programming. However, few studies reported the customer preference. Chen et al. [7] studied the inventory problem assuming a simple form for the customer preference, by proposing linear and exponential price-demand function.

3 Mathematical Model

In this section, we present the mathematical model for a multi-period dynamic lot sizing model. Before presenting the model, we first define the notation as follows:

Parameters:

i: Index for production period, $i \in \{1, 2, \ldots, n\}$

j, k: Index for production status, $j, k \in \{1, 2, \ldots, m\}$

SP_i: Setup cost for production period i

SC_{ijk}: Setup cost for conversion from status j to status k in period i

h_{ij}: Holding cost for product with status j in period i

p: Production cost ($/unit)

c_{jk}: Conversion cost from status j to status k ($/unit)

d_{ij}: Demand for product in status j in period i

I_{ij}: Inventory carried over after period i for product with status j

PN_{i1}: Production node in period i

CN_{ij}: Conversion node in period i with product status j

D_i: The total demand of all product statuses in period i

Decision variables:

pr_j: Selling price of product with status j

x_i: Production quantity in period i

q_{ijk}: Conversion quantity from status j to status k in period i

$\zeta_i := 1$ if produces in period i; $= 0$ otherwise

σ_{ijk}: $= 1$ if converts products from status j to status k in period i; $= 0$ otherwise

Based on the predefined notation, the MILP of the proposed problem is formulated as follows:

$$\text{Max} \quad \sum_{i=1}^{n}\sum_{j=1}^{i} pr_j \times d_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{i} h_{ij} \times I_{ij} - \sum_{i=1}^{n} (p \times x_i + SP_i \times \zeta_i) - \sum_{i=1}^{n}\sum_{j=1}^{i}\sum_{k=1}^{j} \left(d_{ij} \times q_{ijk} + SC_{ijk} \times \sigma_{ijk}\right) \tag{1}$$

s.t.:

$$x_i = d_{i1} + I_{i1} - \sum_{j=1}^{i} q_{ij1} \text{ where } i \in \{1, \ldots, n\} \tag{2}$$

$$I_{i-1,j-1} = d_{ij} + I_{ij} + \sum_{k=1}^{j-1} q_{ijk} \text{ where } i = j, i \in \{2, \ldots, n\} \tag{3}$$

$$I_{i-1,j-1} = d_{ij} + I_{ij} + \sum_{k=1}^{j-1} q_{ijk} - \sum_{k=j+1}^{i} q_{ijk} \text{ where } j \le i, i \in \{2, \ldots, n\} \tag{4}$$

$$x_i \le M \times \zeta_i \text{ where } i \in \{1, \ldots, n\} \tag{5}$$

$$q_{ijk} \le M \times \sigma_{ijk} \text{ where } k \le j, j \le i, i \in \{2, \ldots, n\} \tag{6}$$

$$I_{nj} = 0 \tag{7}$$

The objective function is presented in Eq. (1). First term calculates the sum of revenue made from selling all the products. Second, third and last terms represent the total holding cost, production cost, setup cost and conversion cost, respectively. Equation (2) defines the flow balance for production node PN_i. Equations (3) and (4) require that at the conversion node CN_{ij}, the number of inventory carried from period $i-1$ must equals to the sum of outgoing flow including demand d_{ij}, inventory carry-over in period i and outgoing conversion quantity q_{ijk} minus the sum of incoming conversion quantity q_{ikj}, if any. Equations (5) and (6) limit the value of production quantity x_i and conversion quantity q_{ijk}. M is taken as a value large enough to satisfy the production speed. Equation (7) states the inventory carry-over in the last period n should be zero.

The demand of each model in each period depends on the price of all models, which are given below:

$$D_i = \pi_i\left(1 + \frac{pr_1 - \overline{pr}}{pr_1}\right), \text{ where } \overline{pr} = \frac{\sum_{j=1}^{m} pr_j}{m}.$$

Here π_i is a coefficient for demand which can be determined by past sales history. The demand of product model with status j in each period i can be further represented as:

$$d_{ij} = \frac{Q_j - \alpha_j \times pr_j - \sum_{k=1}^{m} \beta_{jk}\left(pr_j - pr_k\right)}{\sum_{j=1}^{m}\left[Q_j - \alpha_j \times pr_j - \sum_{k=1}^{m} \beta_{jk}\left(pr_j - pr_k\right)\right]} \times D_i \text{ for } k \ne j,$$

where α_j, β_j, Q_j are the coefficients for this demand price function and they are determined by consumer behavior.

4 Solution Methodology

Due to the complexity of the problem, instead of using the traditional analytical method, we propose an integrated three-stage approach in this study. Details of each stage are presented below:

- Stage 1: Design of experiments

Central Composite Design is utilized to generate the combinations of decision variables $(\Delta P_1,\ \Delta P_2,\ \ldots,\ \Delta P_{n-1})$. Note that ΔP is the price difference between each model, i.e.

$$\Delta P_1 = pr_2 - pr_1, \cdots, \Delta P_{n-1} = pr_n - pr_{n-1}.$$

Each control variable is divided into a number of levels and the value of α is selected according to the design.

- Stage 2: MILP optimization

In this study, CPLEX is employed to solve the problem. The MILP for the network flow problem is input and coded in CPLEX. In each run, the data of price and demand are changed according to the design of experiments. Obtained optimal solutions and data are recorded for further analysis in Stage 3.

- Stage 3: Response surface method

We utilize full quadratic regression function is selected to find the relationship between control variables and response.

5 Numerical Experiments

In this section, we conduct one numerical example to evaluate the performance of the proposed method. This example investigates a model with 4 periods, each decision variables are divided into five levels, which are set at (−1.682, −1, 0, 1, 1.682). In total, we conduct 15 runs of experiments. For the basic demand in each period, it is given as $\pi_i = 500, 800, 1300, 700$. The coefficients for the demand price function are $Q_j = 240, 240, 20, 10$; $\alpha_j = 0.3, 0.6, 0.05, 0.025$; $\beta_{j,k} = (0.1, 0.6, 0.05, 0.025)$, $(0.02, 0.01, 0.2, 0.02), (0.01, 0.01, 0.01, 0.05)$. The price of new product for all the period is set at \$400. The range of each price difference ΔP_1, ΔP_2, ΔP_3 is assumed to be from 1 to 100, which means discount rate within range from 0% to 25%. After conducting the design of experiments, and solving the MILP using CPLEX, the results data for profit are analyzed using Minitab by adoption of full quadratic regression analysis. For illustration simplicity, pr_1, pr_2, and pr_3 have been replaced by A, B, and C, respectively.

The result of Analysis of Variance shows that R-sq, R-sq(adj) and R-sq(pred) equals to 99.77%, 99.56% and 98.22% respectively, which means the regression function can well describe the behavior of the model proposed. Figure 1 illustrates the response surface of the regression model. As can be observed from the surface plot, the function shows concavity in all the three sub-figures. Through the regression model shown in (14), the optimal combination of (ΔP_1, ΔP_2, ΔP_3) is determined as (14, 34, 1). Figure 2 shows the optimal solution for pricing strategy. The optimal prices for all the four models are ($400, $386, $352, $351). To be noticed, the optimal value of C, which represents ΔP_3, lies beyond the minimum range designed. It means that the optimal price difference between third and fourth product status should be smaller than $1. Under this circumstance, the results suggest that the price of fourth model should be kept as the same as the third model which leads to zero demand for the fourth model. It can also be interpreted that the fourth model should be removed from the product line.

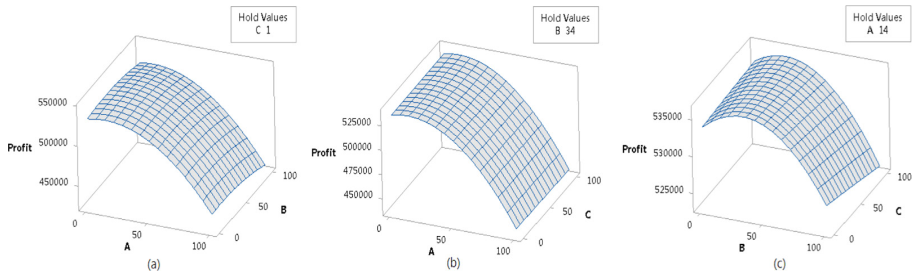


Fig. 1. Response surface of the regression model in Example 1 (a) *A* vs *B* (b) *A* vs *C* (c) *B* vs *C*.

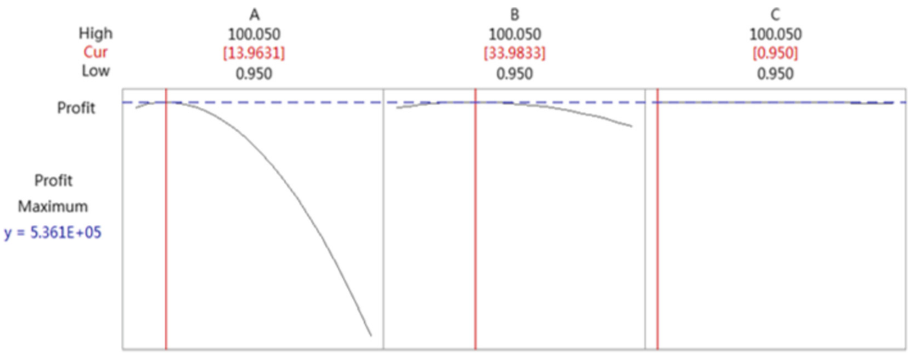


Fig. 2. Predicted optimal pricing strategy.

6 Conclusions

This research specifically looked at a problem inspired by a practical example of electronic product, a multi-period, multi-item dynamic lot sizing model is used to formulate the problem. An integrated three-stage method is utilized to solve the problem proposed which consists of Design of Experiment, MILP and Response Surface method. One example also shows the impact of changing cost structure on the joint strategy. The results show that the proposed method can provide satisfactory performance to this type of problem. Both the production and pricing strategies are optimized. This study can provide managerial implication and practical guidance to decision makers on the selection of optimal pricing and production strategies.

Acknowledgement. The work described in this paper was supported by research grants from the Natural Science Foundation of China (Grant No. 71571111); The Hong Kong Polytechnic University (Project No. 4-BCCM); The Hong Kong Polytechnic University internal grant (Grant No. G-UADM); and the Research Committee of The Hong Kong Polytechnic University under student account code RTYN.

References

1. Zhou, E., Zhang, J., Gou, Q., Liang, L.: A two period pricing model for new fashion style launching strategy. Int. J. Prod. Econ. **160**, 144–156 (2015)
2. Friedman, Y., Hoch, Y.: A dynamic lot-size model with inventory deterioration. INFOR: Inf. Syst. Oper. Res. **16**(2), 183–188 (1978)
3. Hsu, V.N., Li, C.-L., Xiao, W.-Q.: Dynamic lot size problems with one-way product substitution. IIE Trans. **37**(3), 201–215 (2005)
4. Bakker, M., Riezebos, J., Teunter, R.H.: Review of inventory systems with deterioration since 2001. Eur. J. Oper. Res. **221**(2), 275–284 (2012)
5. Shin, H., Park, S., Lee, E., Benton, W.C.: A classification of the literature on the planning of substitutable products. Eur. J. Oper. Res. **246**(3), 686–699 (2015)
6. Dong, L., Kouvelis, P., Tian, Z.: Dynamic pricing and inventory control of substitute products. Manufact. Serv. Oper. Manag. **11**(2), 317–339 (2008)
7. Chen, W., Feng, Q., Seshadri, S.: Inventory-based dynamic pricing with costly price adjustment. Prod. Oper. Manag. **24**(5), 732–749 (2015)

Improving Carry-Out Operations of Inbound Containers Using Real-Time Information on Truck Arrival Times

Sanghyuk Yi[1,2](✉), Lin Gui[2], and Kap Hwan Kim[2]

[1] University of Bremen, Hochschulring 20, 28359 Bremen, Germany
[2] Pusan National University, Busandaehak-ro 63 beon-gil 2, 46241 Busan, Republic of Korea
{yisanghyok, kapkim}@pusan.ac.kr

Abstract. Multiple inbound containers are piled up at the same stack in container terminals, which causes re-handles during the retrieval or carry-out process by road trucks. This inefficiency of the retrieval operation comes from the fact that the retrieval sequence of inbound containers is extremely uncertain and the retrieval sequence is not from the top to the bottom. This study discusses how the re-handling operations can be reduced by utilizing information on the estimated truck arrival times which may be collected from GPS in a smartphone owned by the truck driver. Algorithms for scheduling the pre-marshaling operation and determining the storage locations of re-handled containers are proposed. This study relaxed the constraint that a yard crane may relocate a container into another slots only in the same bay. The performances of the proposed algorithms are compared with each other by simulation studies.

Keywords: Truck arrival information · Container terminal · Re-marshaling
Inbound containers · Simulation

1 Introduction

At container terminals, when an inbound container to be picked up (target container) is not at the top of a stack, then all the containers placed on the top of the target one have to be relocated to other stacks, which is unproductive and called re-handling operation. The re-handling operation is due to the fact that the positions of the containers do not are matched with the retrieval sequence of containers. When containers are positioned at the locations where no re-handlings are necessary, we say that the containers are well placed.

There have been two types of previous studies on container re-handling problems in container yards. The first one is the Container (Block) Relocation Problem (CRP or BRP) where, for a given priority of containers for retrievals, the container to be retrieved next and the locations of the relocated containers for the retrieval should be determined [1, 3, 6]. The other is the Container Pre-Marshalling Problem (CPMP) in which, for a given priority of containers for the retrieval, containers are relocated in advance (before trucks arrive at the yard) so that they are well placed [2, 5, 7]. Related

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 457–463, 2018.
https://doi.org/10.1007/978-3-319-99704-9_56

to utilizing the information of truck arrival times, the connection between container relocation and truck arrival sequence is presented [8]. Recently, the container relocation problem with the truck appointment system was combined [6]. They introduced a CRP model under the assumption that container retrieval times are provided in terms of time windows of specific length. In [4], the yard management by utilizing the real-time location information of trucks was firstly discussed.

This paper extends the pre-marshalling operation with real-time information of truck arrival by considering the gantry move of yard crane during pre-marshalling or re-handling operations, which provides better candidate stacks with blocking containers to be move to. The objective of this paper is to minimize the number of re-handles and the turnaround time of trucks for inbound containers considering estimated arrival information of trucks.

2 Estimating the Possibility of Re-handles

As illustrated in Fig. 1, a terminal operation system (TOS) receives the real-time position of each truck from real-time truck locating systems (RTLSs) with the support of information technologies (ex. GPS). Then, TOS will estimate the truck's expectation and standard deviation of the remaining time before the arrival (RTBA) which can be derived by using its expected arrival time and the current time when collecting information. Whenever a yard crane becomes idle, TOS will issue pre-marshalling orders.

This study assumes the uncertainty of an RTBA of a container which is represented

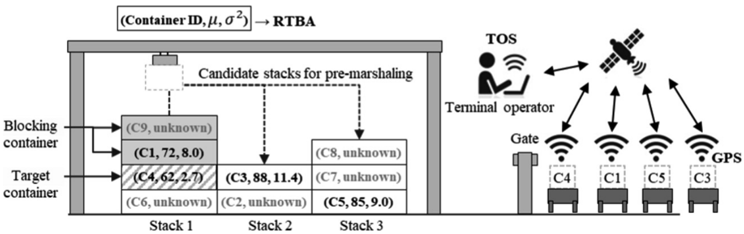


Fig. 1. Real-time truck locating system (RTLS) and information on their arrivals

by a random variable X following a general distribution with parameters μ and σ like Eq. (1). In Eq. (1), f represents a probability density function of X where μ and σ denote the expectation and the standard deviation of RTBA, respectively.

$$X \sim f(\mu, \sigma^2) \tag{1}$$

The container to be relocated to the topmost position during the re-marshalling process is called 'target container,' while containers on the top of the target container are called 'blocking containers.' For a pair of containers in the same stack, let $X_l \sim f(\mu_l, \sigma_l^2)$ for container l in a lower tier and $X_h \sim f(\mu_h, \sigma_h^2)$ for a container h in a higher tier. the probability that container l will be retrieved earlier than container h can be expressed in Eq. (2) where the variance of RTBA is assumed to be proportional to the expectation of RTBA.

$$P(X_l < X_h) = \Phi(\frac{\mu_h - \mu_l}{\sqrt{\mu_h \sigma_h^2 + \mu_l \sigma_l^2}}) \tag{2}$$

A *badly-placed* container (container l) is defined as a container which has at least one container (container h) at a higher tier of the same stack such that

$$P(X_l < X_h) \geq \delta \tag{3}$$

where the threshold δ is a decision parameter that will be found by using a simulation experiment.

Among all the badly-placed containers, only those whose expected value of RTBA is shorter than a lead time for pre-marshalling (T) will be included into the list of containers to be pre-marshalled.

3 Pre-marshalling Algorithm for a Yard Crane with Multi-bay Coverage

The overall pre-marshalling procedure is described as follow:

Step 1: Select the target container for pre-marshalling operation
Step 2: Select the stack for a blocking container to be moved to

The target container of *Step 1* is the badly-placed one with shorter RTBA by using Eqs. (1) and (2). After selecting the target container, the target stacks onto which blocking containers are to be moved must be determined in *Step 2*. The main idea of selecting the target stack is that the blocking container should be moved to a stack where there is a lower possibility of creating additional re-handles. Let

$$P(s_i, b) = \Phi\left(\frac{\mu_{min}(s_i) - \mu_b}{\sqrt{\mu_{min}(s_i)\sigma_{min}^2(s_i) + \mu_b \sigma_b^2}}\right) \tag{3}$$

where μ_b and σ_b^2 represent the mean value and the variance of RTBA of the blocking container (container b), respectively, and $\mu_{min}(s_i)$ and $\sigma_{min}^2(s_i)$ represent the mean and the variance of RTBA of the container whose mean RTBA is smallest in stack i.

Then, $P(s_i, b)$ implies the probability that the relocated container is retrieved earlier than the container whose mean RTBA is smallest in stack i.

In general, the re-handles of a yard crane occur within a bay without its gantry move. In the case of conventional equipment such as a RTGC (Rubber Tired Gantry Crane), it takes quite long time to move in the gantry direction. Thus, it makes sense to re-handle containers within a bay. However, in the case of an automated RMGC (Rail Mounted Gantry Crane), there is no need to restrict the gantry move within a bay during re-handling operation. Therefore, this study allows yard cranes to be able to relocate a container into any slot within the nearest *n* bays during pre-marshaling and re-handling operation.

Let the set of stacks, excluding the stack where container *b* is currently located, whose value of $\mathrm{P}(s_i, b)$ is larger than or equal to a threshold value δ be S^W and those whose value of $\mathrm{P}(s_i, b)$ is smaller than a threshold value δ be S^B. If there exist multiple in S^W, then select the stack with the smallest value of $P(s_i, b)$. If there exists no such a stack, then select the stack with the largest value of $P(s_i, b)$ in S^B. The procedure is summarized as follows:

Step 2-1: Select candidate stacks which are located within the coverage range (*n*) from the target container and have empty slots. Let $S^W = \{i|P(s_i, b) \geq \delta\}$. If $S^W = \emptyset$, then go to Step 2-3; otherwise, go to Step 2-2.

Step 2-2: $s^*(b) = argmin_{i \in S^W} P(s_i, b)$. If there exist multiple candidate stacks, run Tie-Break-Rule and $s^*(b)$ is the target stack for container *b* to be move to. Stop.

Step 2-3: Let $S^B = \{i|P(s_i, b) < \delta\}$. $s^*(b) = argmax_{i \in S^B} P(s_i, b)$. If there exist multiple candidate stacks, run Tie-Break-Rule. Stop.

The following rules are used as the Tie-Break-Rule in the order of (1) lowest position; (2) shortest traveling time of yard cranes; (3) random.

4 Simulation Experiments

A simulation model was developed for evaluating the proposed algorithm. It was programmed by Tecnomatix Plant Simulation, Siemens PLM Software Inc. For the input data, we collected the field data which represents inbound containers for around 2 months at 'S' container terminal in Busan, South of Korea. As attributes of a container, container ID, discharging time and retrieval time were used in the simulation.

It is assumed that the layout of a container terminal consists of 10 blocks with 32 bays, 10 rows, 6 tiers. We assume that the utilization of a bay is 80%. That is, the maximum number of containers that can be stored in a bay was restricted to be 48.

In the experiment, it was assumed that the terminal operator receives the updated information on the expected RTBA for each inbound container in every 10 min after the truck starts its travel.

In the simulation program, the terminal operations were assumed as follows: (i) container discharging and retrieving operations have higher priorities than pre-marshalling operations. It means that pre-marshalling operations are carried out only when a yard crane is idle; (ii) if $\mu_l > \mu_h$, then $\sigma_l^2 > \sigma_h^2$. That is, the travel time with a longer expectation has a larger variation, which is a reasonable assumption.

Effects of Pre-marshaling Operation. In order to evaluate the effect of the pre-marshalling operation (PM), the cases with PM were compared with those without PM where T = 4,800 s, $\sigma = 2.7$, $\delta = 0.52$. Table 1 shows the results of comparison, which estimates that the turnaround time at block per truck can be reduced by 45.0% by the pre-marshalling operation. In addition, the number of re-handles per container during the retrieving operation (RT) can be reduced by 95.7%, while the total re-handles may increase by around 10.5%.

Table 1. Effects of pre-marshaling operation.

Type of operation	Truck turnaround time at block (sec)	The number of re-handles per container		
		During PM (1)	During RT (2)	(1) + (2)
Case without PM	551.43	0.000	1.147	1.147
Case with PM	303.09	1.215	0.054	1.268

In Table 2, the effect of the coverage of yard cranes on the re-handling operation including PM and RT is analyzed. The wider coverage of yard cranes may provide better candidate stacks for a blocking container to be moved to during PM and RT. It means that the relocated blocking containers may have a higher possibility to find a storage location without re-handle. Instead, the longer gantry travel time may result. Table 2 shows that as the coverage of yard cranes becomes wider, the total average number of re-handles is reduced by 22%.

Table 2. Results of pre-marshaling operation considering traveling time of yard crane.

Coverage (n) of yard crane (bays)	Truck turnaround time at block (sec)	Number of re-handles per container		
		During PM (1)	During RT (2)	(1) + (2)
0	303.09	1.215	0.054	1.268
1	301.92	1.169	0.049	1.218
2	301.48	1.161	0.048	1.210
3	301.25	0.955	0.039	0.993

Performances for Various Lead Time of Pre-marshaling (T). Table 3 shows that the performances of the pre-marshalling strategies on the various lead times of pre-marshalling (T) where $\sigma = 2.7$, $\delta = 0.52$. As the value of T is smaller, some opportunities for the pre-marshalling can be missed, which leads to increase the turnaround time of trucks at a block with the increase in the number of re-handles during retrieval operation. On the contrary, as the value of T becomes larger, the number of containers, which are pre-marshalled, increases and thus more re-handles for pre-marshalling occurs. However, those for retrievals slightly decreases.

Table 3. Performances for various lead times for pre-marshalling (T).

T (sec)	Truck turnaround time at block (sec)	Number of re-handles per container		
		During PM (1)	During RT (2)	(1) + (2)
1,200	327.82	1.068	0.121	1.189
2,400	306.34	1.175	0.055	1.230
3,600	306.02	1.199	0.055	1.254
4,800	303.09	1.215	0.054	1.268
6,000	304.60	1.216	0.056	1.272

Impacts of Uncertainty (σ) on Re-handles. Table 4 illustrates how the uncertainty of truck arrival influences terminal operations. The higher uncertain truck arrival means that it is difficult to estimate the truck arrival, which makes the possibility of creating additional re-handles lower. Thus, as σ increases, the number of re-handles during PM declines, but those during RT rises with the growth of truck turnaround time at block. If σ is larger than around 100, then the value of truck turnaround time becomes similar to the case without PM in Table 1, which implies that the information on truck arrivals is less useful.

Table 4. Impacts of uncertainty (σ) of arrival times on re-handles.

σ	Truck turnaround time at block (sec)	Number of re-handles per container		
		During PM (1)	During RT (2)	(1) + (2)
0.1	302.54	1.223	0.047	1.269
2.7	303.09	1.215	0.054	1.268
10.0	323.09	1.160	0.100	1.260
20.0	376.42	1.047	0.188	1.235
…	…	…	…	…
100.0	527.92	0.777	0.408	1.184

5 Conclusions

This paper discusses the pre-marshalling operation for inbound containers by using uncertain truck arrival information. The pre-marshalling algorithm utilizes the uncertainty of truck arrival to reduce the possibility of creating additional re-handles, which leads to decrease the turnaround time of trucks. In addition, we investigate the impact of gantry move of yard cranes during re-handling operation. The simulation model is developed to perform the experiments. The result shows that the pre-marshalling operation can reduce the truck turnaround time by 45.0% in comparison with the case without it. Moreover, the pre-marshalling strategies in practice are examined. Finally, we discuss the valid degree of uncertainty for the implementation. In further researches, it is essential to collect/define information of container retrieval from various stakeholders and evaluate the validation for its application.

Acknowledgments. This work was supported by Jungseok Logistics Foundation Grant.

References

1. Caserta, M., Schwarze, S., Voß, S.: A mathematical formulation and complexity considerations for the blocks relocation problem. Eur. J. Oper. Res. **219**(1), 96–104 (2012)
2. Choe, R., Kim, T., Ryu, K.: Crane scheduling for opportunistic remarshaling of containers in an automated stacking yard. Flex. Serv. Manuf. J. **27**(2), 331–349 (2015)

3. Forster, F., Bortfeldt, A.: A tree search procedure for the container relocation problem. Comput. Oper. Res. **39**(2), 299–309 (2012)
4. Gui, L.: Pre-marshaling inbound containers utilizing truck arrival information with uncertainty. Master thesis, Pusan National University, Republic of Korea (2016)
5. Huang, S.H., Lin, T.H.: Heuristic algorithms for the container pre-marshaling problems. Comput. Ind. Eng. **62**(1), 13–20 (2012)
6. Ku, D.S., Arthanari, T.S.: Container relocation problem with time window for container departure. Eur. J. Oper. Res. **252**(3), 1031–1039 (2016)
7. Wang, N., Jin, B., Lim, A.: Target-guided algorithms for the container pre-marshaling problem. Omega **53**, 67–77 (2015)
8. Zhao, W.J., Goodchild, A.V.: The impact of truck arrival information on container terminal rehandling. Transp. Res. Part E **46**(3), 327–343 (2010)

Dual Resource Constrained Scheduling Considering Operator Working Modes and Moving in Identical Parallel Machines Using a Permutation-Based Genetic Algorithm

Muhammad Akbar(✉) and Takashi Irohara

Department of Information and Communication Sciences, Sophia University, 7-1 Kioi-Cho, Chiyoda-Ku, Tokyo 102-8554, Japan
muhammad@eagle.sophia.ac.jp, irohara@sophia.ac.jp

Abstract. This paper proposes a novel dual resource constrained (DRC) scheduling problem under identical parallel machine environment that consider operator working modes and moving activity between machines with regards to the makespan minimization objective. We define the working modes as all operator activities when the operators interact with the machines such as loading, setup, controlling, and unloading. Firstly, we provide the mathematical model of the problem using Mixed Integer Linear Programming (MILP). We add unloading activity beside setup to be included in the model. Also, we consider the moving activity that is usually neglected in DRC scheduling problem. Moreover, we propose a permutation-based genetic algorithm (PGA) to tackle the computational burden of the bigger size problem. Then, we run a full factorial experiment with replication to compare the solution quality and computational time of our PGA to the solver and random search method. The results show that our proposed PGA could solve the problem in a reasonable time that is faster than the solver with a good quality solution that is better than random search.

Keywords: DRC scheduling · Working modes · Moving · Makespan

1 Introduction

Recently, many industries use partially automated machines for producing products which operators can leave them in the machining time. The operators are necessary for such only activities like the loading and unloading jobs, sometimes controlling or doing the setup [1]. The total idle time of operators becomes the highest if they only operate a machine each. However, assigning an operator to two or more machines results in some machine waiting time that increases the makespan or the tardiness.

Dual resource constrained (DRC) scheduling considers both machine and operator resources as limiting resources [2]. Most research in DRC scheduling deals in a condition that the operator number is not less than the number of machines, e.g. [3, 4]. On the next level, we find articles that deal with fewer operators, but they cannot supervise

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 464–472, 2018.
https://doi.org/10.1007/978-3-319-99704-9_57

many jobs at the time [5, 6]. Only a little research considers an operator can supervise several machines simultaneously [7] as in [1, 8].

There are several approaches to solve the DRC scheduling with each operator can process many jobs simultaneously. One approach uses a given finite set of working modes as a reference to estimate the job processing time using multipliers [1]. The other approach uses mixed-integer linear programming (MILP) model allowing an operator to do many setup activities and leave the machine while processing the job to minimize the makespan [8]. In this work, we combine the advantages of both to propose a new approach by applying MILP model to get a more accurate solution and considering many working modes such as loading, setup and unloading activities. Also, this research considers transportation time between machines.

2 Problem Statement

Figure 1 illustrates the proposed DRC scheduling problem with three identical parallel machines and two same-skill operators with five jobs. It must consider not only the sequence of jobs in each machine but also the activity/task sequence of jobs and moving sequence performed by each operator that makes this problem becomes harder to solve. Therefore, we must include the operators' assignment on the Gantt chart to describe the schedule. The new consideration of task allocation causes the job assignment to the operator becomes more flexible in which one job can be performed by different operators, e.g., setup performed by an operator and unloading by another operator. We only consider setup (that includes loading) and unloading activities in the model. This contribution do not appear in the traditional scheduling problem since the operators always control the same machine. The other contribution related to moving route and time makes the computation of makespan more precise.

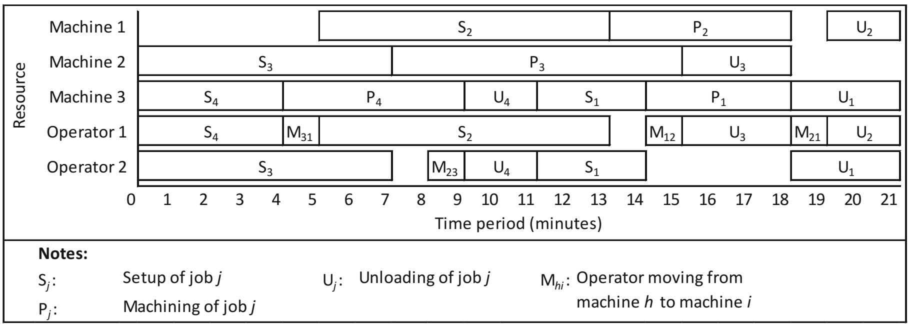


Fig. 1. An illustration of a Gantt chart of the proposed DRC scheduling problem with 5 jobs

We describe the problem statement of this DRC scheduling problem as follows. The production system consists of a set M of m identical parallel machines and a set W of w identical operators where $w \leq m$. This production system must produce a set N of n jobs aiming at the minimization of the makespan. Each job needs three sequence activities, which are setup, machining, and unloading performed on a unique machine. Each operator can contribute to any b activities of working modes from a set B. In our case, the b value is two consisting setup and unloading activities. Thus, each operator could move from one machine after finishing one activity b to the other machine to perform any activity in set B. Any activity b of job i starts if both the assigned machine j and operator k are available.

3 The Mathematical Model

We refer to the previous research [8] then adjust and add some new constraints to build our own MILP model. We adjust some constraints in several ways by adding new activity indices (1 for setup and 2 for unloading) to the decision variables and place the operator indices as the main resource instead of the machine. It is because the operator assignment is more complicated than the machine since two operators are possible to execute the same job. We also include transportation time between machines as a new parameter. The mathematical formulation is reported as follow.

Indices

$f, j, l = 0, 1, 2, \ldots, n$	jobs	$k, q = 1, 2, \ldots, w$	workers
$g, h, i = 1, 2, \ldots, m$	machines	$a, b, c = 1, 2$	activities

Parameters

P_l	the processing time of job l	T_{gi}	the moving time between machine g and i
O_{bl}	the operation time of activity b of job l	B	a big number

Decision variables

$X_{khajibl}$	a binary variable that result in 1 if worker k is assigned to do activity b of job l on machine i after finishing activity a of job j on machine h.
Q_{fl}	a binary variable that result in 1 if setup activity of job l performs before unloading activity of job f in the same machine.
O^c_{bl}	the operation completion time of activity b of job l
P^c_l	the processing completion time of job l
T^c_{bl}	the transportation/moving completion time before doing activity b of job
C_{max}	the makespan

Model

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

Subjet to:

$$\sum_{k=1}^{w}\sum_{h=1}^{m}\sum_{a=1}^{2}\sum_{j=0}^{n}\sum_{i=1}^{m} X_{khajibl} = 1 \quad \forall b = 1,2;\ l = 1,2,\ldots,n \tag{2}$$

$$\sum_{k=1}^{w}\sum_{h=1}^{m}\sum_{i=1}^{m}\sum_{b=1}^{2}\sum_{l=1}^{n} X_{khajibl} \leq 1 \quad \forall a = 1,2;\ j = 1,2,\ldots,n \tag{3}$$

$$\sum_{h=1}^{m}\sum_{i=1}^{m}\sum_{b=1}^{2}\sum_{l=1}^{n} X_{kh20ibl} \leq 1 \quad \forall k = 1,2,\ldots,w \tag{4}$$

$$\sum_{h=1}^{m}\sum_{i=1}^{m}\sum_{b=1}^{2}\sum_{l=1}^{n} X_{kh10ibl} = 0 \tag{5}$$

$$\sum_{k=1}^{w}\sum_{h=1}^{m}\sum_{a=1}^{2}\sum_{j=0}^{n} X_{khaji1l} - \sum_{q=1}^{w}\sum_{g=1}^{m}\sum_{c=1}^{2}\sum_{f=0}^{n} X_{qgcfi2l} = 0$$

$$\forall i = 1,2,\ldots,m;\ l = 1,2,\ldots,n \tag{6}$$

$$\sum_{h=1}^{m}\sum_{a=1}^{2}\sum_{j=0}^{n} X_{khajibl} \geq \sum_{g=1}^{m}\sum_{c=1}^{2}\sum_{f=1}^{n} X_{kiblgcf} \quad \forall k = 1,2,\ldots,w;$$

$$i = 1,2,\ldots,m;\ b = 1,2;\ l = 1,2,\ldots,n \tag{7}$$

$$O_{bl}^{c} - T_{bl}^{c} \geq O_{bl}\ \forall b = 1,2;\ l = 1,2,\ldots,n \tag{8}$$

$$T_{bl}^{c} - O_{aj}^{c} \geq \sum_{h=1}^{m}\sum_{i=1}^{m}\sum_{k=1}^{w} T_{hi}\cdot X_{khajibl} - B\cdot\left(1 - \sum_{h=1}^{m}\sum_{i=1}^{m}\sum_{k=1}^{w} X_{khajibl}\right)$$

$$\forall b = 1,2; l = 1,2,\ldots,n; a = 1,2; j = 0,1,\ldots,n \tag{9}$$

$$O_{2l}^{c} - P_{l}^{c} \geq O_{2l} \quad \forall l = 1,2,\ldots,n \tag{10}$$

$$P_{l}^{c} - O_{1l}^{c} = P_{l} \quad \forall l = 1,2,\ldots,n \tag{11}$$

$$\begin{cases} O_{1l}^{C} - O_{2f}^{C} \geq \sum_{k=1}^{w}\sum_{h=1}^{m}\sum_{a=1}^{2}\sum_{j=0}^{n} o_{1l}\cdot X_{khaji1l} - B.\left(2 - \sum_{k=1}^{w}\sum_{h=1}^{m}\sum_{a=1}^{2}\sum_{j=0}^{n}\left(X_{khaji1l} + X_{khaji1f}\right) + Q_{fl}\right) \\ O_{1f}^{C} - O_{2l}^{C} \geq \sum_{k=1}^{w}\sum_{h=1}^{m}\sum_{a=1}^{2}\sum_{j=0}^{n} o_{1f}\cdot X_{khaji1l} - B.\left(2 - \sum_{k=1}^{w}\sum_{h=1}^{m}\sum_{a=1}^{2}\sum_{j=0}^{n}\left(X_{khaji1l} + X_{khaji1f}\right) + 1 - Q_{fl}\right) \end{cases}$$

$$\forall i = 1,2,\ldots m; f = 1,2,\ldots,n;\ l = f+1, f+2,\ldots,n \tag{12}$$

$$O_{20}^{c} = 0 \tag{13}$$

$$C_{max} \geq O_{2l}^{c} \quad \forall l = 1,2,\ldots,n \tag{14}$$

$$X_{khajibl} \in \{0;1\} \quad \forall k = 1,2,\ldots,w;\ h = 1,2,\ldots,m;\ a = 1,2;\ j = 0,1,\ldots,n;$$

$$i = 1,2,\ldots,m;\ b = 1,2;\ l = 1,2,\ldots,n \tag{15}$$

$$Q_{fl} \in \{0;1\} \quad \forall f = 1,2,\ldots,n;\ l = f+1, f+2,\ldots,n \tag{16}$$

Constraint (2) ensures the assignment any activity of specific job to only one operator and one machine, and there is only one activity of one job which precedes. Constraint (3) forces that each activity of one job precedes at most one other activity of one job conducted by the same operator. Constraint (4) denotes each worker starts by unloading of job 0. Constraint (5) ensures that there is no assignment for setup of job 0. Constraint (6) forces that setup and unloading activities of one job must perform on the same machine. Constraint (7) ensures the feasibility of sequence of activity by each operator: if activity b of job l precedes activity c of job f, it must have a predecessor of activity a of job j. Constraint (8) states that the minimum time lag between the operation completion time of and the moving completion time before activity b of job l must be equal to its operation time. Constraint (9) denotes that the difference between the moving completion time to do activity b of job l and the completion time of previous activity a of job j is at least equal to the moving time required by itself. Constraint (10) ensures, on each machine, that the unloading activity is possible after the machine finishes processing the job. Constraint (11) forces that each machine starts processing the job immediately after the setup activity. The twofold constraints (12) accommodates the feasibility sequence on each machine: if setup activity of job l and unloading activity of job f processed on the same machine, then unloading activity of job f must be completed before setup activity of job l starts, or vice versa. Constraint (13) fixes there is no time for unloading activity of job 0. Constraint (14) defines the makespan value. Finally, Constraint (15) and (16) define the corresponding binary variables.

4 The Proposed Permutation-Based GA

One of the most common meta-heuristic technique used in scheduling problem is Genetic Algorithm (GA) [9]. Since it is proven and easier to develop, we consider GA to solve our problem at first that can perform as the basic comparator to other techniques for the future research. Genetic algorithm (GA) that is found by Holland in 1975 mimics the biological processes [10]. This meta-heuristic procedure works with a set of solutions (*chromosomes*) called as *population*. A chromosome, which contains alleles, represents one solution that is evaluated by its *fitness* value that indicates the objective function. The initial population usually comes from a random process. At every iteration, the *selection* mechanism chooses a couple of chromosomes (*parents*). The parents follow the *crossover* mechanism to generate new solutions (*offspring*) by combining their structure. Moreover, each chromosome can experience changing of allele sequence based on the *mutation* scheme to prevent the solution trapped into local optima. Finally, this algorithm will stop to iterate after it meets the stop criterion such as the maximum iteration number (*generation number*).

The encoding scheme plays a vital role to yield the effectiveness and the efficiency of the algorithm [7]. On the other hand, our DRC scheduling deals with three kinds of assignments: sequence of activity between jobs, operator to each activity, and machine to each job. We use a simple single-string as one chromosome containing n alleles that represent the sequence of jobs. In decoding phase, this sequence becomes a reference in resulting those three assignments to get the fitness value (the makespan). In the mathematical formulation, let $\bar{l} = \pi_{(i)}$ becomes the job on the i-th allele to represent a job sequence chromosome (see Fig. 2).

$\pi_{(1)}$	$\pi_{(2)}$	$\pi_{(3)}$	$\pi_{(4)}$	$\pi_{(5)}$
4	1	5	3	2

Fig. 2. An example of a chromosome represents a job sequence (4-1-5-3-2) with n = 5 jobs

Our decoding algorithm consists of seven steps (as follow) that need an iterative process as many as the number of activities, which is twice of the jobs number.

Procedure of decoding

1. Set parameters for the zero iteration (y = 0): setup number (z) = 0; assigned activity (b^*) = ∅; assigned job (l^*) = ∅; operator k expected moving completion time (TMW_k) = 0 $\forall k$; assigned operator (k^*) = ∅; assigned machine (i^*) = ∅; unloading waiting list in machine i (WL_i) = ∅ $\forall i$; busy machine matrix (B) = ∅; operator k earliest assigning time (TW_k) = 0 $\forall k$; operator k last machine location (L_k) = ∅ $\forall k$ and machine i earliest assigning time (TM_i) = 0 $\forall i$.
2. Add y by 1. If $y > 2n$ stop the iteration and compute makespan that is equal to the maximum value of TW_k of all k. Otherwise, continue to step 3.
3. If $z < n$, set $i^* = i \; \exists i = 1, 2, \ldots, m \mid TM_i = \min_i TM_i$ Otherwise, set $i^* = i \; \exists i \in B \mid TM_i = \min_{i \in B} TM_i$
4. Compute expected moving completion time to machine i^* of all operator k using equation (17).
$$TMW_k = TW_k + m_{ij} \forall k = 1, 2, \ldots, w, i = L_k, j = i^* \quad (17)$$
Then, set $k^* = k \; \forall \; k = 1, 2, \ldots, w$ if $TMW_k = \min_k TMW_k$ and update $L_{k^*} = i^*$
5. Set $b^* = 1$ if $i^* \notin B \; \cup n_s < n$. Otherwise, $b^* = 2$
6. If $b^* = 0$, add z by 1, $l^* = \pi_{(z)}$, add j^* to the B, and update $WL_{j^*} = l^*$. Otherwise, set $b^* = 2$, $l^* = WL_{j^*}$, remove j^* from the B and update WL_{j^*} = ∅.
7. Update TM_{i^*} and TW_{k^*} using equation (18) and (19) and back to step 2.
$$TM_{i^*} = \begin{cases} s_{l^*} + max\{TM_{i^*}, TMW_{k^*}\} + p_{l^*}, \text{ if } b = 0 \\ u_{l^*} + max\{TM_{i^*}, TMW_{k^*}\}, \text{ otherwise} \end{cases} \quad (18)$$
$$TW_{k^*} = \begin{cases} s_{l^*} + max\{TM_{i^*}, TMW_{k^*}\}, \text{ if } b = 0 \\ u_{l^*} + max\{TM_{i^*}, TMW_{k^*}\}, \text{ otherwise} \end{cases} \quad (19)$$

We use the binary tournament as our selection method since it is more efficient than rank method and more effective than roulette wheel method [11, 12]. Moreover, we choose two-point crossover that has been largely adopted in combinatorial problem and block swapping scheme [13] for our crossover and mutation schemes. Finally, the stop criterion is the number of generations.

5 Numerical Examples and Computational Results

The objective of this benchmark is to compare the performance of the solution quality and run time between solver (SLV) using Gurobi 7.5.2, PGA, and random search (RS) which are executed on 16-GB RAM PC powered by an octa-core 3.6-GHz processor. The PGA and RS have been coded in RUBY® language. The RS uses same encoding and decoding scheme as in PGA to get the fitness value of a string. The stop criterion for RS is the number of evaluated strings as many as in PGA.

Our experiment consists three cases based on the number of jobs (n), machines (m), and operators (w) – small, medium, and big-sized problem (see Table 1). We generate all parameters from uniform distributions which are U[1, 79], U[1, 99], U[1, 20], and U [3, 10] respectively for setup, machining, unloading, and moving time. The solver is time limited in the medium-sized problem for 300 s and not run in the big-sized problem despite memory problem.

Table 1. Computational results

Case	Subcase ($n \times m \times w$)	Gurobi gap** (%)	RPD Mean			Run Time Mean (sec)		
			SLV	PGA	RS	SLV	PGA	RS
Small-sized problem PGA parameter* [10; 20; 0.5; 0.1]	4 × 3 × 2	0.00	0.00	0.00	0.00	8.93	0.01	0.00
	4 × 4 × 2	0.00	0.00	0.75	0.75	1.49	0.01	0.01
	4 × 4 × 3	0.00	0.00	0.00	0.00	0.69	0.01	0.01
	5 × 3 × 2	0.00	0.00	0.00	0.00	116.99	0.01	0.01
	5 × 4 × 2	0.00	0.00	6.00	6.00	46.89	0.02	0.01
	5 x 4 x 3	0.00	0.00	0.00	0.00	637.52	0.01	0.01
	Average	**0.00**	**0.00**	**1.13**	**1.13**	**135.42**	**0.01**	**0.01**
Medium-sized problem PGA parameter* [50; 150; 0.5; 0.1]	9 × 4 × 2	55.36	20.43	0.65	1.29	300	0.60	0.58
	9 × 4 × 3	50.82	23.98	0.33	0.65	300	0.74	0.71
	9 × 5 × 2	52.53	13.26	0.93	1.00	300	0.61	0.58
	9 × 5 × 3	48.10	37.62	0.29	1.71	300	0.75	0.72
	10 × 4 × 2	66.87	56.21	1.03	2.07	300	0.66	0.63
	10 × 4 × 3	59.35	46.43	0.79	1.90	300	0.81	0.79
	10 × 5 × 2	70.36	74.48	0.76	1.52	300	0.67	0.65
	10 × 5 × 3	60.11	74.0	1.02	2.22	300	0.83	0.80
	Average	**57.94**	**43.31**	**0.72**	**1.55**	**300.00**	**0.71**	**0.68**
Big-Sized Problem PGA parameter* [150; 200; 0.8; 0.05]	100 × 15 × 7	–	–	0.47	5.02	–	75.47	68.69
	100 × 15 × 9	–	–	0.38	3.99	–	88.22	80.23
	100 × 20 × 7	–	–	0.80	3.57	–	77.75	70.69
	100 × 20 × 9	–	–	1.27	6.34	–	94.98	84.32
	Average	–	–	**0.73**	**4.73**	–	**84.10**	**75.98**

*PGA parameter respectively consists of generation number, population size, and crossover and mutation probability

** Gurobi gap measures the difference between its lower and upper bound

Before comparing, we set GA parameter using a full factorial experimental design without replication for each case and analyze the result using graphical descriptive statistics to find the convergence point that represents the optimal generation number and Tukey test with 95% confidence interval to find the least population size from the best. Then, both parameters are used in another full factorial experimental design to find the optimal crossover and mutation probability in each case.

The number of strings needed to reach convergence point becomes higher when the case becomes more complex. The algorithm needs only 200 strings in the small-sized problem and needs more strings of 7,500 and 30,000 strings respectively for medium and big-sized problems. On the other hand, the generation number is always smaller than the population size in all cases. Also, in our experiments, we acknowledge that the crossover probability never becomes lower when the case becomes more complex, which needs to be analyzed more deeply in the future.

We implement a full factorial experiment design with five replication for PGA and RS and without replication for the solver. To evaluate the solution quality, we use relative percentage deviation (RPD) for each method i according to the Eq. (20):

$$RPD_i = 100 \cdot \frac{TCT_i - TCT_i^{min}}{TCT_i^{min}} \tag{20}$$

Where TCT_i is the total completion time (makespan) resulted from method i and TCT_i^{min} is the best makespan among all methods.

Table 1 also shows that PGA and RS can yield the optimal solution in the small-sized problem except for subcase $4 \times 4 \times 2$ and $5 \times 4 \times 2$. We acknowledge that our decoding algorithm always assigns a resource immediately after it is free, but, in that subcase, the optimal solution has different sequence logic. Our meta-heuristics also have better computational time than the solver in the small-sized problem.

The PGA outperforms other methods for average RPD in the medium-sized problem respectively with only 0.72% compared to RS with 1.55% and solver with 43.31%. Also, in the big-sized problem, the average deviation of PGA solution from the best is only 0.73% compared to the RS with 4.73%. By running for 5 min, the Gurobi solver can only reach 57.94%, on average, of the difference between its upper and lower bounds in the medium-sized problem. We also acknowledge that the solver cannot reach the optimal solution after one day running. Moreover, the computational (run) time of PGA is very reasonable compared to the RS that the difference is not more than 15 s even in the big-sized problem.

6 Conclusions

In this paper, we propose a novel DRC scheduling under an identical parallel machine environment that considers operator working modes and moving activity concerning the makespan minimization objective. We develop a MILP model at first, but it can only solve the small-sized problem in reasonable time. Therefore, we propose a permutation-based genetic algorithm (PGA) to tackle the computational burden. To test its performance in solution quality and computational time, we compare the PGA to the solver and RS. Firstly, we set the PGA parameter using statistical approaches. We acknowledge that the appropriate parameters depend on the case. The comparison results show that the PGA could solve the problem in a reasonable time that is faster than the solver with a good quality solution that is better than random search. There are several ideas for improvement for the next potential research. First, to involve a new social objective function such as operator's productivity or workload balance. Second, to extend the model into more complex machine configuration, e.g., flow shop or job shop. Third, to implement other meta-heuristics methods.

References

1. Baptiste, P., Rebaine, D., Zouba, M.: FPTAS for the two identical parallel machine problem with a single operator under the free changing mode. Eur. J. Oper. Res. **256**, 55–61 (2017)
2. ElMaraghy, H., Patel, V., Abdallah, I.B.: Scheduling of manufacturing systems under dual-resource constraints using genetic algorithms. J. Manuf. Syst. **19**(3), 186–201 (2000)
3. Hu, P.: Minimizing total flow time for the worker assignment scheduling problem in the identical parallel-machine models. Int. J. Adv. Manuf. Technol. **25**, 1046–1052 (2005)
4. Chaudry, I.A., Drake, P.R.: Minimizing total tardiness for the machine scheduling and worker assignment problems in identical parallel machine using genetic algorithms. Int. J. Adv. Manuf. Technol. **42**, 581–594 (2009)
5. Agnetis, A., Flamini, M., Nicosia, G., Pacifici, A.: A job-shop problem with one additional resource type. J. Sched. **14**, 225–237 (2011)
6. Paksi, A.B.N., Ma'ruf, A.: Flexible job-shop scheduling with dual-resource constraints to minimize tardiness using genetic algorithm. In: IOP Conference Series: Materials Science and Engineering, vol. 114, p. 012060, Yogyakarta (2016)
7. Baptiste, P., Rebaine, D., Zouba, M.: Solving the two identical parallel machine problem with a single operator. In: Framinan, J.M., Gonzalez, P.P., Artiba, A. (eds.) Proceedings of 2015 International Conference on Industrial Engineering and System Management (IESM), pp. 502–507. I^4e^2, Spain (2015)
8. Costa, A., Cappadonna, F.A., Fichera, S.: A hybrid genetic algorithm for job sequencing and worker allocation in parallel unrelated machines with sequence-dependent setup times. Int. J. Adv. Manuf. Technol. **69**, 2799–2817 (2013)
9. Abedinnia, H., Glock, C.H., Groose, E.H., Schneider, M.: Machine scheduling problems in production: a tertiary study. Comput. Ind. Eng. **111**, 403–416 (2017)
10. Holland, J.H.: Adaption in Natural and Artificial Systems, 1st edn. MIT Press, U.S.A. (1992)
11. Zhong, J., Hu, X., Gu, M., Zhang, J.: Comparison of performance between different selection strategies on simple genetic algorithms. In: International Conference on CIMCA-IAWTIC 2005 (2005)
12. Razali, N.M., Geraghty, J.: Genetic algorithm performance with different selection strategies in solving TSP. In: Proceedings of the World Congress on Engineering II, London (2011)
13. Costa, A., Cappadonna, F.A., Fichera, S.: A hybrid genetic algorithm for minimizing makespan in a flow-shop sequence-dependent group scheduling problem. J. Intell. Manuf. **28**, 1269–1283 (2017)

Process Planning Assessment Framework

Günther Schuh, Jan-Philipp Prote, and Philipp Hünnekes(✉)

Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen University, Aachen, Germany
{g.schuh, j.prote, p.huennekes}@wzl.rwth-aachen.de

Abstract. In order to rationalize process planning activities or to improve process planning outcomes, various process planning approaches with different degrees of computerized support and automation have been established. Ranging from general to very specialized approaches to specific problems, these approaches have specific advantages and drawbacks. When designing new approaches as well as selecting existing ones for application in the field, their properties have to be considered comprehensively. However, existing research only selectively touches on the objectives regarding the planning process or the quality of information generally requested from process plans. This paper presents the synthesis of a comprehensive process planning assessment framework, including planning process and outcome related criteria, based on an extensive literature review.

Keywords: Process planning · CAPP · Assessment framework CAPP selection

1 Challenges Assessing Process Planning Approaches

The necessity to rationalize process planning activities has led to the establishment of various planning approaches with different degrees of computerized support and automation [1]. Next to an increase in planning efficiency, the proposed planning approaches aim at improving the quality of the process sheets, which in many cases do not meet the requirements of the stakeholders [2].

Ranging from general to very specialized approaches to specific problems, these approaches have specific advantages and drawbacks [3]. As the importance of single properties of these approaches naturally depends on the specific application scenario, companies have to cover their basic process planning needs by producing reliable documents for production scheduling and control activities. Therefore, when designing new approaches as well as selecting them for application in the field, the properties and suitability of the approaches should be considered comprehensively.

While standard references in the production engineering field cover the conventional contents of the final process plans, their description of the planning process usually does not deliver a target system or criteria for optimization [1, 4]. Newly developed planning approaches mostly do state their specific motivation and the improvement potentials regarding the planning process or outcome they want to

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 473–481, 2018.
https://doi.org/10.1007/978-3-319-99704-9_58

address. However, there are no comprehensive assessment frameworks for process planning available.

The paper is structured as follows. In Sect. 2, we give an overview over existing approaches for assessing process planning. We then outline the research methodology of the extensive literature review. In Sect. 3, we analyze the relevant evaluation criteria. In Sect. 4, we present the synthesis of the criteria in the assessment framework. In Sect. 5, we present a brief first case study for basic validation, and, in Sect. 6, we conclude the paper.

2 Theoretical Framework

2.1 Deficiencies of Existing Approaches

Standard references in the field of production engineering and management provide a generally applicable and neutral definition of the planning process and the desired outcomes (e.g. [4]). Additionally, for evaluating the planning process success, some publications refer to the general objective of achieving an optimal relation between the use of resources and desired outcome (e.g. [1]). Beyond this hardly tangible objective regarding the characteristics of the resulting process plan, the authors describe general trends like Simultaneous Engineering (SE), the questioning of the separation of planning and control, as well as decentralization and automation of the planning process [1]. However, stated benefits [4] of automating the planning process can be interpreted as assessment criteria for process planning: *improved productivity*, *lower production cost*, *consistency*, *time savings* and *rapid integration of new production capabilities*.

Research articles focusing on process planning in many cases focus on enhancing understanding and technology regarding specific planning problems, e.g. the automated selection of machining parameters [5], automated discovery of typical process routes [6] or selecting "optimal" process plans [7]. The researchers usually either loosely state their objectives or feature explicit, even multi-criteria, objective functions [8] with regard to the specific planning problem at hand. Denkena et al. [9] provide research touching on a wider range of relevant criteria regarding technological and business considerations. However, to the knowledge of the authors, there are no research articles providing a comprehensive overview over all relevant criteria.

Although neither evaluation criteria for the planning process, nor the resulting process plans are well covered, methods for performance measurement of general business processes might partially be applicable to process planning. While widespread methods for BPM assessment (e.g. CMMI and BPMM) rely on rather abstract process maturity models, more tangible process KPIs are usually company and process specific. However, Fishermanns [10] provides several universal criteria that can partially be adapted to the planning process: *repetitiveness, personnel qualification, personnel count, intensity of communication, intensity of documentation, process complexity, determinacy, task difficulty, consistency, external relations, relevance of quality, time and cost*.

2.2 Research Methodology

In order to achieve the stated objective of developing a comprehensive assessment framework, the evaluation criteria to be considered, are extended by a rigorous and systematic literature review. The review is considered an explorative background review, in order to inform the design process. This section shall provide information on the coverage of the review [11].

The review was largely organized sequentially [11]. The search covered literature since 2000. The search string was *("process plan") AND (quality OR requirements OR assessment OR criteria)* and its German equivalent. Table 1 provides an overview of the databases and search providers as well as the results.

Table 1. Database search

Provider	Database	Language	Limitation	Hits	Reviewed
Google scholar	Any	English	None	*(16.100)*	28
Google scholar	Any	German	None	*(14.200)*	4
wti	Technik	German	None	197	4
IEEE Xplore	Any	English	None	25	9
EBSCOhost	Business source premier	English	None	54	7
ScienceDirect	Any	English	Review & research papers	*(5.044)*	6

Many articles identified by the keyword searches ('hits') do not focus on the research question at hand, but merely offer insights into the topic incidentally as described in Sect. 1. In addition, the search string has widespread application beyond the field of production engineering. Therefore the articles have been evaluated (the most highly prioritized hits in the cases of google scholar and ScienceDirect) based on their abstracts, in order to assess their relevance for the review ('reviewed') [12]. 58 articles have been reviewed (cf. Table 2). Other Journals include the International Journal of Computer Integrated Manufacturing (3), Annals of the CIRP (2), Journal of Materials Processing Technology (2) and several more.

Table 2. Literature review

Journal/Conference paper	2000–2004	2005–2009	2010–2014	Since 2015	Total
International journal of advanced manufacturing technology	3	4	2	0	**9**
Conference papers	0	5	2	2	**9**
International journal of production research	3	1	2	0	**6**
ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb	1	0	0	5	**6**
Procedia CIRP	0	0	1	4	**5**
Journal of intelligent manufacturing	3	0	1	0	**4**
Other	8	6	5	0	**19**
Total	**18**	**16**	**13**	**11**	**58**

3 Evaluation Criteria for Process Planning

The relevant literature has been analyzed for references to criteria, requirements and objectives regarding the planning process and the resulting process plan. The criteria listed in Fig. 1 represent the references in the reviewed articles in the most objective way, but are not completely mutually exclusive.

Planning process

Criteria	References
Collaboration/Integration	29
Duration	20
Effort	18
Reliance on experts	18
Knowledge management req.	18
Real-time ability	15
Adaptability	14
Standardization	13
Information requirements	12
Other	32

Resulting process plan

Criteria	References
Manufacturing costs	27
Flexibility	26
Quality of finished components	20
Processing time	16
Feasibility of process	13
Resource utilization	10
Accuracy	9
Robustness/Resilience	7
Standardization	7
Other	16

Fig. 1. Criteria referenced in the reviewed literature

Other criteria are *flexibility* (10), *process capability* (6), *transparency* (6), *ease of use* (4), *costs* (3) and *iterations* (3) as well as *process capability* (4), *integrity* (3), *energy consumption* (3), *resource consumption* (3), *timeliness* (2) and *emissions* (1).

The criteria have been synthesized from the illustrated literature review, structured and aggregated in order to generate comprehensive listings to be used in the assessment framework described in Sect. 4.

4 Process Planning Assessment Framework

4.1 Application

The process planning assessment framework is aimed at informing the decision-making process of researchers and practitioners. It is supposed to ensure that all relevant criteria are taken into consideration. Subject of the assessment are the planning process, albeit manual or automated, and the resulting process plan. The following Sect. 4.2 contains the comprehensive listings of the respective assessment criteria. To aid understanding and standardized assessment, descriptions on their relevance as well as examples are provided. As the criteria are multi-dimensional and not fully independent from each other, they partially complement or conflict with each other. Therefore, in application, the criteria have to be prioritized. The approach follows a traditional multi-criteria utility analysis [13], as shown in Fig. 2.

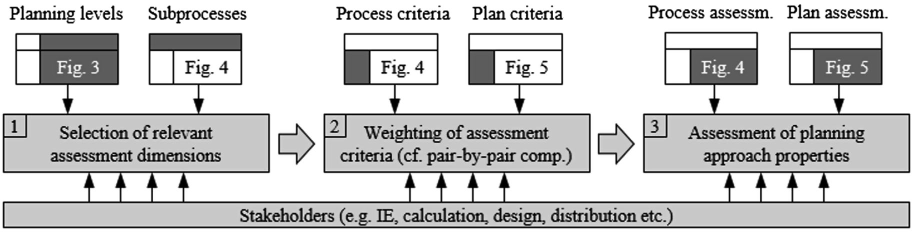


Fig. 2. Assessment approach

The planning levels of process/operations planning (Fig. 3) serve as assessment dimensions for the process plan assessment. During assessment, the user applies the relevant criteria to the required information of the planning level of interest. The subprocesses shown in Fig. 4 are selectable assessment dimensions of the planning process.

Planning level	Macro level/ process plan		Micro level/ operations plan	Further information
Information [1,4]	Blank (material, dimensions, shape), operations sequence (number, description), resource allocation (workstation or group ID), standard times (processing time, setup time)	E.g. tools, jigs/fixtures, setup description etc.	E.g. clamping, cutting path, process parameters (e.g. feed, cutting speed, depth of cut, material removal rates) etc.	E.g. NC-code, wage groups, lot-size range, tolerances, transition times etc.

Fig. 3. Planning levels

4.2 Assessment Criteria

The criteria for the assessment of the planning process (Fig. 4) are structured into cost related criteria, criteria regarding desirable process characteristics and criteria related to user interaction with the process and its tools.

Due to the limitations of the format [12], selective references are provided in the figure.

The criteria for the assessment of the resulting process plan (Fig. 5) are structured into objective data requirements as well as subjective optimization criteria.

<table>
<tr><th colspan="2" rowspan="2">Assessment criteria</th><th colspan="3">Subprocess</th></tr>
<tr><th>Initialize/setup</th><th>Plan/run</th><th>Maintain/update</th></tr>
<tr><td rowspan="3">Costs [9,14]</td><td>Duration</td><td rowspan="2">Relevance: Costs for required personnel
Example: Defining database with company-specific planning rules</td><td>Relevance: Product development lead-time
Example: Variant planning and/or automation to reduce planning period</td><td>Relevance: Timeliness of generated plans
Example: Automated analysis of feedback data</td></tr>
<tr><td>Effort</td><td>Relevance: Relative planning costs per unit produced
Example: Variant planning and/or automation to reduce planning effort</td><td>Relevance: Relative planning costs per unit produced
Example: Automated analysis of feedback data</td></tr>
<tr><td>Investment</td><td colspan="3">Relevance: Relative planning costs per unit produced
Example: Investment costs for automation systems (especially generative CAPP)</td></tr>
<tr><td rowspan="6">Characteristics</td><td>Standardization [15]</td><td colspan="3">Relevance: Reproducible, dependent outcomes
Example: Documentation, change processes, knowledge management, interfaces, data formats</td></tr>
<tr><td>Adaptability [15]</td><td colspan="3">Relevance: Ability to adjust to changes in production capacity and functionality
Example: CAPP systems ability to expand beyond prismatic components</td></tr>
<tr><td>Flexibility [16]</td><td>n.a.</td><td colspan="2">Relevance: Quick reaction to unforeseen events
Example: Generating several alternative process plans</td></tr>
<tr><td>Collaboration/ integration [7,9]</td><td colspan="3">Relevance: Increasing the efficiency of involved functions
Example: Integration of planning and scheduling, support for collaboration with design/calculation (SE)</td></tr>
<tr><td>Real-time ability [17]</td><td>n.a.</td><td colspan="2">Relevance: Timeliness of generated plans, integration of planning and scheduling
Example: Receive and process shop-floor information in real-time</td></tr>
<tr><td>Knowledge management [9,14]</td><td colspan="3">Relevance: Standardization and automation potential
Example: Automated knowledge acquisition from data, formalization and integration of expert knowledge (infrastructure, products, processes)</td></tr>
<tr><td rowspan="3">Interaction [18]</td><td>Dependency on experts</td><td colspan="3">Relevance: Personnel availability and cost
Example: Codification of expert knowledge and process automation</td></tr>
<tr><td>Transparency</td><td>n.a.</td><td colspan="2">Relevance: Trustworthiness of planning results
Example: User interaction and participation in decision making</td></tr>
<tr><td>Ease of use</td><td colspan="3">Relevance: Efficiency of process
Example: User-friendliness of processes, software and tools</td></tr>
</table>

Fig. 4. Planning process assessment

During assessment, the user applies the relevant criteria to the required information of the planning level of interest (Fig. 3). For example, when choosing or designing a process planning approach for individual production, the stakeholders might decide that the planning approach should primarily provide information on *macro/process plan level* because the *operations planning* is left to experienced machine operators.

Assessment Criteria		Description
Data requirements [19]	Integrity	*Relevance*: Existence of necessary data (database entry not empty, complete, in permissible value range, and corresponding to domain) in order to generate information *Example*: Workstation ID existing as four digit-number for every process listed, process description being a subset of as permissible defined operations
	Consistency	*Relevance*: Ability to generate information from data without contradictions *Example*: Conflicting instances of a certain process step (number) in the operations sequence
	Correctness	*Relevance*: Correct reflection of reality *Example*: Workstation ID in process plan matching transaction data from executed orders
	Accuracy	*Relevance*: Precision of reflection of reality for data on continuous or near ordinal scale *Example*: Workstation ID of a workstation with capabilities 'close' to the correct one and/or specificity of the data/information itself (e.g. workgroup ID instead of workstation ID)
	Timeliness	*Relevance*: Feasibility of execution of process plan *Example*: Standard times information generated based on latest process parameters
Optimization criteria	Processing time	*Relevance*: Affecting manufacturing costs in conjunction with machine hour rates *Example*: Minimizing makespan/throughput time and resource utilization of an order
	Resource utilization	*Relevance*: Efficiency of resource utilization *Example*: Ensuring balancing of resource utilization while meeting requirements for feasibility
	Feasibility [17]	*Relevance*: Producability according to plan and to product specifications *Example*: Operations sequence suitable to generating features in product specifications
	Robustness/ resilience	*Relevance*: Process capability *Example*: Enabling SPC, consideration of machine failure rates etc.
	Flexibility	*Relevance*: Enabling integration of planning and scheduling *Example*: Designation and selection of master/variant process plans, networked process plans
	Standar-dization [20]	*Relevance*: Optimization of processes and concentration of material flows on the shop-floor *Example*: Substantial conformity of process plans of similar components
	Environmental impact	*Relevance*: Affecting manufacturing costs *Example*: Resource consumption (e.g. processing times, energy consumption, scrap material, consumables) and emissions

Fig. 5. Process plan assessment

5 First Case Study and Basic Validation

The assessment framework is illustrated with the example of an industrial partner in the metal working industry. All subprocesses are determined to be relevant dimensions, while only the macro planning level is of interest in this case (cf. Fig. 2, step 1). Weighting the assessment criteria in a pair-by-pair comparison (cf. Fig. 2, step 2), effort and duration prove important for the planning process. Most important criteria for the resulting process plan are feasibility, integrity and correctness/accuracy.

Figure 6 shows two macro level process plans for a piston variant, generated manually and by a generative computer-aided process planning (CAPP) system. The relevant stakeholders have assessed (cf. Fig. 2, step 3) the rather quick manual planning process positive in terms of duration and effort. The automated and even faster generation by the CAPP system is rated very positive, however length and effort of the CAPP system setup and update process are rated very negatively.

Comparing the resulting process plans to several executed manufacturing orders for the parts number, the characteristics of the manually generated process plan are established as very positive. It is showing occasional deviations to other workstations with the same capabilities as well as statistical variations of processing and setup times.

Manually generated process plan

Op.	Work-station	Process	t_r [min]	t_e [min]
010	0911	Withdraw	0	0
020	0815	Turn	35	4.8
030	0112	Control	0	0
040	0398 (ext.)	Surface	0	0
050	0110	Inspection	0	0
060	4711	Polish	9	1.2
070	0112	Control	0	0

Automatically generated process plan

Op.	Work-station	Process	t_r [min]	t_e [min]
010	0815	Turn	65	3.243
020		Surface	0	0
030	4711	Polish	9	1.970
040		Control	0	0

Fig. 6. Process plans for machining a piston variant

The characteristics of the automatically generated process plan, without any further human intervention, are assessed as neutral. All necessary machining operations are included in the right order, however the operations sequence needs to be complemented. Two workstation IDs are missing for integrity, while the accuracy of the standard times is significantly off in several instances.

According to the assessment regarding the criteria relevant to the company, it becomes obvious, that at the current stage manual process planning remains the norm, while further capability improvements of the CAPP system will be investigated.

6 Conclusion

The assessment framework presented in this paper offers comprehensive criteria and corresponding descriptions for both the planning process, as well as the resulting process plan. It can serve researchers developing new process planning approaches for reference and enables practioners reengineering their planning process to assess their respective options with the criteria relevant to them. The assessment framework was validated with an SME.

Further research needs to be done on the measurability of the criteria. More validation needs to be done to further detail the approach and to ensure applicability in various fields/sectors.

Acknowledgement. The authors would like to thank the German Research Foundation DFG for the kind support within the Cluster of Excellence “Integrative Production Technology for High-Wage Countries”.

References

1. Wiendahl, H.-P.: Betriebsorganisation für Ingenieure, 8th edn. Hanser, München (2014)
2. Yusof, Y., Latif, K.: Survey on computer-aided process planning. Int. J. Adv. Manuf. Technol. **75**(1–4), 77–89 (2014)
3. Schuh, G., Prote, J.-P., Luckert, M., Hünnekes, P.: Automatisierung in der Arbeitsplanung. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb **112**(12), 827–830 (2017)

4. Chryssolouris, G.: Manufacturing Systems: Theory and Practice, 2nd edn. Springer, New York (2006). https://doi.org/10.1007/0-387-28431-1
5. Amaitik, S., Kiliç, S.: An intelligent process planning system for prismatic parts using STEP features. Int. J. Adv. Manuf. Technol. **31**(9–10), 978–993 (2007)
6. Liu, S., Zhang, Z., Tian, X.: A typical process route discovery method based on clustering analysis. Int. J. Adv. Manuf. Technol. **35**(1–2), 186–194 (2007)
7. Lee, H., Kim, S.S.: Integration of process planning and scheduling using simulation based genetic algorithms. Int. J. Adv. Manuf. Technol. **18**(8), 586–590 (2001)
8. Šormaz, D.N., Rajaraman, S.N.: Problem space search algorithm for manufacturing cell formation with alternative process plans. Int. J. Prod. Res. **46**(2), 345–369 (2008)
9. Denkena, B., Shpitalni, M., Kowalski, P., Molcho, G., Zipori, Y.: Knowledge management in process planning. CIRP Ann. – Manuf. Technol. **56**(1), 175–180 (2007)
10. Fishermanns, G.: Praxishandbuch Prozessmanagement, 9th edn. Schmidt, Gießen (2010)
11. Vom Brocke, J., Simons, A., Riemer, K., Niehaves, B., Plattfaut, R., Cleven, A: Standing on the shoulders of giants: challenges and recommendations of literature search in information systems research. In: Communications of the Association for Information Systems, vol. 37, no. 1, pp. 205–224, Article no. 9 (2015)
12. Vom Brocke, J., Simons, A., Niehaves, B., Riemer, K., Plattfaut, R., Cleven, A.: Reconstructing the giant: on the importance of rigour in documenting the literature search process. In: ECIS 2009 Proceedings, Paper 161, pp. 2206–2217 (2009)
13. Guarnieri, P. (ed.): Decision Models in Engineering and Management, 1st edn. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-11949-6
14. Schuh, G., Prote, J.P., Luckert, M., Hünnekes, P.: Knowledge discovery approach for automated process planning. Procedia CIRP **63**, 539–544 (2017)
15. Park, S.C.: Knowledge capturing methodology in process planning. Comput. Aided Des. **35** (12), 1109–1117 (2003)
16. Chu, X.N., Tso, S.K., Tu, Y.L.: A novel methodology for computer-aided process planning. Int. J. Adv. Manuf. Technol. **16**(10), 714–719 (2000)
17. Li, X., Zhang, C., Gao, L., Li, W., Shao, X.: An agent-based approach for integrated process planning and scheduling. Expert Syst. Appl. **37**(2), 1256–1264 (2010)
18. ElMaraghy, H.A.: Reconfigurable process plans for responsive manufacturing systems. In: Cunha, P.F., Maropoulos, P.G. (eds.) Digital Enterprise Technology, pp. 35–44. Springer, Boston (2007). https://doi.org/10.1007/978-0-387-49864-5_4
19. Brambring, F.: Steigerung der Datenintegrität in der Produktionssteuerung, 1st edn. Apprimus, Aachen (2017)
20. Nöhring, F., Sackermann, R., Krebs, M., Deuse, J.: Moderne Zeitwirtschaft in der Einzel- und Kleinserienfertigung. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb **111**(5), 256–260 (2016)

Dynamic Scheduling of the Dual Stocker System Using Reinforcement Learning

Seol Hwang, Sang Pyo Hong, and Young Jae Jang(✉)

Department of the Industrial and Systems Engineering,
Korea Advanced Institute of Science and Technology,
Daejeon 305-701, Republic of Korea
yjang@kaist.ac.kr

Abstract. The stocker system is the most widely used material handling system in LCD and flat panel fabrication facilities (FABs). The stocker mainly consists of one or two cranes moving along a single track to transport lots, or cassettes, containing 10 to 30 thin glass substrates between processing machines. Because the stocker system is the primary material handling system in the FABs, its performance directly affects the overall performance. In this study, we investigate the scheduling of a dual stocker system operating with two cranes simultaneously on a single track and propose a learning-based scheduling algorithm for the system. We report some of the results of our long-term efforts to dynamically optimize the dual-crane stocker. We fisrt show the modeling and algorithm to minimize the make-span of the jobs. We incorporate the model to dynamically allocate jobs. In particular, we use a reinforcement learning method in the scheduling algorithm. The model is validated in an extensive simulation study based on actual data.

Keywords: Reinforcement learning · Scheduling · AMHS

1 Introduction

The thin film transistor liquid crystal display (TFT-LCD) is one of the most widely used LCD due to its high image quality. An automated material handling system (AMHS) is commonly exploited in TFT-LCD manufacturing to deal with complicated movements of cassette, a container holding LCD glasses. The stocker system is a main component of AMHS in TFT-LCD fabrication facilities (FABs), which consists of one or two cranes on a single rail and shelves used as buffer spaces. The processing machines are attached to the stocker system (Fig. 1). The crane travels along with a rail and moves up and down to pick up and set down a cassette. Recently, two cranes are usually used in most TFT-LCD FABs in order to increase throughput of the stocker system, which is referred to as the *dual crane stocker*.

Since two cranes travels on a single rail simultaneously in the dual crane stocker, a strategy to avoid collision within cranes should be designed. Most

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 482–489, 2018.
https://doi.org/10.1007/978-3-319-99704-9_59

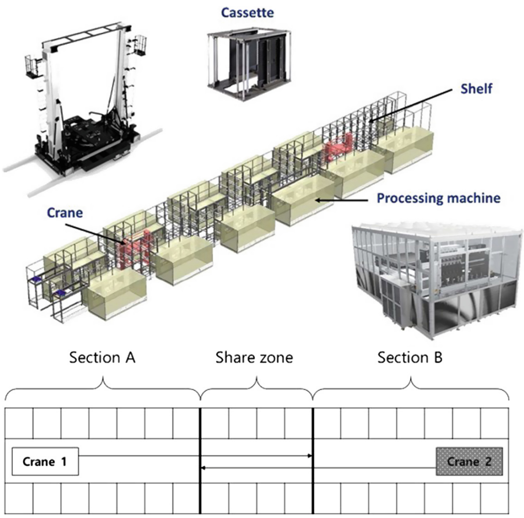


Fig. 1. The stocker system

dual crane stockers in industry adopt first-in-first-out (FIFO) rule based on an area segregation. As shown in Fig. 1, the stocker is divided three sections and each crane travel only up to share zone and only one of cranes can occupy share zone to avoid a collision. Although this operation rule is simple and effective in avoiding collisions, it arouses two kinds of inefficiency. First, when a crane use the share zone, another crane should wait until the occupying cranes work is done, which is called blocking. Second, an additional movement is necessary to hand over a cassette to another crane when the cassette could not be transported directly by a crane. For example, if a cassette should move from section A to section B, crane 1 transports the cassette from section A to an empty buffer in the share zone. Then crane 2 picks up the cassette on the share zone and transports it to the destination in section B. These inefficiency could be handled by effectively determining the size or location of the share zone. However, a proper scheduling rule without the share zone would be the best way to maximize the stocker systems capacity as long as the collision is avoided. There were a few studies about the stocker system in TFT-LCD. Jang et al. [4] proposed an analytical model for measuring the performance of the single crane stocker system. Several studies dealt with the stocker for layout design with TFT-LCD plant and suggested mathematical model including determination of the share zone [3,7]. Reinforcement learning is a method that learn a policy based on an action value from experience. Once the agent is trained through many experiences, it can select an appropriate action in a short time. Most researches in this field focused on choosing appropriate heuristics [1,8] which is different with our approach in that dual crane stocker scheduling problem do not have typical scheduling rules. Meanwhile, Bradtke [2] showed that DP-based reinforcement learning converged to the optimal policy with non-linear function approximators. Dietterich et al. [9]

applied TD(λ) to train a neural network to learn heuristic evaluation function in job-shop scheduling problem. These results presented a possibility of DP-based scheduling with neural network could work in other domain. Recently, Google Deep Mind team showed that Deep-Q Network, combination of reinforcement learning and deep neural network [5], could learn policies successfully in Atari games and surpass the performance of all previous algorithms. In this paper, we formulate a scheduling problem for dual crane stocker applying dynamic programming (DP). DP approach could find an optimal solution for a static case, but curse of dimensionality makes the computation time to increase exponentially. Thus we used neural network to approximate non-linear relationship within features. In particular, we suggested a novel image based input shape to represent the state accurately and adopted convolution layer to take into account interactions between movements.

2 Modeling Assumptions

The assumptions for the stocker model are as follows.

- Both a transportation from a processing machine to a shelf and from a shelf to a processing machine were considered as a same kind of a job.
- Initial jobs were generated randomly with pre-determined origin location and destination.
- Though vertical and horizontal movement of the crane occur simultaneously, the horizontal movement was solely considered. Since it takes much more time to move horizontally than vertically, vertical movement of a crane is negligible.

We used a term bay as a unit of a location in the stocker system. There are two sets of load ports, the spaces for cassettes, in upper and lower side of Fig. 1 (lower panel). However, it is not necessary to distinguish transports into load ports at upper or lower since the total travel time is same as long as the bay number is same. The difficulty of dual crane stocker problem comes from collision avoidance movement. The cranes should maintain safety distance to avoid collision. Even if same crane selects same job, the processing time could be quite different because of an interference within two cranes. The final objective of the dual stocker scheduling problem is finding an optimal scheduling rule on dynamic environment that jobs are generated continuously. In order to achieve that goal, we first focused on scheduling for the given jobs in static case whose measurement is makespan.

3 Dynamic Programming

The problem can be formulated using dynamic programming (DP). Some notations are defined as follows. $\mathbf{B} \in [1, b_e]$ is the set of bay numbers in the stocker system where b_e is a last bay number. Each job is numbered according to the entering sequence and represented with origin location and destination as $j_i = (o_i, d_i)$

where $(o_i, d_i) \in \mathbf{B}$. The state of the stocker we made consisted of crane work state and waiting job list, $\mathbf{S} = <\mathbf{C}, \mathbf{J}>$.

- $\mathbf{C} = \{c_1, c_2 \,|\, c_1, c_2 \in \{0, j_1, ..., j_N\}\}$ represent which job is transported by the cranes at the state. If a crane is not assigned by any job, 0 is used.
- $\mathbf{J} = \{j_{i \in \mathbf{W}} \,|\, \mathbf{W}$ is a set of waiting jobs$\}$ is waiting job list. At the initial state, $\mathbf{J} = \{j_1, ..., j_N\}$. If a job is selected by decision making agent, the job is deleted from the set $\mathbf{J}$. Thus, $\mathbf{J} = \emptyset$ at the terminal state.

As we mentioned, the state of the stocker in DP is a decision point of decision making agent. Since the decision making agent choose jobs from waiting job list, action set $\mathbf{A}$ is same with set $\mathbf{J}$. Though the state is defined, more information is necessary to express a specific status of the system. It is referred to as attribute and they consisted of locations, destinations, operation status and remaining time of the cranes.

- $\mathbf{L} = \{l_1, l_2 \,|\, l_1, l_2 \in \mathbf{B}\}$ represents locations of the cranes
- $\mathbf{D} = \{d_1, d_2 \,|\, d_1, d_2 \in \mathbf{B}\}$ represents destinations of the cranes
- $\mathbf{O}^s = \{o_1^s, o_2^s \,|\, o_1^s, o_2^s \in \{Retrieve, Pickup, Deliver, Setdown, Idle\}\}$
- $\mathbf{T}^r = \{t_1^r, t_2^r \,|\, t_1^r, t_2^r \in \mathbb{R}^+\}$ represents the remaining time in current status of the cranes.

After defining the state, we developed the optimization problem to minimize the makespan of the given job. This makespan minimization is structurally equivalent to the shortest path problem and it can be solved using a DP approach. Since the states were defined as the decision points and we considered the optimal makespan for given jobs, the model is categorized as a deterministic finite state, discrete time DP model. The notation for the model was as follows:

- s_t: state of the stocker system at time t;
- a_t: decision for the next job at time t;
- $\mathbf{P}_t(s_t, a_t)$: interval time between s_t to s_{t+1} when action a_t is taken at s_t; and
- $\mathbf{V}_t(s_t)$: total time from time t at the current state s_t. (cost-to-go function).

Then the recursive equation is

$$\mathbf{V}_t(s_t) = \min_{a_t}\{\mathbf{P}_t(s_t, a_t) + \mathbf{V}_{t+1}(s_{t+1})\} \quad (1)$$

To solve this equation, it is necessary to expand overall state space in order to compute $P_t(s_t, a_t)$ for all t. Then calculate $V_0(s_0)$ by backwards induction using (1). Although DP approach find optimal solution, the computation time increases exponentially. When the number of initial job is up to five, it took less than 10 s. However, it took about 200 s in six initial jobs and more than 3 hours in seven, which is not applicable practically.

4 Deep Q Network

Deep Q network (DQN) is a reinforcement learning algorithm adopting neural network as an approximate function. We introduce DQN briefly and explain a novel shape we made in order to increase a performance of the algorithm. The key points of DQN are experience replay and separate network, which are the techniques for training neural networks without diverging. Experience replay is a methodology that storing agents experiences at each time step to a replay memory and exploiting mini-batch data drawn at random from the pool of stored samples for Q-learning. This technique makes the training data not to have a bias due to a correlation between adjacent data. Next, DQN copies a target network $\hat{Q}$ from learning network Q in order to generate Q-learning targets (y_j). The algorithm become more stable by preventing the network Q from oscillation or divergence. The full algorithm of DQN is presented in Algorithm 1. We implemented this algorithm using a tensorflow.

Algorithm 1. Deep Q network

Initialize replay memory D
Initialize action value function Q with weight θ using Xavier initialization
Initialize target action value $\hat{Q}$ with weight $\theta^{-} = 0$
for $episode = 1, M$ **do**
    Initialize s_0
    for $t = 1, T$ **do**
        Choose $a_t \sim \epsilon$-greedy policy
        Take action a_t, observe r_t, s_{t+1}
        Store transition (s_t, a_t, r_t, s_{t+1}) in D
        Sample random minibatch of transitions (s_j, a_j, r_j, s_{j+1}) from D
        $y_j = \begin{cases} r_j & \text{if } j+1 = T \\ r_j + \gamma \min_{a'} \hat{Q}(s_{t+1}, a'; \theta^{-}) & \text{otherwise} \end{cases}$
        Perform a gradient descent with respect to the network parameter θ
        Every C steps update $\hat{Q} = Q$
    end for
end for

The performance of deep Q-learning or neural network depends on various factors. Though the system environment is identical, the result can be considerably different in accordance with the shape of input data. We suggest two kinds of shape, simple integer type and vector expression of moving trace. Though an integer shape contains all information of a state, it could be not efficient for a neural network to predict an action value due to its excessive simplicity. The action value of a state is determined by cranes movement and remained jobs origin-destination (OD) pair. From this attribute, visualizing the traces of movement and od pair might be a new approach for input shape. For instance, with a case in Fig. 2, first moving trace of crane 1 is delivering movement from bay 4 to bay 8. Likewise, if the picked action has been job 4, first moving trace of crane 2 is a retrieving movement from bay 17 to bay 13, and second is a delivering from bay 13 to bay 9. Moving direction is expressed with color that red is toward right side and blue is the opposite. The remained jobs trace also could be drawn in the same way (Fig. 2). The drawn traces are converted to a number matrix. In the first column, crane moving priority index is added to describe which crane would move first. The other values are converted from the traces using integer 1 and −1, which represent moving to right and left respectively. Therefore, the size of the matrix is $(N + 4) \times (b_e + 1)$.

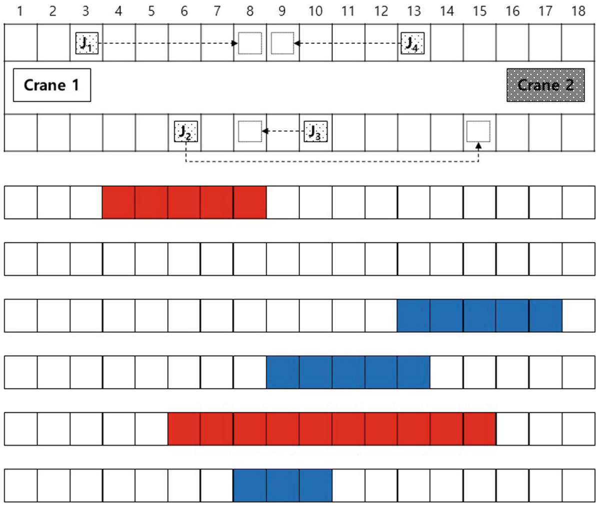


Fig. 2. Trace-shape of movements

5 Experiment Result

5.1 Static Case

The scheduling performance comparison of dynamic programming (DP), deep Q-network (DQN) and first-in-first-out rule (FIFO) was conducted using 100 randomly generated test set along with various initial job numbers from 3 to 10. The performance of learning based algorithms was evaluated after learning with 50,000 episode and hyper-parameters of each method was tuned respectively. We constructed neural network with two layers and 8 filters for convolution, two hidden layers and 32 nodes for fully connected network. The learning rate was 0.001 and the exploration rate was 0.2 for DQN.

Figure 3(a) is summarized graph comparing the makespan of three methods. Since DP guarantee optimal solution, any other methods cannot be better than the DP solution. However, since DP needs enormous computation time as the initial job number increases, results for more than 7 initial jobs were not computed.

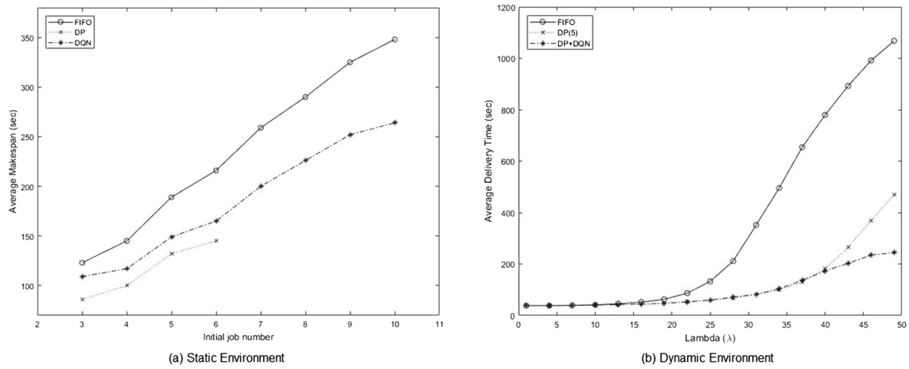


Fig. 3. Performance comparison graph

5.2 Dynamic Case

The dynamic case considers the dynamic job allocation to the stocker crane when jobs are continuously created. With the insight gained from the static case, we applied the the DQN model to the dynamic case with some modification of the model. The primary goal of the dynamic model is to reduce the average waiting time of the lots with an optimal job allocation policy. The dynamic model is created through the following three steps.

First, it create a neural network from the approach of the rolling horizon approach extended from the static case. That is, the results of the dynamic allocation from the rolling horizon approach have been used to train the neural network. Second, the Q-value based priority rule is developed on top of the neural network. The jobs in the queue are prioritized based on the Q-value of each job—the lower the Q-value, the higher the priority the job is given. This approach significantly reduces the waiting time of the jobs. The third step is that the neural network with the Q-value based priority rules is modified with rolling out heuristics approach which is proposed in [6]. We call this approach developed from the three step, *DP+DQN* model.

Figure 3(b) shows the preliminary result of the dynamic case. The y-axis and x-axis represent the average delivery time of the lots and the load factor, λ. The constant value is multiplied to the base from-to value. The higher the load factor, the higher from-to deliver requirement. The proposed DP+DQN is compared to the FIFO rule and the static DP with rolling horizon case. The result shows that the DP+DQN outperforms compared to the rest of the approach. It also shows a stable performance even the load factor reached to the 50, where the rest of the cases tend to increase the waiting time significantly.

6 Conclusion

In this paper, we suggested dynamic programming model for dual crane stocker scheduling problem and developed the model into the deep Q network (DQN).

We obtained an optimal solution considering interference within two cranes in case of relatively small number of initial jobs using DP approach. We proposed the trace shape of input data and applied convolution layer to improve the performance of neural network. The model is first developed for a static case where the model seeks to optimal crane move sequence to minimize the makespan of the jobs in the queue. With the insight gained from the static case, we further developed the dynamic case to find an optimal policy to allocate the jobs in a dynamic environment. The preliminary case shows that the proposed DQN+DP outperforms the FIFO and DP with rolling horizon.

The work is still far from complete. An extensive numerical cases studies are still needed to verify the approach. Also, we still need to provide logical and numerical verification that how the proposed approach outperforms the existing approach. Also we still need to investigate in which case the effectiveness of the proposed case is weakened. We proposed this to the future study.

References

1. Aydin, M.E., Öztemel, E.: Dynamic job-shop scheduling using reinforcement learning agents. Robot. Auton. Syst. **33**(2–3), 169–178 (2000)
2. Bradtke, S.J.: Reinforcement learning applied to linear quadratic regulation. In: Advances in Neural Information Processing Systems, pp. 295–302 (1993)
3. Ho, Y.C., Su, T.S.: The machine layout within a TFT-LCD bay with a multiple-stacker crane in-line stocker. Int. J. Prod. Res. **50**(18), 5152–5172 (2012)
4. Jang, Y.J., Choi, G.H., Kim, S.I.: Modeling and analysis of stocker system in semiconductor and LCD FAB. In: 2005 IEEE International Symposium on Semiconductor Manufacturing, ISSM 2005, pp. 273–276. IEEE (2005)
5. Mnih, V., et al.: Human-level control through deep reinforcement learning. Nature **518**(7540), 529 (2015)
6. Powell, W.B.: Approximate Dynamic Programming: Solving the curses of Dimensionality, vol. 703. Wiley, New York (2007)
7. Su, T.S., Hwang, M.H.: Efficient machine layout design method with a fuzzy set theory within a bay in a TFT-LCD plant. Procedia Manuf. **11**, 1863–1870 (2017)
8. Wang, Y.C., Usher, J.M.: Application of reinforcement learning for agent-based production scheduling. Eng. Appl. Artif. Intell. **18**(1), 73–82 (2005)
9. Zhang, W., Dietterich, T.G.: A reinforcement learning approach to job-shop scheduling. In: IJCAI, vol. 95, pp. 1114–1120. Citeseer (1995)

Knowledge Based Engineering

Integrating Experiential Learning and Accreditation Requirements – A Case Study Based Course

Khaled Medini(✉)

Mines Saint-Etienne, Univ Clermont Auvergne, CNRS, UMR 6158 LIMOS, Institut Henri Fayol, 42023 Saint-Etienne, France
khaled.medini@emse.fr

Abstract. The increasingly evolving industrial context in manufacturing and service industries calls for an adaptation of the practices and content of engineering education curricula. More active learning approaches are required in order to easily grasp new business challenges and strategies, such as customer centric enterprise and mass customisation. This paper reports on a case study based lecture about mass customisation which was given to students pursuing a Master of Science degree in Industrial Engineering. The lecture echoes the Kolb model for Experiential Learning and refers to guidelines about accreditation requirements. An analysis of the achievement of learning outcomes is realized based a student survey conducted upon two different classes.

Keywords: Industrial transition · Case study · Experiential learning Accreditation · Mass customisation

1 Introduction

Manufacturing and service industries challenges are increasingly evolving which calls for a proactivity of the company so as to keep up with these evolutions. Recent technological advances, increasing market segmentation and individualised demands, competition on both prices and quality, are among the factors motivating companies to pursue more customer centric business strategies, such as mass customisation (MC). In a simple way, MC aims to fulfil customer individual demands with near mass production efficiency (Salvador et al. 2009; Medini 2015). A full understanding of MC and customer orientation in operations management requires an adaptation of the practices and content of engineering education curricula, towards more active learning approaches (Kolb and Kolb 2005; Bassetto et al. 2011; Visich et al. 2012; Peillon et al. 2016; Medini 2018).

This paper reports on a case study based lecture about MC, which has been given to students pursuing a Master of Science in Industrial Engineering. The lecture echoes the Kolb model for Experiential Learning and refers to guidelines about accreditation requirements. An analysis of the achievement of learning outcomes is performed based a students' survey conducted upon two different classes.

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 493–501, 2018.
https://doi.org/10.1007/978-3-319-99704-9_60

The remainder of the paper is organised as follows: Sect. 2 provides a brief overview of the related background literature. Section 3 reports on a method for designing a course integrating an active learning approach and accreditation requirements. Section 4 shows a designed course following the proposed method. Section 5 discusses the achievement of the learning outcomes based on students' perceptions, considering two courses with different integration levels of experiential learning. Concluding remarks are given in Sect. 6.

2 Background Literature – Experiential Learning Theory and Application in Engineering Education

Experiential Learning theory sees the learning as "*the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience*". According the experiential learning theory, learning is a recursive process assimilated to a four-stage cycle spanning over: concrete experience (CE), reflective observation (RO), abstract conceptualization (AC), and active experimentation (AE) (Fig. 1). Students can start learning through concrete experience that they observe and reflect upon, deriving from their reflection abstract concepts. They then draw new implications from these abstract concepts and test them through active experimentation (Kolb 1984; Kolb and Kolb 2005).

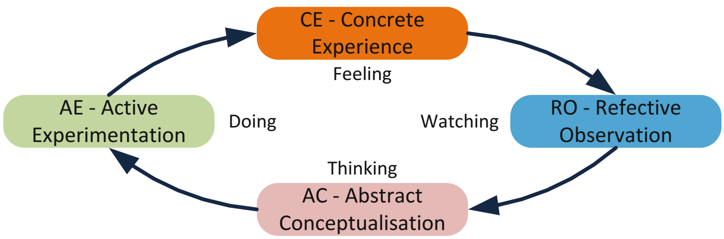


Fig. 1. Kolb learning cycle

Kolb and Kolb (2005) identified a number of educational principles that ensure the consistency of the experiential learning experience of the students and avoid miss-educative experiences: respect for learners and their experience, begin learning with the learner's experience of the subject matter, creating and holding a hospital space for learning, making space for conversational learning, making space for development of expertise, making space for acting and reflecting, making spaces for feeling and thinking, making space for inside-out learning, making space for learners to take charges of their own learning. These practices within engineering courses support an improvement of the students' retention rate (Kolb and Kolb 2005).

Experiential learning has been widely used in a variety of engineering education contexts and within many universities all over the world; examples of these are reported in the following research works (Bassetto et al. 2011; Visich et al. 2012;

Medini 2018). Despite the large use of experiential learning and the increasing awareness of its benefits to the students, guidelines for designing effective experiential learning courses or activities are scarce. Most of experiential learning applications are inspired by the basic learning cycle and design methods of the activities or courses, are either implicit or briefly presented.

3 Course Design Following EUR-ACE Guidelines and Experiential Learning Principle

This section provides a structured method for course design following an experiential learning principle. The method builds on EURA-ACE (European Accreditation for Engineering) guidelines for educational programmes design, and on learning cycle and educational principles from the experiential learning theory. More specifically, the general steps of the method are inspired by previous works on how to develop a programme based on accreditation criteria (EURA-ACE) (Chuchalin and Kriushova 2011). The identification and articulation of learning modules and modes is inspired by the experiential learning cycle and educational principles.

Figure 2 shows the steps of the method, reported on in the boxes. Vertical arrows refer to the main used concepts from literature. Full line horizontal arrows illustrate the sequence of the steps, while the dashed arrows show some of the main iterations which occur during the design process. The general design steps are needs analysis, general objectives identification, learning outcomes definition, learning modules identification, building syllabus, and course assessment plan.

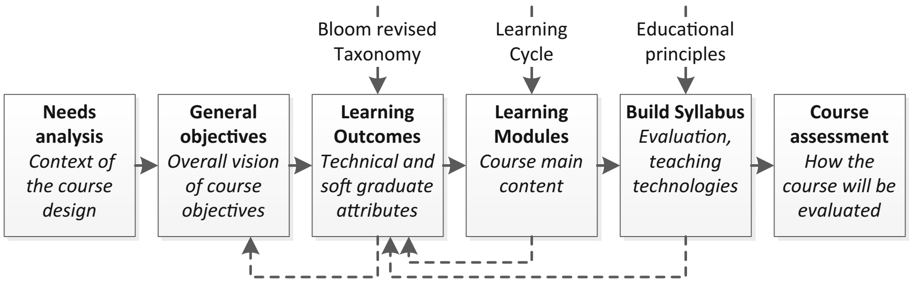


Fig. 2. Course design method

Needs analysis is recognized as an important step in course design which contributes towards more contextualised content (Lekatompessy 2002). This step is expected to enlighten the course designers on the learners' current skills, knowledge gaps, objective and subjective needs, and on the expected use of the know-how and knowledge transmitted through the course. Needs analysis is not a one-shot action; on the contrary, it should support a continuous improvement process of the course.

Needs analysis contributes to the subsequent steps namely the formalisation of the course *general objectives* and *learning outcomes*. Similarly to the programme design context (ENAEE 2005), in course design, the general objectives should reflect how the needs of the students (or any other targeted public) are met through the course.

Learning outcomes refer to the graduate attributes in terms of technical and soft skills that can be achieved through the course (Chuchalin and Kriushova 2011). The definition of *learning outcomes* uses the revised taxonomy of Bloom (Krathwohl 2002). The dimensions of the revised taxonomy are as follows: ***Remember*** **–** Retrieving relevant knowledge from long-term memory. ***Understand*** **–** Determining the meaning of instructional messages, including oral, written, and graphic. ***Apply*** **–** Carrying out or using a procedure in a given situation. ***Analyze*** **–** Breaking material into its constituent parts and detecting how the parts relate to one another and to an overall structure or purpose. ***Evaluate*** **–** Making judgments based on criteria and standards. ***Create*** **–** Putting elements together to form a novel, coherent whole or make an original product.

In the next step of course design, the learning modules are identified and mapped to learning outcomes. The share of the grades among learning modules is partly based on learning modules importance to learning outcomes achievement. The identification of learning modules is inspired by experiential learning theory in order to define the learning cycle. The four learning stages of experiential learning theory are used as guidelines to identify the focus of each learning module. Altogether, learning modules should support a specific learning cycle.

The subsequent step, *build syllabus*, consists in defining how learning modules will be actually conducted (e.g. sequence, organisation, teaching technologies, etc.) and how the grades are assigned. This step is referred to in Fig. 2 by *Build Syllabus*.

In the final step in course design, *course assessment*, the methods and ways of assessing the course will be designed. Usually, students' surveys are an easy-to-implement method and provide valuable insights into student perceptions.

4 Designed MC Course

This section reports on the design of new course following the presented method, starting from a similar course which has been given to MSc students in 2016. The use of the method supported substantial modifications in both objectives and content of the course. Next paragraphs illustrate the six design steps.

Needs Analysis. The course is developed within an MSc programme in Industrial Engineering. The students have backgrounds in industrial or mechanical engineering. They hold either a bachelor or an Engineer or equivalent MSc degree in these domains. Most of the students are international and come from Europe, North Africa, Asia and Latin America. This also means that the course language should be no other than English, as it is the most likely common language for all students. Within the context of industrial transition, the students lack a deep understanding of how business strategies such as MC could foster the industrial renewal and how they can actually be implemented.

General Objectives. The objective of the course is threefold; first introduce MC as a customer centred strategy, second enlighten the students on how MC can actually be implemented in the manufacturing and service industries, third enhance students' research abilities and critical thinking.

Learning Outcomes (LOs). The learning outcomes of the course are as follows:

- LO1 – *Understand* MC philosophy and main capabilities (choice navigation, solution space development, robust process design (Salvador et al. (2009));
- LO2 – *Analyse* how these capabilities can be put in practice;
- LO3 – *Evaluate* the experience of a given company with MC implementation;
- LO4 – *Plan* the required actions for a service company to benefit from MC;
- LO5 – *Criticize* the soundness of case studies analysis performed by other peers.

Learning Modules (LMs). Learning modules include the following:

- LM1 – An introduction into the topic.
- LM2 – A seminal paper reading about MC capabilities.
- LM3 – Analysis of mass customisation case studies.
- LM4 – Review of peers' work about case studies analysis.

The planned contribution of learning modules to the learning cycle is reported on in Fig. 3.

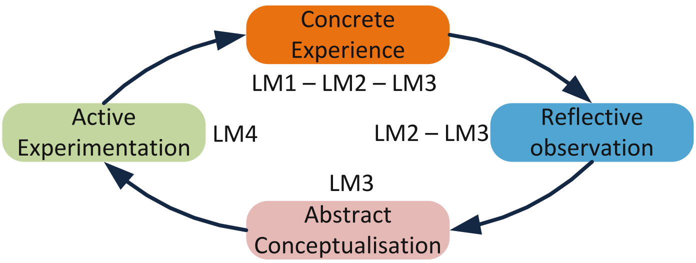


Fig. 3. LMs mapping to learning cycle

Table 1 reports on the mapping between learning modules and learning outcomes: a '+' in the crossing between a given row *i* and a given column *j* means that LM*i* contributes to the achievement of LO*j*. Clearly, case studies (LM3) have the most significant contribution to learning outcomes. However, these cannot be achieved without the other learning modules altogether. This is quite expected because of the involvement of LM3 in various learning stages of the experiential learning cycle.

Build Syllabus. The course is organised as follows; LM1 is planned in the beginning so as to provide an introduction and the instructions to the students. Afterwards, students are left with the paper reading (LM2). A summary of the paper is required which enhances also the reflective observation activity in reference to experiential learning cycle. Upon finishing off with the seminal paper, students start working on three assigned case companies (LM3). The students are asked to report on how these companies implemented the three MC capabilities, seen in LM2. The provided input

Table 1. LOs and LMs mapping

	LO1	LO2	LO3	LO4	LO5
LM1	+				
LM2	+	+			
LM3	+	+	+	+	
LM5		+	+		+

material consists basically of (i) written interviews of mass customisation experts speaking about case companies' experiences with MC, and (ii) case companies' websites. A first deliverable including the article summary and case studies analysis is due one week after the beginning of the course. Then students are asked to identify the actions required to pursue MC considering an integrated product and service offering. A second deliverable summing up this effort is due two weeks after the beginning of the course. Upon receiving students' deliverables, a peer review process is launched and need to be finished within one week. A presentation session is planned few days later to discuss the case studies. The interactions between students are enhanced by their recent peer review experience.

Requisite skills can be met with an industrial engineering or engineering management background. The evaluation is based on the deliverable quality, the presentation and discussion, and a final exam about MC case.

Course Assessment. The questionnaire will be given to students few days after the last session. A hard copy is used to increase the response rate and avoid non-exploitable answers. The questionnaire include the following sections: students background, MC implications to firms strategy and competitiveness, MC implications to variety management, MC implications to production and supply chain management, Experiential learning approach, and MC topic relevance. A full version of the questionnaire can be found in Medini (2018).

5 Students Perception and Insights into Learning Outcomes Achievement

A survey was conducted in 2018 upon achieving the course. In order to evaluate the course improvement actions, the results were compared with the ones from a previous survey conducted in 2016 with another class taking the same course but with a different structure (Medini 2018). Figure 4 depicts the aggregate results of the surveys according to the questionnaire sections.

In the case of the adapted course, the sample size ranges between 12 and 13 while in the case of the traditional course the sample size is in the range 14–17. The questions are answered using a 5 levels grid (1 strongly disagree, 5 strongly agree). In student surveys of the previous traditional course and the redesigned, adapted course, most of the students are international and have similar past education.

Overall, it can be seen that there is an improvement in the achievement of the objectives. Unsurprisingly, MC implications to production and supply chain management

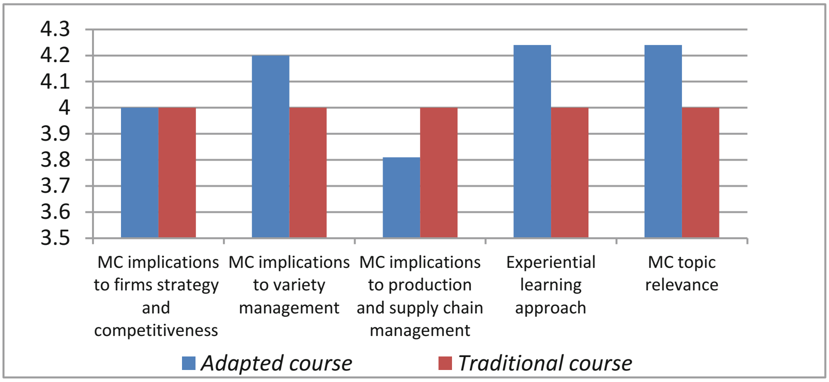


Fig. 4. Summary of the survey results

were better grasped in the traditional course. This is because the case studies are not directed towards these topics. Moreover, the traditional course included two simulation sessions addressing partly production management issues. However, the perceptions of the students from the adapted course indicated that this course brings more evidence of the relevance of the MC topic, and of the experiential learning approach.

Figure 5 shows a world cloud derived from students' answers to the open-ended questions of the survey, related to the adapted course. The size of the words is proportional to their frequency of occurrence. The world cloud is generated by the R software (Ihaka and Gentleman 1996) with the following rules: number of the words in the cloud should not exceed 30 (for the sake of readability), and minimum occurrence frequency of the words in students comments is 2 (to cover as many topics as possible).

Fig. 5. Word cloud of students' comments

It can be seen that case studies are prevailing in the answers of the students, highlighting particularly a positive perception of the students. The case studies helped some students to understand *'…in a more concrete and independent way how mass customisation is implemented…"*. Some other less frequent key words reflect the positive impact of the learning practices, e.g. *self-learning*, *apply*, *real*. Interestingly, the word "*prof*" (professor) appeared several times highlighting the need of some students to get continuous feedback on their work by the instructor. This can be addressed by intermediate discussion sessions. The survey revealed another potential improvement avenue that is, to visit companies and gain more insights into their experience with the mass customisation.

Although these findings need more evidence, they provide valuable insights into the impact of the proposed approach and into some potential improvement avenues.

6 Conclusion

The interdisciplinary topics brought by the industrial transition require proactivity on the side of academicians so as to design adapted course content and use appropriate teaching methods. This paper calls for integrating experiential learning theory and accreditation guidelines in the (re)design of courses in the engineering education domain to keep up with the industrial transition context. It was shown through the surveys that these approaches are likely to improve the achievement of the course objectives and student satisfaction.

Acknowledgements. The author would like to thank Omar Ezzat for his support in the peer review process and the management of the various deliverables from the students.

References

Bassetto, S., Fiegenwald, V., Cholez, C., Mangione, F.: Experiencing production ramp-up education for engineers. Eur. J. Eng. Educ. **36**(4), 313–326 (2011)

Chuchalin, A., Kriushova, A.: Engineering curriculum design based on accreditation criteria. In: SEFI Annual Conference, pp. 641–644. European Society for Engineering Education, Lisbon (2011)

ENAEE – European Network for Accreditation of Engineering Education: EUR-ACE (2005). http://www.enaee.eu/wp-assets-enaee/uploads/2015/04/EUR-ACE-Framework-Standards-and-Guidelines-Mar-2015.pdf. Accessed Apr 2018

Ihaka, R., Gentleman, R.: R: a language for data analysis and graphics. J. Comput. Graph. Stat. **5**, 299–314 (1996)

Kolb, A.Y., Kolb, D.A.: Learning styles and learning spaces: enhancing experiential learning in higher education. Acad. Manag. Learn. Educ. **4**(2), 193–212 (2005)

Kolb, D.A.: Experiential Learning: Experience as the Source of Learning and Development. Prentice Hall, Upper Saddle River (1984)

Krathwohl, D.R.: A revision of bloom's taxonomy: an overview. Theory Pract. **41**(4), 212–218 (2002)

Lekatompessy, F.M.: Needs Analysis in Curriculum Development Report on the Third Chapter of Jack Richard's book (Curriculum Development in Language Teaching). Cambridge University Press, Cambridge (2002)

Medini, K.: Customer order fulfilment in mass customization context: an agent based approach. Int. J. Simul. Process Model. **10**(4), 334–349 (2015)

Medini, K.: Teaching customer-centric operations management – evidence from an experiential learning-oriented mass customisation class. Eur. J. Eng. Educ. **43**(1), 65–78 (2018)
Peillon, S., Medini, K., Dubruc, N.: An initial training program on Product-Service Systems and servitization for engineering students. Procedia CIRP **47**, 282–287 (2016)
Salvador, F., Holan, P.M., Piller, F.: Cracking the code of mass customization. MIT Sloan Manag. **50**(3), 70–78 (2009)
Visich, J.K., Gu, Q., Khumawala, B.M.: B2C mass customization in the classroom. Decis. Sci. J. Innov. Educ. **10**(4), 521–545 (2012)

Towards the Generation of Setup Matrices from Route Sheets and Feedback Data with Data Analytics

Moritz Schröter(✉), Ben Lütkehoff, Markus Fischer, Matthias Blum, and Volker Stich

Institute for Industrial Management (FIR), RWTH Aachen University, Campus-Boulevard 55, 52074 Aachen, Germany
moritz.schroeter@fir.rwth-aachen.de

Abstract. The function or department of production control in manufacturing companies deals with short-term scheduling of orders and the management of deviations during order execution. Depending on the equipment and characteristics of orders, sequence dependent setup times might occur. In these cases for companies that focus on high utilization of their assets due to long phases of ramp up and high energy costs, it might be optimal to choose sequences with minimal setup time times between orders. Identifying such sequences requires detailed and correct information regarding the specific setup times. With increasing product variety and shorter lot sizes, it becomes more difficult and rather time intense to determine these values manually. One approach is to analyse the relevant features of the orders described in the route sheets or recipes to find similarities in materials and required tools. This paper presents a methodology, which supports setup optimized sequencing for sequence dependent setup times through constructing the setup matrix from such route sheets with the use of data analytics.

Keywords: Production control · Setup time optimizing sequencing Feedback data

1 Introduction

In manufacturing industry, the adherence to delivery dates is one of the main logistics goals to stay competitive in a global market. Companies that use energy-intense assets such as the plastics industry also pursue a high utilization of their assets to reduce production costs per part. The following paper deals with a practical use-case derived from an ongoing research project. The overall project aims to improve production control through application of Artificial Intelligence. The specific company manufactures plastic films and bags with help of blow film extrusion in a high variety. Due to the various fields of application for plastic bags, these are available in a wide range of colors, thickness and compositions of material. Depending on several product features, the changeover processes varies depending on warm-up and cleaning phases of the machines as well as on material changeovers that require flushing and batch number restrictions. In consequence, the setup times vary between orders and currently are

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 502–509, 2018.
https://doi.org/10.1007/978-3-319-99704-9_61

taken into account manually based on experience but not with different setup times in the planning system.

Over the past years, the company has created more than 1,000 customer specific recipes stored in route sheets in the ERP-System. At this time, there is no option implemented, that visualizes known or undiscovered similarities between orders to simplify this planning step, although the production planners assume, that setup times actually vary between orders. The idea is to support a sequence dependent sequencing by calculating the setup times between orders from feedback data and building up a setup matrix. This information is a feasible input for scheduling software. The developed concept will allow companies with sequence dependent setup times to derive setup matrices automatically from once defined input data.

The remainder of this paper is organized as followed: Initially existing literature in the field of generation of setup matrices is reviewed as well as a brief description of similar problems such as paint-job sequencing. Secondly, we present our proposed methodology to define required data and the formulation of hypothesis. Finally, an extended generic setup matrix is presented to depict the results of our pursued analysis.

2 Literature Review

The overall goal of setup time optimizing sequencing in flow-shops and job-shops is to reduce the setup times between successive orders with sequence dependent setup times by finding a suitable, nearly optimal sequence. This requires a sufficiently large number of possible subsequent orders. Implemented correctly, such an optimization will likely reduce setup costs and at best can increase the available capacities of a workstation or even of the entire production system if the workstation is a throughput bottleneck. In the latter case, setup time optimizing sequencing can even positively affect the schedule reliability when reducing the production's backlog [1]. It should be noted, that reducing actual setup times with concepts such as SMED (Single Minute Exchange of Die) in most cases has a bigger impact on the overall optimization of production systems but cannot be realized without investments in new equipment [2].

Sequence dependent setup times occur, when different products are processed on the same machine and a change of equipment, such as tools, is necessary to manufacture a specific variant. Furthermore, the amount of time necessary must vary due to a different extent of work depending on the prior setup situation [3]. Besides tool changes, sequence dependent setup times can also occur when changing the material or additives (such as paint) when using machines that depend on a continuous flow of material like in paint shops or in our case blow film machines.

To depict the different setup times between variants, changeover matrices are used to consider the actual setup time between two specific product options with its features (see Table 1). Such matrices consist of discrete setup times between each product or whole product families. Similar matrices are used in paint shops with a high variety of colors to reduce flushing times between colors that otherwise would mix and result in color defects [4]. Modern production planning and scheduling tools offer the capability to consider such setup times in form of matrices in regard to specific products or product groups [5]. SAP APO even allows the automatic generation of setup groups and setup matrices from up to six characteristic values. Therefore, the individual and disjunctive characteristics must be known, which is not the case in our example [6].

Table 1. Example for a changeover matrix with five different products

From/to operation	Product 1	Product 2	Product 3	Product 4	Product 5
Product 1	-	14	25	15	20
Product 2	25	-	17	12	21
Product 3	33	17	-	18	10
Product 4	15	12	8	-	7
Product 5	20	25	35	5	-

In Operations Research, a vast number of heuristics exists to solve scheduling problems with sequence-dependent setup times. A comprehensive overview is presented by Allahverdi [7]. With more than 500 papers, the topic seems to be of high scientifically relevance. In contrast to this, the practice often lacks robust data to feed such algorithms. To address this issue, White and Wilson [8] develop an approach which estimates setup times by applying classification to a limited number self-recorded setup times. The classification structure consists of several elements such as the number of work pieces operated simultaneously, the loading of the work pieces and distinguishing features of products and implications to the required tools. The required data is presented with a real world example of a lathe. As a result, the setup times are estimated with a statistical regression model. Furthermore, an efficient heuristic to sequencing orders is presented. The approach does not take into account start-up phases and is limited to a set of 93 input data sets [8]. Bagherpour et al. [9] present an approach with the application of fuzzy logic to estimate setup times in sequence dependent single machine scheduling problems. In contrast to many other approaches, the setup time is not assumed as deterministic, but depends on the level of technology and the degree of the similarity of the operations carried out by the machine [9]. Unfortunately, the authors do not elaborate this statement.

Whereas in areas with discrete manufacturing such as machining, setup times mainly depend on the actual work that has to be done when doing a changeover and therefore can be related to the tools [8], in process industry the values may depend on several different factors such as the previous material color, density, batch number etc. To the best knowledge of the authors this topic hast no been discussed in research dealing explicitly with the ex-ante estimation or calculation of sequence dependent setup times from feedback data and routing tables.

3 Deriving Setup Time Matrices from Routing Tables

The following section includes the description of the proposed methodology for generating setup matrices from route sheets and feedback data. The procedure consists of four steps (see Fig. 1), which are described in the following. The image is simplified for better comprehension; in practice, it might be necessary to do the steps 2 to 4 in an iterative manner to achieve the best results due to recognition of previously unknown features in data required.

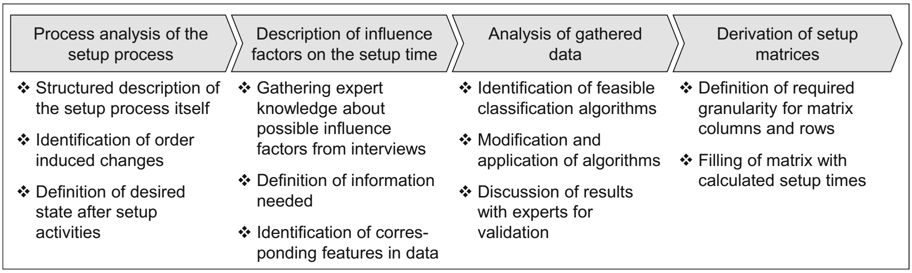


Fig. 1. Overview of the proposed methodology to generate setup matrices from route sheets and feedback data

3.1 Process Analysis of Setup Process

Since the setup matrix consists of changeover times between products, the first step of the methodology includes a detailed analysis of the setup process itself. Hereby a process flow chart should give an overview of all necessary and possible activities related to the setup process. In some cases, dedicated setup plans might be available and already give a good overview of all work steps regarding the different adjustment options and changeable tools on the machine. The flow chart should not only visualize the actual order of working steps, but also include following information defined by White and Wilson [8] and be complemented by own findings:

- How the material in the machine is clamped/fixed within the machine,
- what the moving parts of the machine are and how they are adjusted (e.g. description, scale and range),
- how the material is loaded into the machine and from the machine,
- which features of the loading/unloading device have to be adjusted,
- what the product features are and how these are related to the tool/tools characteristics,
- what product features are influenced by the features of the former material during the run-up period of the process (e.g. colour, density, etc.).

When doing material changeovers on machines that use a continuous flow of material (such machines for film blowing machines or plastic injection molding), it has to be defined which quality of the final product can be regarded as acceptable. For applications of automated data processing, these quality features should be measurable and stored in an appropriate frequency.

3.2 Description of Known and Presumed Influence Factors on the Setup Time

The formerly described factors lead in practice to a specific setup time. In contrast to the approach of White and Wilson [8], our methodology aims at the extraction of the features from already preserved data in business applications such as the ERP-System (Enterprise Resource Planning) and a Process Data Acquisition (PDA). Whereas White and Wilson [8] consider manual recorded setup processes with a predefined structure, we pursue to do the regression by the analysis of the existing routing tables and orders (which include the required tools as well as the material processed in the machine.). These data is stored in different tables of the ERP-System like route sheets, past production orders and recipes. The durations for the changeover are derived from feedback data gathered at the machine from manual and automated inputs. As stated before, the changeover is seen as finished, when the product has achieved the desired quality. Therefore, we also take into account the waste produced during run-up and run-down phases. All data has been extracted by doing a so-called database dump.

Although in our case a lot of the necessary historical data is already stored in the database, the influences on the relations between several features is often only know to the production planner. In the presented case a longer cleaning run after black and red colours is necessary. Furthermore, the change of density of the final product between two processed batches is crucial to the time needed for adjustment needed during run-up. With the help of expert interviews, we were able to formulate three starting hypotheses for the classification of factors. These are:

1. The changeover from a setup with for medium density films to a setup for high-density films is less critical in terms of duration and scrap than vice versa.
2. The changeover to another colour from a red or black colour additive takes a longer run-up phase to achieve the desired colour accuracy and therefore more crap and a longer setup (ramp-up) time.
3. The changeover of the format might require a change of take-up reels and therefore a longer setup time due to more work.

Beside the formulation of hypotheses, the required information has to be defined. The actual setup times have to be extracted from the feedback data that includes the reported time spent for setup operations. Furthermore, the weight of wasted material during the run-up phase is stored and assigned to the order. Those data can be found in a variety of business applications such as ERP-System or the Manufacturing Execution System (MES). If the data is not available, historical data can also be extracted from the machine itself, e.g. an installed process control system. In other cases, it might be even necessary to digitize handwritten or unstructured data from printed templates. Table 2 gives an overview of the defined data and data sources for our use case.

Table 2. Defined input data to calculate setup times

Name	Format	Description	Source
Order number	String		ERP (list of orders)
Format	Integer		ERP (routing table)
Colour	String	RAL Code	ERP (bill of material)
Materials used	Int		ERP (bill of material)
Density of final product	String		ERP (bill of material)
Processing time (plan)	Real	Time in seconds	ERP (route sheet)
Previous order	String		ERP (feedback data)
Subsequent order	String		ERP (feedback data)
Duration of setup	Real	Seconds	MDA/PDA
Duration of production run	Real	Seconds	MDA/PDA
Produced scrap during run up	Real	Meters	MDA/PDA
Produced scrap during run down	Real	Meters	MDA/PDA

MDA: Machine Data Acquisition; PDA: Personal Data Acquisition

3.3 Analysis of Gathered Data

The next step in automated generation of setup matrices is the analyses of the previously defined data. The most feasible algorithms have to be defined yet. Nevertheless, we present a conceptual problem description to execute multivariable regressions.

To describe the characteristics that have an impact on the actual setup times we propose a classification scheme based on a tuple notation. In a tuple notation characteristics are referenced by a symbolic notation, so that instead of the multitude of possible order characteristics, a particular setup situation can be briefly described by a tuple [10]. For our example of the blow film machine, we identified three main characteristics.

1. Density of main ingredient $\alpha_1 \in \{\mathrm{H}, \mathrm{L}, \mathrm{Lin}\}$ whereby *H* is for “High Density”, *L* is for “Low Density” and *Lin* is for linear low-density polyethylene.
2. Desired colour of the final product $\alpha_2 \in \{\circ, \mathrm{b}, \mathrm{r}\}$ whereby $\circ$ is for any colour except *r* for red and *b* for black.
3. Format of the uncut film $\alpha_3 \in \{06, 08, 10, 12, 16\}$ whereby the number gives the wide of the film in decimetres.

The corresponding data will be stored in one database by joining different tables from the various IT-systems. It might be necessary to perform some prior calculations, such as the derivation of the setup time from two timestamps. This highly depends on the specific structure of the data. With help the of regression analysis such as regression trees [11] or using pivot tables, each tuple-set of an order will be compared to the tuple-set of the previously processed order. From those combinations, specific values are calculated whenever possible. With an increasing number of characteristics, (exceeding the three initially defined), it might be necessary to classify orders in terms of several attributes. Those must not consist of only one characteristic, but also can represent a combination of characteristics.

3.4 Derivation of Setup Matrices

The results of the regression analysis and changeover process classification shall lead to quantitative relationships between setup characteristics. Those are depicted in an extended setup matrix (see Table 3). The highlighted elements mark the concept of visualizing changeover situations that have shown major deviations from the planned setup-times in the past. This information could result in the planning decision to schedule a utility worker for the affected shift. The table only includes production orders and not all possible combinations.

Table 3. Example for an extended setup matrix generated from historical data

From/to Order	Order 715	Order 716	Order 717	Order 718	Order 719
Order 715 (L |○| 10)	-	μ = 13,2 σ = 3,6	μ = 10,3 σ = 2,5	μ = 14,7 σ = 3,3	μ = 11,5 σ = 2,8
Order 716 (H |○| 08)	μ = 17,3 σ = 4,4	-	μ = 17,6 σ = 4,5	μ = 10,7 σ = 2,6	μ = 14,3 σ = 3,1
Order 717 (L |○| 12)	μ = 5,1 σ = 1,2	μ = 13,7 σ = 3,4	-	μ = 9,6 σ = 1,9	μ = 11,8 σ = 2,9
Order 718 (H|r|12)	μ = 21,2 σ = 5,2	μ = 13,1 σ = 2,7	μ = 4,3 σ = 0,9	-	μ = 22,7 σ = 5,5
Order 719 (L|b|08)	μ = 14,1 σ = 2,8	μ = 13,3 σ = 2,8	μ = 15,2 σ = 3,1	μ = 18,7 σ = 3,9	-

Compared to static setup matrices, the proposed extended setup matrix combines two new aspects: Instead of relating to a specific product or material number, actual orders and the main characteristics for the changeover are visualized. These helps when dealing with a big variety of material. Since the data has some uncertainty, we state the mean value μ as well as the sample standard deviation σ of the analyzed setup times. The setup matrix can either be used as a visual support the production planner or (reduced to its mean values) further processed for scheduling tools such SAP APO [12]. The setup matrices should not only be considered for already known setup situations, but adapt to new possible sequences. Those arise from new rout sheets, which are created when designing new products. Therefore, a continuous analysis of recipes, orders and feedback data is advised.

4 Conclusion and Outlook

Setup matrices are required to schedule setup time optimizing sequences to increase the utilization of costs intense assets. It has been shown, that most research work assumes deterministic setup matrices but only few deal with the determination of actual setup times. With an increasing number of product variants, the number of different route sheets and varying setup times increases as well. The paper presents an approach to generate setup matrices by analyzing routing tables and feedback data. In the next step, the formulated hypotheses will be analyzed to do the classification. The results will then be discussed with the experts from the company and adjusted where necessary. In future research it has to be evaluated which data analysis approach (e.g. data mining) and which algorithm is the most suitable for such a problem.

Acknowledgement. The research project iProd is funded by the European Union (grant number EFRE/ERDF-0800924) in the context of the Operational Program for the promotion of investments in growth and employment for North Rhine-Westphalia from the European fund for regional development (OP ERDF NRW).

References

1. Lödding, H.: Handbook of Manufacturing Control. Fundamentals, Description, Configuration. Springer, Heidelberg (2013). https://doi.org/10.1007/978-3-642-24458-2
2. Shingo, S.: A Revolution in Manufacturing. The SMED System. Productivity Press, Cambridge (1985)
3. Allahverdi, A., Ng, C.T., Cheng, T.C.E., Kovalyov, M.Y.: A survey of scheduling problems with setup times or costs. Eur. J. Oper. Res. (2008). https://doi.org/10.1016/j.ejor.2006.06.060
4. Spieckermann, S., Gutenschwager, K., Voß, S.: A sequential ordering problem in automotive paint shops. Int. J. Prod. Res. (2007). https://doi.org/10.1080/00207540310001646821
5. Herrmann, J.W. (ed.): Handbook of Production Scheduling. International Series in Operations Research & Management Science, vol. 89. Springer, Boston (2006). https://doi.org/10.1007/0-387-33117-4
6. SAP SE: Automatic Generation of Setup Groups and Setup Matrices. https://help.sap.com/viewer/c95f1f0dcd9549628efa8d7d653da63e/7.0.4/en-US/fba1ff3f-8297-4796-b1e7-e29609094230.html. Accessed 27 Mar 2018
7. Allahverdi, A.: The third comprehensive survey on scheduling problems with setup times/costs. Eur. J. Oper. Res. (2015). https://doi.org/10.1016/j.ejor.2015.04.004
8. White, C.H., Wilson, R.C.: Sequence dependent set-up times and job sequencing. Int. J. Prod. Res. (1977). https://doi.org/10.1080/00207547708943117
9. Bagherpour, M., Noghondarian, K., Noori, S.: Applying fuzzy logic to estimate setup times in sequence dependent single machine scheduling problems. IJCSNS Int. J. Comput. Sci. Netw. Secur. **7**(1), 111–118 (2007)
10. Graham, R.L., Lawler, E.L., Lenstra, J.K., Kan, A.H.G.R.: Optimization and approximation in deterministic sequencing and scheduling. A survey. In: Hammer, P.L., Johnson, E.L., Korte, B.H. (eds.) Annals of Discrete Mathematics: Discrete Optimization II, vol. 5, pp. 287–326. Elsevier, Amsterdam (1979). https://doi.org/10.1016/S0167-5060(08)70356-X
11. Rokach, L.: Data Mining with Decision Trees. Theory and Applications. Series in Machine Perception and Artificial Intelligence, vol. 81, 2nd edn. World Scientific Pub. Co., Singapore, Hackensack (2015)
12. SAP SE: Setup Matrix for Characteristic Values (2018). https://help.sap.com/viewer/c95f1f0dcd9549628efa8d7d653da63e/7.0.4/en-US/d7dc54d7-3c9f-413f-ae15-83ae04b948d3.html. Accessed 27 Mar 2018

Evaluation of Leadership in Nontechnical Skills

Haruka Ohba[1], Shinya Mizuno[1](✉), Yoshikazu Fujisawa[2,3], Masashi Uramatsu[3], Mikihiro Kano[4], Naoki Hirabayashi[4], and Takahiro Souma[5]

[1] Shizuoka Institute of Science and Technology, Fukuroi, Shizuoka, Japan
mizuno.shinya@sist.ac.jp

[2] The Department of Social Engineering and Community Science, Miyagi University, Taiwa, Miyagi, Japan

[3] The Department of Patient Safety and Quality, Tokyo Medical University, Shinzuku, Tokyo, Japan

[4] The Department of Gastrointestinal Surgery, Hiroshima City Asa Citizens Hospital, Asakita, Hiroshima, Japan

[5] The Department of Medical Safety Management, Chiba University Hospital, Chuou, Chiba, Japan

Abstract. Among the knowledge, skills, and abilities related to safety that are required in healthcare practitioners, the present study focuses on skills other than specialized techniques (nontechnical skills), which have drawn much interest, especially in recent years. From our previous research, we know that nontechnical skills may greatly increase the safety of operating rooms, which is also increasingly being recognized by medical workers. Therefore, in this research, we investigated the usefulness of evaluation of nontechnical skills in Japan. We collected data for evaluation at a hospital from between February to and August 2014 using the nontechnical skills (NOTSS) assessment system. The total number of data sets was 270. 18 doctors participated, including five evaluators. We found it difficult for us to evaluate leadership in NOTSS. To perform NOTSS in Japan, different evaluation indicators may be necessary that change to leadership. We will propose that indicator in the future.

Keywords: Nontechnical skill · Leadership · ANOVA

1 Introduction

Among the knowledge, skills, and abilities related to safety that are required in health-care practitioners, the present study focuses on skills other than specialized techniques (nontechnical skills), which have drawn much interest, especially in recent years. Research concerning human error in aviation started in the 1960s because flight crew were unable to say anything to the aircraft pilots, who wielded absolute power, which led to aircraft accidents [1,2]. Previous studies [3–5] have

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 510–517, 2018.
https://doi.org/10.1007/978-3-319-99704-9_62

shown that nontechnical skills are essential to increase safety standards further, which is increasingly being recognized by health-care practitioners. The construction of an effective and efficient evaluation system for nontechnical skills is extremely important, and the development of educational programs to link the results of such an evaluation system with the improvement of nontechnical skills is essential [6]. Nontechnical skills can be examined in all facets of medical care, however, because surgical treatments are invasive and put patients at high risk, increasing safety is especially in line with policy priorities. Therefore, the present study focuses on the field of surgery [7]. The principal aim of the present study is to evaluate of leadership in nontechnical skill for surgeons (NOTSS). It is often said that Japanese do not demonstrate leadership, so we confirm it in actual surgical operation. In this study, it is an analysis of leadership using medical data, but we think that this study has needs in a wide field including such as management engineering.

1.1 The Importance of Nontechnical Skills

It has become clear that when performing medical activities, most problems that occur during operative treatment are related to nontechnical skills (Table 1). It has been reported that 43% of surgical errors are due to a lack of communication [8] and 97% of bile duct injuries are due to a failure to recognize a situation [9].

Table 1. Report on medical accidents. (Japan Council for Quality Health Care [10]).

Reason for accident	Percentage
Knowledge was insufficient	3.4%
Technical skill was insufficient	2.4%
Confirmation was neglected, observation was neglected, or explanation was insufficient	59.2%
Others	35%

Furthermore, *the World Health Organization (WHO)* has published a standardized guide for hand hygiene and a safety checklist for operative patients [11], and a global movement to improve patient safety has begun. *The WHO* safety checklist for operative treatment has been tested in various countries worldwide and the incidence of complications and mortality associated with operative treatment decreased 36% and 47%, respectively, after the introduction of the checklist.

There has been a trend to focus on skills related to medical treatment to achieve good results, but whether or not the medical practitioners possess superior skills, the team performance is low when individual situation awareness and decision-making skills are insufficient, when communication with other team members cannot be performed well, or when leadership cannot be exercised. Therefore, we introduce an educational program for the specialization of nontechnical skills for surgeons during operative treatment to ensure the maximization of the operative team performance [12].

1.2 Organization of Nontechnical Skills

To utilize the NOTSS system and assess behaviors effectively, Yule et al. [13] noted that the following three points are necessary: (i) fundamental knowledge concerning NOTSS and human performance and error management, (ii) fundamental principles in the use of psychometric tools to understand the NOTSS system and to evaluate behaviors in the clinical setting, and (iii) training in the use of a corrective program to construct objective evaluation criteria. To achieve these points, Yule et al. [13] categorized nontechnical skills into four groups, and each skill was further subcategorized into three elements (Table 2).

Table 2. NOTSS: four skill classifications and the three elements for each classification.

Classifications	Elements
Situation awareness	Gather information Understand information Foresee the future and act accordingly
Decision making	Examine choices Make a choice and share with team members Carry out the choice and confirm the progress
Communication and teamwork	Share information with team members Build mutual understanding Coordinate team behaviors
Leadership	Set performance standards and maintain them Support members Manage team pressure

Using evaluation criteria as such as that shown in Table 3, each category was scored and the evaluation criteria were standardized.

Table 3. NOTSS: standardization of the evaluation criteria.

Criteria value	Evaluation criteria contents
4. Good	The operative treatment performance was consistently high. Standards were maintained and treatment was also a good example for the promotion of patient safety
3. Acceptable	Standard and satisfactory performance, but with room for improvement
2. Marginal	Elements for concern were present and there was considerable room for improvement
1. Poor	Patient safety was compromised and there were potentially dangerous elements present. Significant improvement is needed
N/A. not applicable	In this case, “skill” was not necessary

2 Evaluation of Nontechnical Skill

2.1 Basic Nontechnical Skill Evaluation Data

Evaluations were performed on site using the NOTSS assessment system. We collected data at a hospital from between February to and August 2014. The medical facility had 527 beds and 150 doctors. Nineteen surgeons, including six residents, work in the 60-bed surgical ward. About 1200 cases are operated annually. We assume a target performance of one operation per day. We included surgeons who have performed the same procedure more than 10 times. Therefore, high-risk operations were not included and infrequent procedures in which surgeons do not have much experience were not included. We also assumed that emergency surgeries would be excluded from this study because the NOTSS assessment system should be used in operations when the surgeon has plenty of time to prepare for the operation and can usually operate without being stressed during the procedure.

Evaluation was performed by having a single evaluator evaluate a single surgeon. The total number of data sets was 270. Eighteen doctors participated, including five evaluators. We removed an executive surgeon from the operator evaluations for the statistical analysis. The evaluation data was input by each evaluator using a personal computer or tablet. In the data tabulation, each element was scored out of a total of 48 points, with three elements in each category. Each element had a maximum score of four points. Therefore, each category had a total of 12 points, with 48 points in total. Data for elements that did not have an evaluation value were treated as missing values as appropriate. The NOTSS evaluation data is shown in Table 4. From these results, the evaluation of situation awareness has high scores and small variations, but the leadership evaluation shows that the scores vary with low scores. For the correlation coefficient, the value related to leadership is low.

Table 4. Basic NOTSS evaluation data (Mean, standard deviation, correlation coefficient).

Classifications	Mean	Dev	Situa	Decision	Commu	Leader
Situation awareness	10.03	3.83	1.0	0.87	0.81	0.67
Decision making	9.94	4.39	0.87	1.0	0.86	0.73
Communication and teamwork	9.89	4.53	0.81	0.86	1.0	0.72
Leadership	9.49	5.66	0.67	0.86	0.72	1.0

Next, when performing the principal component analysis, the results are as shown in the Fig. 1. From Table 5, principal component 2 has a positive leadership value, and the influence of leadership is significant. From Fig. 1, we get that the variation in the PC 1 direction is small, but the variation in the PC 2 direction is large. From this result, we think that the quality of evaluation differs from that of other categories in the evaluation of leadership.

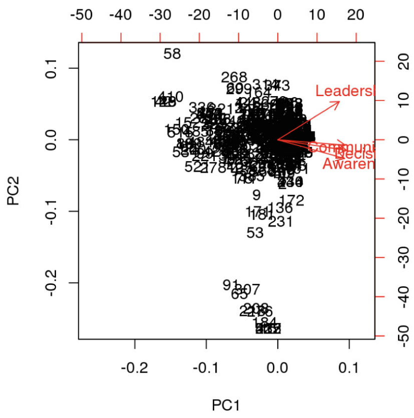


Fig. 1. Principal component analysis of 4 categories.

Table 5. Principal component analysis of 4 categories.

Classifications	PC1	PC2	PC3	PC4
Situation awareness	0.504	−0.424	0.563	0.498
Decision making	0.520	−0.240	0.075	−0.815
Communication and teamwork	0.509	−0.122	−0.801	0.286
Leadership	0.464	0.864	0.184	0.058
Cumulative proportion	0.833	0.925	0.971	1.000

2.2 Analysis by Two-Way Factorial ANOVA Without Replication

We are interested in whether NOTSS was different for every surgeon and every category. Using a statistical method, we analyze the obtained data to derive our results. We categorize two types, such as surgeon and evaluator, and analyze by two-way factorial analyses of variance (ANOVA) without replication.

We focus on the mean for each surgeon. Figure 2 indicates four categories of means for each surgeon. We used two-way factorial ANOVA without replication for Fig. 2 to produce an ANOVA table (Table 6). From Table 6, we find $P = 4.84E - 23$ for surgeons. Therefore, significant difference is found between surgeons for a mean NOTSS with 95% significance. Similarly, we find $P = 1.87E - 4$ for categories. Thus, there are significant differences between categories.

2.3 ANOVA of Categories

We know there are significant differences in means and variance for surgeons (Table 6). Here, we explore which pairs of categories have significant differences.

As shown in Fig. 2, the horizontal axis indicates the Surgeon ID. Figure 3 indicates the boxplot for four categories. We can find the whole to have a low

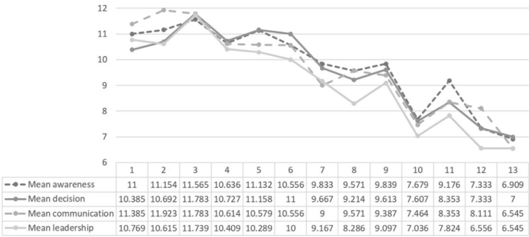


Fig. 2. Four categories of means for each surgeon.

Table 6. ANOVA table of four categories of means for each surgeon.

Variation factor	Variation	Degree of freedom	Variance	Observed variance ratio	P-value	F boundary value
Surgeon	124.203	12	10.350	89.163	4.843E-23	2.033
Category	3.012	3	1.004	8.650	1.870E-4	2.866
Error	4.179	36	0.116			

item of the leadership. First, we use the Bartlett test to confirm the homogeneity of variances ($P = 0.116$) for these categories. We set the significance level at 5%. The null hypothesis is that the mean of the population of each category is equal. An alternative hypothesis is that there is a difference in the means in at least one set in each category. We use the Bonferroni adjustment method to obtain P-values (Table 7). Thus, we find that leadership differs from the awareness, decision, and communication categories with 5% significance.

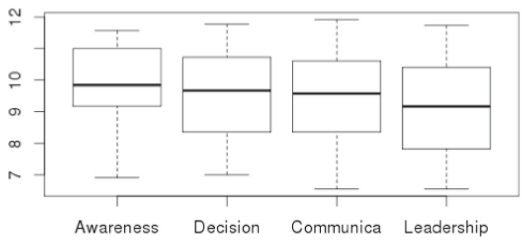


Fig. 3. Boxplot for the surgeon means in each category.

2.4 Analysis Using Surgeon's Experience and Surgical Difficulty

Next we analyzed using surgeon's years of experience and surgical difficulty level [14]. Surgical difficulty is classified in three level. The correlation coefficient between experience years and surgical difficulty level is 0.70, which shows that a

Table 7. ANOVA results for means of categories.

Pairs	Awareness	Decision	Communication	Leadership
Awareness	-	-	-	-
Decision	1	-	-	-
Communication	1	1	-	-
Leadership	1.00E-03	2.27E-02	5.40E-03	-

veteran doctor is conducting a surgery with a high degree of difficulty. From the Fig. 4, the higher the surgical difficulty level, the higher the leadership evaluation tends to be. However, there are similar trends in other categories, not limited to leadership. Scatter plot of surgical difficulty level and leadership evaluation is shown in Fig. 5. The correlation coefficient between experience years and leadership evaluation is 0.64, which is the largest among the categories. The variance of the leadership evaluation of doctors with experience years less than 10 years is 5.09, which is the largest among the categories. On the other hand, the distribution of the leadership of doctors with more than 10 years of experience has fallen sharply to 1.34. From this data, we consider that the years of experience has an influence on leadership.

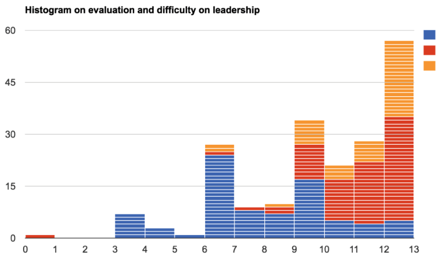


Fig. 4. Histogram of surgical difficulty level and leadership evaluation.

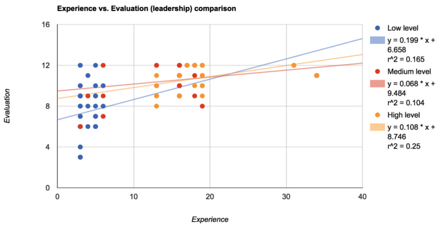


Fig. 5. Scatter plot of surgical difficulty level and leadership evaluation.

3 Conclusion

In this study, it is difficult for us to evaluate leadership in NOTSS. There are differences in values for the respective roles and we need to standardize this aspect of evaluation. Especially for Japanese, leadership is difficult to evaluate. To perform NOTSS in Japan, different evaluation indicators may be necessary that change to leadership. We will propose that indicator in the future. These study results show that the experience of the surgeon is influential for NOTSS. Therefore, hospitals should necessarily cooperate with an education system to provide NOTSS to their staff [15]. We hope that NOTSS will be applied widely in hospitals.

References

1. Helmreich, R.L., Anca, J.M., Barbara, G.K. (eds.): Crew Resource Management. Elsevier, London (2010)
2. Andries, C.: Crew resource management. In: Defense Resources Management in the 21st Century (2013)
3. Soma, T.: Development of an educational training program for nontechnical skills in the field of surgery and the construction of an evaluation system for the program. Annual report for 2012 (2012)
4. Soma, T.: Nontechnical skills from the viewpoint of medical safety-specific problematic behaviors as seen from surgeon training programs in Australia and New Zealand. Clin. Surg. **68**(7), 764–772 (2013)
5. de Vries, E.N., et al.: Effect of a comprehensive surgical safety system on patient outcomes. N. Engl. J. Med. **363**, 1928–1937 (2010)
6. Flin, R., Yule, S.: Report on the University of Aberdeens Non-Technical Skills for Surgeons project. Advances in patient safety: non-technical skills in surgery. Surgeonsnews, vol. 4, pp. 83–85 (2005)
7. Vincent, C., Moorthy, K., Sarker, S.K., Chang, A., Darzi, A.W.: Systems approaches to surgical quality and safety from concept to measurement. Ann. Surg. **239**, 475–482 (2004)
8. Gawande, A.A., Zinner, M.J., Studdert, D.M., Brennan, T.A.: Analysis of errors reported by surgeons at three teaching hospitals. Surgery **133**, 614–621 (2003)
9. Way, L.W., et al.: Causes and prevention of laparoscopic bile duct injuries: analysis of 252 cases from a human factors and cognitive psychology perspective. Ann. Surg. **237**(4), 460–469 (2003)
10. Japan Council for Quality Health Care: The 20th report (2009)
11. World Health Organization: Multi-professional Patient Safety Curriculum Guide (2011)
12. Flin, R., Patey, R., Glavin, R., Maran, N.: "Anaesthetists" non-technical skills. Br. J. Anaesth. **105**(1), 38–44 (2010)
13. Yule, S., et al.: Experience matters: comparing novice and expert ratings of non-technical skills using the NOTSS system. ANZ J. Surg. **79**, 154–160 (2009)
14. The Japanese Society of Gastroenterological Surgery: Gastroenterological surgeon specialist training curriculum. https://www.jsgs.or.jp/modules/others/index.php?content_id=7. Accessed 30 Mar 2018
15. Yule, S., et al.: Debriefing surgical trainees on non-technical skills (NOTSS). Cogn. Technol. Work **10**, 265–274 (2008)

A Framework for Task-Based Ambidexterity in Manufacturing SMEs

Kristina Sollander(✉), Annika Engström, and Joakim Wikner

Jönköping University, Jönköping, Sweden
kristina.sollander@ju.se

Abstract. To be competitive, it is important for companies to create a breeding ground for innovation without jeopardizing productivity. The challenge posed by industrial companies and the innovation research community is how to promote innovation while achieving efficient execution. The ability to balance execution and innovation is referred to as organizational ambidexterity (OA), which includes several dimensions, concepts and approaches where a central task can be identified. The purpose of this paper is to investigate what consequences result from different dimensions of a task in relation to the types of its actions, and their effects on OA. The focus of the task is firstly investigated, followed by the development of nine scenarios via combining the designers' and the performers' perspectives of the task. A brief analysis of the scenarios indicates that there is no single optimal scenario; rather, the scenarios represent different states that are appropriate for certain conditions, and dynamic adaptation should be encouraged in relation to the changing conditions. This type of dynamics is particularly expected to prevail in small and medium-sized enterprises (SME) because the roles that are responsible for tasks in these organizations are less specialized. Therefore, SMEs must define tasks that include both explorative and exploitative parts, either simultaneously or sequentially, to stimulate employees to work ambidextrously and thereby develop the concept of task-based ambidexterity.

Keywords: Organizational ambidexterity · Task-based · SME

1 Introduction

An important contribution of the field of operations management is the strengthening of the manufacturing industry [1]. Competitiveness is challenging to establish; as shown by Porter [2], it can be either strictly focused on cost leadership or differentiation by other means. For a company to be competitive regarding differentiation by other means, it is of particular importance to create a good breeding ground for innovation. To support differentiation it is important that innovation embrace implementation of new and/or significantly improved processes and methods as well as develop new products for the market, however, a narrow focus regarding innovation can jeopardize productivity if it is not carefully employed [3]. Some ideas are not fruitful, and "trial and error" might require the use of several resources without significant results [4]. By

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 518–525, 2018.
https://doi.org/10.1007/978-3-319-99704-9_63

contrast, the drive for efficiency might inhibit innovation [3], and lack of time, reduction of risk, and variation all affect the innovation culture negatively [5].

From this perspective, a workplace can be seen as a site of two logics [6] that are interdependent but often competing for resources. One logic is characterized by exploitation, the use of current knowledge to execute a task. The other logic is characterized by exploration, the development of new knowledge to innovate. Here, we face a dilemma. The challenge posed by industrial companies is how to promote innovation while achieving efficient execution. The ability to balance execution and innovation, which is referred to as organizational ambidexterity (OA), is essential for sustained growth and survival [7].

Current OA frameworks are primarily developed in larger multi-divisional organizations and typically based on split organizational designs, where execution-exploitation actions are relegated to established operations divisions, while innovation-exploration actions are mainly the responsibility of research & development (R&D) and new venture divisions. However, the organization of small- and medium-sized enterprises (SMEs) is not suitable for such a division because these organizations are usually based on a more integrative perspective. SMEs provide particular opportunities for investigating and extending the knowledge of OA because of the more integrative organizational design of SMEs. The need for OA research in manufacturing SMEs is consequently interpreted as a two-fold issue: SMEs have a strong potential to take advantage of adapting OA practices and the SME context provides interesting opportunities for capturing the OA-phenomenon.

A key characteristics of SMEs is their flat and flexible organizational structures which put more emphasis for their success, compared to larger organizations, on the CEO's knowledge and competence versus managerial practices and processes [8]. Furthermore, these organizations are also more dependent of the CEO's capability to innovate [9]. Recently, scholars have questioned whether small companies' dependence on the CEO's individual knowledge is effective or whether it actually underutilizes other employees' talents and knowledge [10]. Knowledge creation in SMEs is often based on experience, is tacit, and is generally strongly connected to a few individuals [11]. Their small organizational numbers mean that they rarely have the aforementioned split arrangements found in larger firms. It is typical for one employee to be responsible for several functions [10]. Within the context of manufacturing SMEs it is therefore relevant to consider both managers and other employees as developers of their own work [9]. Expertise, experience, ideas, creativity, and skills among employees are drivers as well as valuable resources regarding the company's innovative work [6, 12]. A concept known as employee-driven innovation (EDI), which emphasizes the importance of the employees' contribution in innovation, regardless of their position in the company, has therefore been suggested [12]. From this perspective, new knowledge of ambidexterity can be developed from understanding how the phenomenon occurs within the SME context and thus supporting SMEs to benefit from the new knowledge on how to manage the balance between exploitation and exploration.

The research area of OA includes several dimensions, concepts and approaches of ambidexterity. Structural ambidexterity is the most researched concept of ambidexterity in organizational structures, it deals with integrative structural mechanisms to achieve ambidexterity [7]. Contextual ambidexterity means that an organization shifts form exploitation to exploration according to the changing demands of its operating environment (its context) [13]. The concept of individual ambidexterity emphasizes an individual's ambidexterity versus that of the organization [14]. There are also sequential and simultaneous ambidexterity approaches, where the main difference is temporal [15]. The task is a central level of analysis for them all.

The purpose of this paper is to investigate what consequences result from different dimensions of a task in relation to the types of its actions, and their effects on OA. Furthermore, the paper outlines empirical studies to pursue in relation to manufacturing SMEs and the findings.

2 Research Method

This conceptual paper stems from a research project about innovation capabilities within manufacturing SMEs, initiated in 2018, and up till this point no empirical data has been analyzed. The literature was collected through snowball sampling with the purpose of understanding the concepts, approaches, dimensions, and types of actions within OA from a task-based perspective.

3 Theoretical Framework

The unit of analysis here is the task to be performed, which acts as a foundation for the introduced concepts, approaches, dimensions, and types of actions that are connected to OA. OA is firstly outlined, including the knowledge dimensions of exploration and exploitation. Then, the three concepts of OA, structural, contextual, and individual, are described. Thereafter, the sequential and simultaneous approaches are presented. Finally, the designing and performing of the task's knowledge dimensions of execution and innovation are outlined.

3.1 Dimensions of OA

March [4] concluded that, to stimulate OA, an organization needs to adapt quickly to employees' ideas rather than *vice versa*. He developed two knowledge dimensions, exploration and exploitation, which he recommends should be balanced within organizations. His definitions of the terms are as follows: "Exploration includes things captured by terms, such as search, variation, risk-taking, experimentation, play, flexibility, discovery, and innovation. Exploitation includes such things as refinement, choice, production, efficiency, selection, implementation, and execution." [4, p. 71]. Companies tend to focus their resources in exploitation mode [6]. A study by O'Reilly and Tushman [7] indicated that innovative projects proved to be more successful if they were based in an ambidextrous organization that had the ability to balance the exploration of new possibilities and the exploitation of old certainties. If the focus was on exploration without exploitation, the cost of experimentation would be high and often without benefit. If the opposite occur, and the focus was on exploitation without including exploration, there would be a high risk of facing a suboptimal stable equilibrium [4].

3.2 Concepts of OA

The concepts of particular significance for OA are related to structural, contextual, and individual perspectives. Structural ambidexterity, the most researched concept, occurs when firms jointly conduct exploration and exploitation activities by developing specialized compartmental structures [16]. It could be viewed as structuring the organization's business units to achieve ambidexterity, where the business units are either independent or interdependent of each other [15]. Contextual ambidexterity is defined as "the behavioral capacity to simultaneously demonstrate alignment and adaptability across an entire business unit" [13]. All aspects of the organization are working together toward the same goal, and activities are adapted within the business unit to meet changing demands. Individual ambidexterity is defined as a human's cognitive ability to flexibly adapt by shifting between exploitation and exploration in a simultaneous or sequential cycle [14]. If the organizational context is dynamic and unpredictable, it is necessary to have individual ambidexterity to achieve success [17].

3.3 Approaches of OA

The approaches of OA have either sequential or simultaneous character. In the sequential approach, the organization periodically switches between exploration and exploitation either within or between business units to become ambidextrous over time. It is believed that it is possible for a company to find focus and be efficient by being internally consistent [16]. The simultaneous approach is connected to adaptive systems research, and it is believed that successful businesses should be able to balance both explorative and exploitative tasks via either separated or united performers at once because they often reinforce one another. Some studies have indicated that organizations that balance ambidexterity simultaneously tend to be more innovative [16]. However, to ensure that business units align, overall values and strategies should be shared [7].

3.4 Designing and Performing Tasks

To stimulate employees' contributions, tasks can be designed by the organization to include important ingredients, such as the following: (1) variation to support the use of different skills, (2) opportunities to see the entire picture (i.e., the complete product realization process as well as employees gaining an understanding of the meaning of their work as part of a whole), (3) autonomy to influence the situation, (4) autonomy in the development of the task, and (5) feedback on performance [18]. More or less complex tasks cause different patterns of behavior and require different types of learning and knowledge- from routines to reflection [6].

A task consists of activities which is the sum of aggregated actions performed by employees and/or machines. An action stands for the smallest entity of work that an activity can be divided into [19]. An execution action involves the responsibility to follow instructions and procedures to control product quality. An innovation action involves the responsibility to develop and improve the nature of the task itself [6].

4 OA from a Task Perspective

To achieve OA, the task perspective is interesting to investigate since it offers an opportunity to study the interplay between the task designer and the task performer. As a foundation for task-based ambidexterity, the focus of the task is first established. Thereafter, the task is defined in terms of "design" and "perform", which, in combination, make it possible to identify nine scenarios of the task.

4.1 Task Focus

One way of explaining a task's focus is through the knowledge dimensions, including exploration only, exploitation only, or both (Table 1). If there is no influence of neither exploration nor exploitation it is categorized as void based on these two dimensions (1). When only exploration is required, the focus of the task is to innovate (2). If only exploitation is required, the focus of the task is to execute (3). Finally, when the task requires both exploration and exploitation at the same time, both dimensions are needed to execute and innovate, which here is called exovate (4), meaning that simultaneous ambidexterity is required.

Table 1. The focus of the task, based on Engström and Wikner [12]

	No exploration	Exploration
No exploitation	1. Void	2. Innovate
Exploitation	3. Execute	4. Exovate

If sequential ambidexterity is applied, the task's focus switches between innovate (2) and execute (3); however, no exact estimation regarding how much time could pass between the two states of a task, and still refer to the ambidexterity as sequential, has been identified in the literature.

4.2 Ambidexterity Scenarios Based on Task Design and Task Perform

Task design can be conducted by either an organization or a manager, or by an employee without a formal management position. The task is designed in one of three different dimensions (Table 1, focuses 2–4). If the designer promotes innovation, it will encourage development through new ideas, questioning current work processes, and experimentation. If it promotes execution, it will encourage effectiveness, following routines, and adjusting current work processes. If the designer has expectations regarding exovation, it will encourage both innovation and execution simultaneously.

Employees consequently perform tasks focusing on either execution, innovation, or exovation. Actions of execution are defined as exploitative, actions of innovation are defined as explorative and actions of exovation are defined as both, simultaneously. By combing the design and perform parts of a task, it is possible to identify nine scenarios, as shown in Table 2, where Exe indicates Execute, Inn indicates Innovate, and Exo indicates Exovate.

Table 2. Designing and performing a task

	Design (task dimension)			
		Execute	Innovate	Exovate
Perform (type of action)	Execute	*Exe-Exe*	*Exe-Inn*	*Exe-Exo*
	Innovate	*Inn-Exe*	*Inn-Inn*	*Inn-Exo*
	Exovate	*Exo-Exe*	*Exo-Inn*	*Exo-Exo*

In Exe-Exe, the focus of both the designer and the performer is execution, which is characterized by short-term efficiency. Importantly, this might lead to suboptimal stable equilibrium if extended long term. In Inn-Inn, the focus is on innovation, which is likely conducive to growing ideas; however, if it is not based on applicability regarding execution, there is a great risk of implementing an expensive experiment that is either impossible or ineffective. In Exo-Exo, both parties design and perform the task simultaneously ambidextrous, which is likely a good environment for applying innovative ideas and streamlining operations. Exe-Inn and Inn-Exe are both interesting because their foci differ between the designer and the performer. In Exe-Inn, the focus of the designer is on innovation, while the performer stresses execution. One cause for this could be overly high expectations from the designer compared to the capability of the performer, which can cause frustration for both parties. In Inn-Exe, the designer's focus is execution, while the performer emphasizes innovation. One cause for this could be that the performer uses potential innovations that the designer is unable to capture. Although this could cause frustration and dejection within the company, it could potentially be solved by creating different forums for innovation. Notably, both Exe-Inn and Inn-Exe offer strong possibilities for development. In the scenarios of Exe-Exo and Inn-Exo, exovation is encouraged by the designer but is performed as either execution or innovation. Further study is needed in this area; yet, it could be related to a combination of the same issues as in Exe-Inn and Inn-Exe (i.e., lack of performer competence and/or a designer who is unable to capture innovation). The scenarios of Exo-Exe and Exo-Inn, where the performer is exovate but the designer only requires execute or innovate, represent situations where performers are more capable than needed.

Interestingly, this brief analysis indicates that Exe-Exe, Exe-Inn, Inn-Exe, Inn-Inn and Exo-Exo all seem to have limitations in that each scenario is not sustainable in the long-term. All scenarios offer advantages and disadvantages but remaining in one scenario for an extended time will probably be costly in some form.

Moving between Exe-Exe, Inn-Inn, and Exo-Exo and utilizing ambidexterity in either a sequential or simultaneous way could potentially be more efficient from a long-term perspective. Scenarios in which the designer and the performer are aligned and share the same view of the task will more likely be fruitful, easier regarding resource allocation and finding the right competences, and better at avoiding frustration. Being in Exo-Exe and Exo-Inn could be better if the aim is either Exe-Exe, Inn-Inn, or Exo-Exo compared to being in Exe-Exo or Exe-Inn. This is because it is probably easier for the designer to consider if the task should be designed differently and, if so, to change it compared to changing either the competence or the culture of the performer(s).

5 The Concept of Task-Based Ambidexterity

By identifying and mentally visualize the concept of task-based ambidexterity we can identify the interplay between the designer and the performer, thus, finding a way to study the phenomenon of ambidexterity more thoroughly. EDI supports the idea of all employees' contributions to innovation; however, the concept of task-based ambidexterity outlined here highlights the importance of employees also focusing on exovation to create a balance between innovation and execution. This requires the organization to design tasks that include both explorative and exploitative parts, which are implemented either simultaneously or sequentially, to stimulate employees to work ambidextrously. This relates well to Hackman's [18] critical aspects of tasks that help employees stimulate knowledge creation in organizations and March's [4] statement that organizations need to adapt quicker to employees than *vice versa*.

Since the SME context is often both dynamic and unpredictable compared to the context of larger organizations, it is crucial for SMEs to stimulate their employees to be ambidextrous to achieve success. This indicates that SMEs could benefit from more knowledge about OA to make explicit decisions, moving between the different scenarios. Studying the context of SMEs can provide mutual benefits; such as insights into the concept of task-based ambidexterity together with benefits that SMEs can obtain.

This research clearly indicates that ambidexterity is more than a static mode; instead, it can be achieved in several ways both sequentially and simultaneously. Future research could examine the time perspective as well as how OA occurs on different organizational levels. Empirical studies could also be used to understand the interplay between the performer and the designer, including how employees perceive the task given by the designer and *vice versa.* By using either an in-depth or a narrative approach, it would be possible to gain a deeper understanding of the phenomenon.

Acknowledgements. This research was performed in collaboration with industry in project Innovate (KKS-20170312) and were financed by the research environment SPARK at Jönköping University and The Knowledge Foundation (www.kks.se).

References

1. Slack, N., Chambers, S., Johnston, R.: Operations Management. Pearson Education, London (2010)
2. Porter, M.E.: Competitive Advantage of Nations: Creating and Sustaining Superior Performance, vol. 2. Simon & Schuster, New York (2011)

3. Lovén, E.: Kreativitet, innovation och lean. In: Sederblad, P. (ed.) Lean i arbetslivet. Liber, Stockholm (2013)
4. March, J.G.: Exploration and exploitation in organizational learning. Organ. Sci. **2**(1), 71–87 (1991)
5. Hongyi, C., Taylor, R.: Exploring the impact of lean management on innovation capability. In: 2009 Portland International Conference on Management of Engineering & Technology, PICMET 2009, pp. 826–834. IEEE (2009)
6. Ellström, P.-E.: Two logics of learning. In: Antonacopoulou, E., Jarvis, P., Andersen, V., Elkjaer, B., Høyrup, S. (eds.) Learning, Working and Living, pp. 33–49. Palgrave Macmillan UK, London (2005). https://doi.org/10.1057/9780230522350_3
7. O´Reilly, C.A., Tushman, M.L.: Organizational ambidexterity: past, present, and future. Acad. Manag. Perspect. **27**(4), 324–338 (2013)
8. Smith, M.H., Smith, D.: Implementing strategically aligned performance measurement in small firms. Int. J. Prod. Econ. **106**(2), 393–408 (2007)
9. Burton, M.D.: The company they keep: founders' models for organizing new firms. Artic. Chapters **259**, 13–39 (2001)
10. Karltun, J.: On stage. Acting for development of businesses and ergonomics in woodworking SMEs. Linköping University (2007)
11. Ates, A., Garengo, P., Cocca, P., Bititci, U.: The development of SME managerial practice for effective performance management. J. Small Bus. Enterp. Dev. **20**(1), 28–54 (2013)
12. Høyrup, S., Bonnafous-Boucher, M., Hasse, C., Lotz, M., Møller, K. (eds.): Employee-Driven Innovation. Palgrave Macmillan UK, London (2012). https://doi.org/10.1057/9781137014764
13. Gibson, C.B., Birkinshaw, J.: The antecedents, consequences, and mediating role of organizational ambidexterity. Acad. Manag. J. **47**(2), 209–226 (2004)
14. Good, D., Michel, E.J.: Individual ambidexterity: exploring and exploiting in dynamic contexts. J. Psychol. **147**(5), 435–453 (2013). https://doi.org/10.1080/00223980.2012.710663
15. Simsek, Z.: Organizational ambidexterity: towards a multilevel understanding. J. Manag. Stud. **46**(4), 597–624 (2009)
16. Chen, E.L., Katila, R.: Rival interpretations of balancing exploration and exploitation: simultaneous or sequential. In: Handbook of Technology and Innovation Management, pp. 197–214 (2008)
17. Davis, J., Eisenhardt, K., Bingham, C.: Optimal structure, market dynamism, and the strategy of simple rules. Adm. Sci. Q. **54**, 413–452 (2009)
18. Hackman, J.R., Oldham, G.R.: Word Redesign. Addison-Wesley Publishing Company Inc., Boston (1980)
19. Engström, A., Wikner, J.: Identifying scenarios for ambidextrous learning in a decoupling thinking context. In: Lödding, H., Riedel, R., Thoben, K.-D., von Cieminski, G., Kiritsis, D. (eds.) APMS 2017. IAICT, vol. 514, pp. 320–327. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-66926-7_37

Analyzing Intuitive Skills of a Waitperson in a Restaurant Dining Room Using a Serious Game

Fumihide Nishimura[1], Emi Kinoshita[1], Tomomi Nonaka[2], and Hajime Mizuyama[1(✉)]

[1] Aoyama Gakuin University, Sagamihara, Kanagawa 252-5258, Japan
mizuyama@ise.aoyama.ac.jp
[2] Ritsumeikan University, Kusatsu, Shiga 525-8577, Japan

Abstract. It is important to shorten customers' waiting times in a restaurant, and their waiting times at the table are largely affected by how waitpersons perform their tasks in the dining room. However, the quality of their work still depends heavily on their experiences and intuitive skills. Thus, this paper proposes a serious game emulating the tasks of a waitperson in the dining room of a restaurant, and analyzes the intuitive skills for the tasks by using the game. It defines two distinctive tactics called *collection of multiple tasks* and *movement on a prediction basis*, and introduces several measures on these tactics. As a result, by analyzing the game score, waiting times and these measures obtained from game experiments, several characteristics of the skills have been successfully revealed.

Keywords: Serious games · Intuitive skills · Service science
Service management

1 Introduction

In recent years, as the popularized terms *product service systems* (*PSSs*), *servitization*, *service production*, etc. indicate, service providing systems have become an important field of production and operations management research. In the restaurant industry, for instance, it is important to improve customer satisfaction to increase sales. It has been pointed out that the customer satisfaction is affected by various waiting times [1, 2]. The shorter the waiting times, the higher the customer satisfaction in general, and the more customers will visit the restaurant. This also highlights the importance and difficulty of shortening waiting times. Vries et al. [3] empirically shows that the waiting times do have a significant impact on the revenue of a restaurant.

Hwang and Lambert [4, 5] investigated the relationship between the resource levels and the waiting times through numerical simulation. Shimmura et al. [6] also utilized numerical simulation to reduce staff motion and thereby customers' waiting times by redesigning kitchen layout. Further, several authors studied how to shorten the waiting times of customers in the waiting room until they are assigned to a table in the dining room [7–10]. Then, in the dining room, waitpersons are required to take care of the

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 526–533, 2018.
https://doi.org/10.1007/978-3-319-99704-9_64

customers so as not to have them wait too long at the table. Roy et al. [11] and Tanizaki and Shimmura [12] modeled the waitpersons' operations in the dining room using a queuing network and two-dimensional cellular automata respectively, and studied appropriate resource levels.

However, the quality of the operations also depends largely on the experiences and intuitive skills of the waitpersons performing the operations. Since it is not realistic to fully automate the interactions with customers in all the restaurants, it is important to deepen the understanding on the skills and devise how to properly train and/or support them. In order to address this challenge, this paper proposes a serious game emulating the operations of a waitperson in the dining room of a restaurant, and analyzes the intuitive skills for the tasks by using the game. Serious games provide a cost and time efficient tools for collecting (virtual) operational data for skills analysis and it is usually easier to conduct if-then analysis on the games than in actual fields. Games can also be used for training the skills uncovered through the analysis. A similar approach has been successfully applied to table assignment operations in a restaurant in an authors' earlier work [10].

2 Tasks of a Waitperson

The main tasks of a waitperson include seat guidance, receiving orders, serving dishes, clearing dishes and accounting. Among them, this paper focuses on receiving orders, serving dishes and clearing dishes, which are thought to have a big influence on the customers' waiting times at a table. It further defines two distinctive tactics of the waitperson, which are taken while performing the tasks; *collection of multiple tasks* and *movement on a prediction basis*. When a waitperson carries out two or more tasks of receiving orders, serving dishes, or clearing dishes in a single tour departing from the *tray point* until returning to the same point again, it is said that *collection of multiple tasks* is taken. This tactic can be quantified by calculating how many tasks are collected in a tour, how many tasks are performed at a same point without moving, etc. When a waitperson moves closer to a customer in anticipation that she/he will be called by the customer or the customer will finish the meal soon, it is said that *movement on a prediction basis* is taken. In order to capture this tactic, the position of a waitperson before and after a task occurs is compared, and the distance that the waitperson approaches to the task point is calculated. The larger this *approaching distance*, the more it is likely that the waitperson took a *movement on a prediction basis*. This paper analyzes the intuitive skills of a waitperson by focusing on these two tactics.

3 Proposed Serious Game

The proposed game was created using a programming language called Processing [13]. As shown in Fig. 1, the locale of the proposed game is a restaurant dining room having six tables. The customer at each table may require tasks of receiving orders, serving dishes and clearing dishes, and the player is expected to carry them out by controlling a waitperson agent in the dining room.

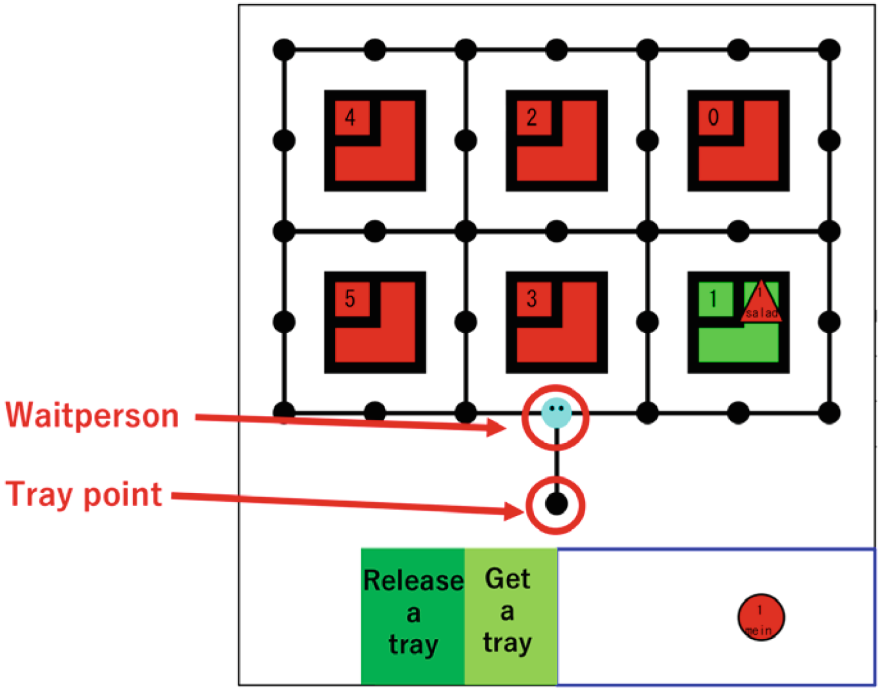


Fig. 1. Restaurant dining room in the game

The player can move the waitperson agent from the current point to an adjacent one on the grid at a time. In order for the agent to carry out a task, it must be at the upper, lower, left-hand or right-hand side point of the table to work on. When the agent performs serving dishes and/or clearing dishes, it has to hold a tray. The number of dishes that can be placed on a tray is limited to five, and the agent can hold at most one tray. Further, dishes to deliver and those to be cleared cannot be kept on a same tray at a same time. There should not be any dishes on the tray, when the agent receives orders from a customer. Accordingly, possible task configurations in a single tour of the waitperson agent can be summarized as shown in Fig. 2.

Customers arrive at the restaurant randomly one by one. Then, they are assigned to a table on first-come first-served basis. When there are two or more tables are available, a table is chosen randomly. After a while, they place an order for up to three dishes only once at a table. Each customer leaves automatically, when the meal is over.

When a task to be done by the waitperson agent occurs, the color of the corresponding element changes from white to yellow, orange and red as time elapses without being handled. When the color of an element is white, it means that the corresponding task has not yet occurred. For example, when a white dish is on a table, the customer is still eating it and the task of clearing it has not yet called for. When the task is carried out by the agent, a certain score is given or deducted according to the color of the corresponding element. That is, if the color is yellow, 10 points are added,

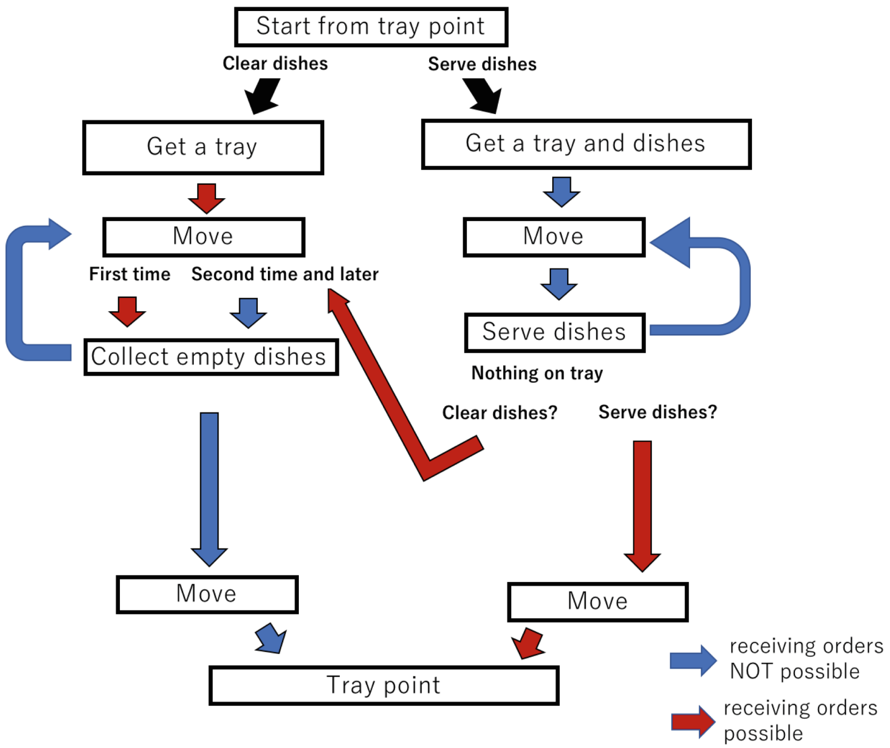


Fig. 2. Possible task configurations in a single tour

and if the color is red, 10 points are subtracted. Further, 10 points are added each time a dish is sold.

4 Game Experiments and Their Results

Game experiments are conducted with 16 university students, and various measures related to the game scores, waiting times and each tactic are calculated from the log data of every game session. Some of the participants have worked in a restaurant as a waitperson, and the others have not. Further, the length of the experience differs among those who have worked in a restaurant. Accordingly, the skill levels of the participants are expected to be significantly varied among them.

4.1 Collection of Multiple Tasks

In order to analyze the intuitive skills concerning *collection of multiple tasks* tactic utilized in the game sessions, cluster analysis and principal component analysis are applied to the data on the total sales, average waiting time of each task, and average number of collected tasks in a single tour (see Fig. 3).

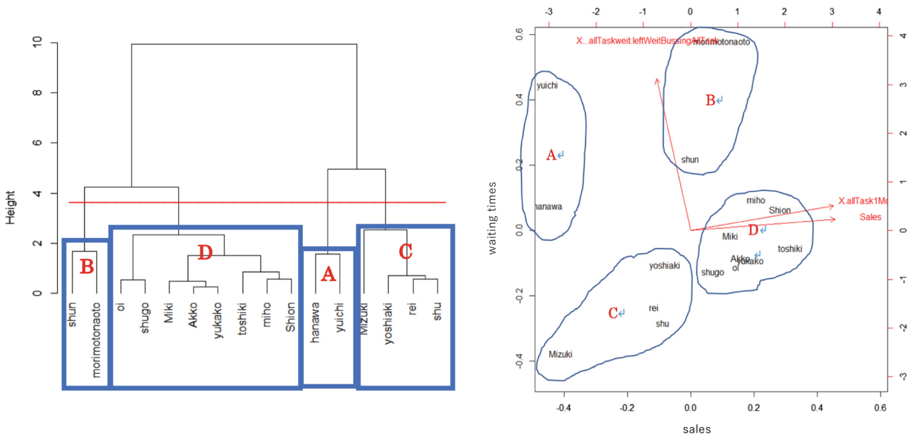


Fig. 3. The results of the analyses on *collection of multiple tasks*

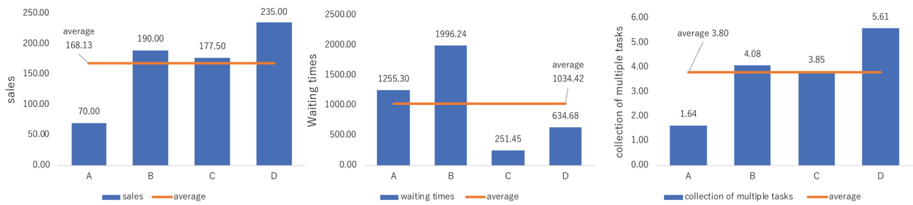


Fig. 4. Averages of *sales*, *waiting times*, and *collection of multiple tasks* in each group

As shown in Fig. 3, players are categorized into four groups, A, B, C and D. How players handle the tasks in each group can be characterized by looking into their game play data more in detail. As shown in Fig. 4, the players in group A did not collect many tasks in a tour and this results in a higher number of inefficient movements. These features further lead to low turnover rates and long waiting times. To sum it up, this is a group of low skill players.

The players in the other groups collected more tasks in every tour. However, the waiting times in group B are significantly larger than the other groups. This shows that the players in group B collected tasks by only considering task efficiency but not waiting times. On the other hand, the waiting times in groups C and D were shorter than average. In these groups, tasks were performed in relatively large batches at an earlier timing, and, as a result, the turnover rate and the sales were increased and the waiting times were shortened. Accordingly, the players in groups C and D seem to possess higher skills.

Comparing these two groups, it seems that the players in group C put a higher weight on shortening the waiting times. Whereas the players in group D seem to pursue two objectives of shortening the waiting times and increasing the task efficiency in a more balanced manner, and, as a result, achieved the highest sales.

How the players in group D perform the tasks can be characterized with two features. The first feature is that they tended to clear dishes after receiving orders. The second feature is that they tended to receive orders after serving dishes. From these two features, it is implied to be important to handle other tasks before clearing dishes.

4.2 Movement on a Prediction Basis

Similarly, the intuitive skills concerning *movement on a prediction basis* tactic utilized in the game sessions are analyzed using the data on the total sales, average waiting time of each task, and average approaching distance (see Fig. 5).

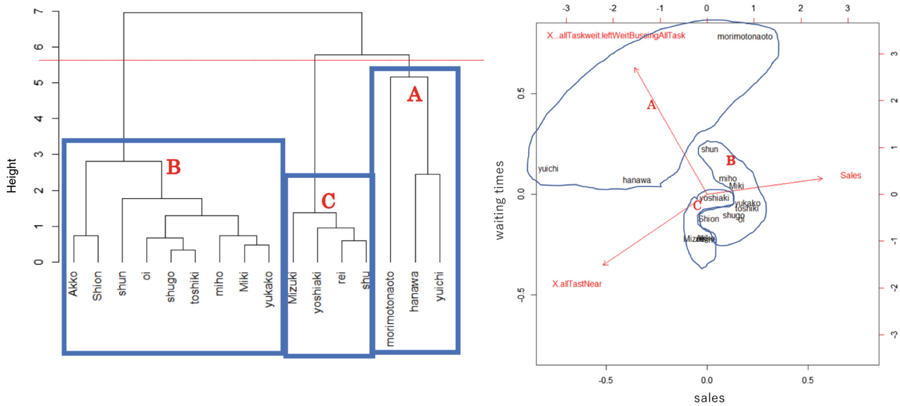


Fig. 5. The results of the analyses on *movement on a prediction basis*

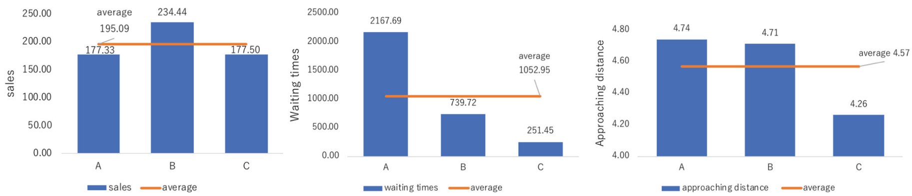


Fig. 6. Averages of *sales*, *waiting times*, and *approaching distance* in each group

As shown in the Fig. 5, players are categorized into three groups, A, B and C, this time. How players handle the tasks in each group is characterized similarly by looking into their game play data.

As shown in the Fig. 6, the average *approaching distance* of the players in group C is significantly shorter than that of the other groups. This shows that the players in this group did not or cannot move the waitperson agent on a prediction basis. As a result, their sales values are lower than the average. To sum up, group C can be deemed as a group of low skill players.

The average approaching distances of groups A and B are equally high, so the players in these groups seem to have taken the tactic well. However, the average waiting times and the resultant sales values are different between the groups. That is, the average waiting times is longer and the sales value is smaller in group A. The reason for this seems to be that the players in this group left some tasks for a long time, and, as a result, the turnover rate became low. Thus, it can be concluded that it is group B that contains the players with high skills.

How the players in group B perform the tasks can be characterized as follows. That is, they tended to shorten the waiting times by properly predicting the completion time of cooking dishes and when customers finish their meal. Therefore, it is implied to be important to predict the completion time of cooking dishes and eating them and to start acting earlier based on the prediction.

5 Conclusions

This paper analyzed a waitperson's intuitive skills for shortening the customers' waiting times at a dining table using a serious game newly developed for this purpose. It defined two distinctive tactics called *collection of multiple tasks* and *movement on a prediction basis*, and introduced several measures on them. By analyzing the game scores, waiting times and these measures obtained from game experiments, several characteristics of the skills have been successfully revealed. That is, it is clarified that two tactics defined are actually utilized by the players, different players apply the tactics differently, and when and how the tactics are applied affects the overall performance of the operations.

However, it is still not clear what makes it possible for skillful players to properly determine when and how each tactic should be applied. To understand this aspect of the skills, it will be helpful to study what input information they utilize when determining when and how they apply the tactics. In order to make this study possible, the game should be extended so that it can control what information and when the players are provided with.

Further, various waiting times at a dining table depend not only on how the waitperson performs the tasks, but also which tables customers are assigned to. That is, if two customers are assigned to tables which are close to each other, it will be easier for the waitperson to work on them efficiently. In this paper, since table assignment is determined automatically in a random manner, the potential interactions between the skills of table assignment and the tasks taken up in this paper are difficult to capture. Thus, an important future research direction is combining the proposed game with the table assignment game developed earlier by the authors, so that the interactions can be studied. It is also interesting to extend the proposed single-player game to a multi-player one and analyze collaborative skills among multiple waitpersons.

References

1. Taylor, S.: Waiting for service: the relationship between delays and evaluations of service. J. Mark. **58**, 56–69 (1994)
2. Fung, K.K.: It is not how long it is, but how you make it long-waiting lines in a multi-step service process. Syst. Dyn. Rev. **17**(4), 333–340 (2001)
3. Vries, J.D., Roy, D., Koster, R.D.: Worth the wait? How restaurant waiting time influence customer behavior and revenue. J. Oper. Manag. (2018, in press)
4. Hwang, J., Lambert, C.U.: The interaction of major resources and their influence on waiting times in a multi-stage restaurant. Int. J. Hosp. Manag. **27**, 541–551 (2008)
5. Hwang, J., Lambert, C.U.: The use of acceptable customer waiting times for capacity management in a multistage restaurant. J. Hosp. Tour. Res. **33**(4), 547–561 (2009)
6. Shimmura, T., Fujii, N., Kaihara, T.: Staff motion reduction at a Japanese restaurant by kitchen layout redesign after kitchen simulation. Procedia CIRP **62**, 106–110 (2017)
7. Bertsimas, D., Shioda, R.: Restaurant revenue management. Oper. Res. **51**(3), 472–486 (2003)
8. Hwang, J.: Restaurant table management to reduce customer waiting times. J. Foodserv. Bus. Res. **11**(4), 334–351 (2008)
9. Guerriero, F., Miglionico, G., Olivito, F.: Strategic and operational decisions in restaurant revenue management. Eur. J. Oper. Res. **237**, 1119–1132 (2014)
10. Mizuyama, H., Yoshida, A., Nonaka, T.: A serious game for eliciting tacit strategies for dynamic table assignment in a restaurant. In: Naweed, A., Wardaszko, M., Leigh, E., Meijer, S. (eds.) ISAGA/SimTecT - 2016. LNCS, vol. 10711, pp. 394–410. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-78795-4_28
11. Roy, D., Bandyopadhyay, A., Banerjee, P.: A nested semi-open queuing network model for analyzing die-in restaurant performance. Comput. Oper. Res. **65**, 29–41 (2016)
12. Tanizaki, T., Shimmura, T.: Modeling and analysis method of restaurant service process. Procedia CIRP **62**, 84–89 (2017)
13. https://processing.org/

Revisiting Challenges in Using Discrete Event Simulation in Early Stages of Production System Design

Erik Flores-Garcia[1(✉)], Magnus Wiktorsson[1,2(✉)], Jessica Bruch[1], and Mats Jackson[3]

[1] Mälardalen University, 631 05 Eskilstuna, Sweden
erik.flores@mdh.se, magwik@kth.se
[2] KTH Royal Institute of Technology, 151 81 Södertälje, Sweden
[3] Jönköping University, 551 11 Jönköping, Sweden

Abstract. This paper presents challenges of using discrete event simulation when supporting decision in early stages of production system design, when significant changes are introduced. It was based on three real-time case studies performed at one manufacturing company during 2014–2016. Challenges in the cases were mapped to previous literature, pointing out discrepancies and highlighting three additional challenges, specifically related to issues in the early stages of the production system design process. The significant change introduced to the assembly system, and the early phases of evaluation put significant challenges to the use of discrete event simulation and the study points out further efforts needed to support manufacturing companies under change, with an established industrial structure and legacy systems to consider.

Keywords: Production system design · Discrete event simulation
Case study

1 Introduction

As manufacturing companies currently meet major change drivers in terms of digitalization, technology development, sustainability and market behavior, many production systems need to deal with significant changes in terms of product portfolio, volumes, and its role in the value chain. In addressing these significant changes, modeling and simulation is a fundamental concept for analyzing behavior and performance in a future setting, and in the area of production system design, literature and practitioners have for long underlined the benefits of discrete event simulation (DES) [1–3]. DES involves the modeling of a series of events when state changes occur at discrete points in time [3], and is used for decision support in production system design because of its ability to evaluate change dynamically [4, 5]. DES is suggested to create knowledge, generate understanding, visualize results, and communicate production system design decisions across different functions within a manufacturing firm [6]. The further development of streamlining simulation-based production systems engineering based on input data from digital twins is a current strong development [7].

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 534–540, 2018.
https://doi.org/10.1007/978-3-319-99704-9_65

However, research has long indicated the limited use of DES at manufacturing companies [8] where specific challenges have been pinpointed. As the DES use can be separated into the three model process phases of *design*, *development* and *deployment* [3], challenges have been discussed from different perspectives. This identification of challenges in DES use for decision support has preponderantly centered on difficulties in the *development* phase of DES models. This approach stems from the realization that a single DES model is often incapable of supporting all production system design decisions and that detailed questions about a production system's performance will arise during the design process [3]. In line with this, Heilala et al. [10] analyze the support of production system design and operations decisions based on DES use. Also, the *deployment* phase are exposed to challenges due to the need to build trustworthy DES models for factory management to commit to production system design decisions. This situation underscores the issues that arise when determining which elements of a production system to represent when supporting decisions through DES during production system design and thereby achieve a successful implementation of DES models [11]. In addition, contextual circumstances related to the introduction of significant changes, such as the lack of information necessary to commit to decisions during production system design, upset the validity of a model and question the credibility of its results [12].

Concluding, current understanding of challenges in DES use for manufacturing applications has so far focused on the use of DES during the operation of a production system or in the final stages of production system design. Thus, the aim of this paper is to revisit the challenges of DES use when supporting decision in early stages of production system design, when significant changes are introduced. We present empirical findings from three real-time case studies performed at one manufacturing company. Each case follows early design stages of a production system and where the DES was suggested to support design decisions. DES was used in two of the three cases, but in one of the cases DES was decided not to be used. The study explores the basis for the decisions of using, or not using, DES during the early design stages where, for the company, new assembly system concepts were to be evaluated. The study contributes to a more established scientific fundament in a practitioner's context, relying on a trial and error tradition. It presents live empirical evidence on challenges while using DES in early design stages of assembly systems for manufacturing companies with an established industrial structure and legacy systems to consider.

2 Material and Method

Three real-time case studies were conducted at a Swedish manufacturing company from the heavy vehicle industry with sites around the globe. Live projects during 2014–2016 were followed and data were collected during 12 months for Case 1, 14 months for Case 2 and for 5 months for Case 3. Data collection for each case included interviews, participant observation, company documents, and discrete event simulation models. Collected data included five interviews per each case. Interviewees were selected on the basis of their participation in each production system design project and included a manufacturing research manager, two logistics developers, two consultants, six manufacturing engineers, two project leaders, a manufacturing engineering manager, and one assembly system concept owner. Interviewees described the reasons behind the start of production system design, and activities in the design of the production system. Finally, interviewees reported on the conclusions and consequences of the designed production system. Interviews were recorded and transcribed and lasted between 38 to 120 min. Interviewees were individually contacted at a later date, and shown the transcribed texts for approval.

Additionally, data were collected through participant observation including weekly project meetings, workshops, informal conversations, and floor shop visits. Also, company documents related to each production system design project were analyzed. Collected data included the examination of seven DES models developed in Cases 1 and 3 which focused on understanding the consequences of introducing production system changes during production system design. Data analysis followed three streams of concurrent activities: data condensation, data display, and conclusion drawing [13]. Each case was first treated individually as a separate study. Then a cross case synthesis and analysis was employed to gain a comprehensive understanding across cases [14]. The analysis was based on earlier identified challenges in using DES in manufacturing application from [1, 9, 11]. Conclusions were finalized based on the comparison and contrasting of theoretical findings with cross case synthesis.

3 Discrete Event Simulation in Three Cases

All three cases were initiated by a corporate decision to allocate resources and actions to the transformation of product-specific assembly systems into multi-product assembly systems. The objectives of this transformations are best explained by the manufacturing research manager of Case A, "*There was the vision to utilize our production system in a more efficient way. We believed it was important to make a better utilization of our industrial footprint, being closer to customers with standardized production of products.*" Design and implementation of multi-product assembly systems was a corporate objective included in the manufacturing company's strategy.

Case 1 explored the design of a multi-product assembly system where five different product families and all variations in each product were to be assembled in one assembly line. This multi-product assembly system included shared technical solutions, assembly processes, tools, assembly operators, and logistics. The aim of this production system design project was to increase the flexibility of manufacturing sites in addition to meeting the company's strategic objectives previously mentioned. Five DES models were developed during the production system design project.

Case 2 concerned the design of an assembly system in which powertrains of five different product families could be assembled in the same multi-product assembly line. When designing the multi-product assembly system, the design project aimed at minimizing product cost and investment levels required to design a multi-product assembly system while at the same time complying with the manufacturing company's strategic objectives. In Case 2 DES use during production system design was proposed; there was interest in using DES in the production system design project team, but DES was ultimately not used during production system design.

Case 3 investigated a production system design project that introduced a multi-product assembly system to replace the site's existing product-specific system in which different families of cabs could be assembled in the same line. The designed production system aimed to comply with the manufacturing company's strategic objectives as well as the site's need to increase production system efficiency and reduce assembly line space. The production system design project included the development of two DES models. Summarizing the findings, Table 1 classifies the identified challenges of DES support of production system design decisions for the three cases (C1, C2 and C3) based on the three DES model process phases [9]. The list of challenges is put together from existing literature [1, 9, 11].

Table 1. Empirical identification of challenges of DES supporting production system design decisions in Cases 1, 2, and 3. List of challenges based on [1, 9, 11].

	Challenges of DES supporting production system design decisions	C1	C2	C3
Design	Decision support restricted by question specific model formulationz	√	√	√
	Representation of production system dynamics and complexity			
	Validity of a model's detail level		√	
	Simplification of production system complexity and factor interdependence			√
	Non-uniform abstraction level for model simplification	√		√
	Modelling combinatorial explosion of options in a production process			
	Incomplete and conflicting production system knowledge	√		√
	Development of simulation and production system knowledge	√		√
	Software diversity and lack of standardization			
Development	Model verification and validation	√	√	√
	Model development time	√	√	
	Input data collection and its analysis	√	√	√
	Input data availability and quality	√	√	√
Deployment	Model interoperability and information sharing across models	√		
	DES industry acceptance	√	√	√
	Communication of results for effective decision making	√		√
	Simulation model maintenance			
	Consideration of trade-off and non-intuitive decisions			√
	High cost and low re-usability of models	√		√

4 Discussion on Why, and Why not, to Use DES

Identified Challenges in DES Model Design Phase

The challenges of DES use supporting production system design decisions seen in the DES model design phase confirm the importance of the objectives of a model [15]. In all cases identifying the specific questions that a DES model should address was a challenge. As expressed by the project manager in Case 1, "*Are we doing the right thing? Should we do it this way? No one really had an answer for that*." This related to specifying the level of abstraction of a model when incomplete and conflicting production system knowledge existed [1]. The point in case is described by the manager in Case 3, "*you can do it in a lot of ways and still get the same result. What should we choose? It's not only about the pieces, it's the system around you, and finding the right solution for you*." This could be explained by the presence of high uncertainties in early design phases [16] and the lack of overall comprehension of the intricacies of a production system during its design [9]. Specifying what to model and how to do so required the assistance of DES experts in all cases. This exposed the lack of resources with the right competence to build DES models [11], the absence of standards to aid the development of DES models [17], and the dependency on individuals instead of processes to achieve DES use during production system design.

Identified Challenges in DES Model Development Phase

DES model development in its relation to input data and DES model verification was the most frequent of challenges of DES use when supporting production system design decisions, a situation consistent with current findings [18]. The reasons behind this challenge were related to the absence of a real world from which to draw data and came as a consequence of introducing a change that was significantly different from the manufacturing company's current operations [19]. This issue was increased by the high levels of uncertainty, which involve the probability that certain assumptions made during design are incorrect or that the presence of entirely unknown facts has a bearing on the future of a designed production system [20]. This is instantiated by the project manager in Case 2, "*There were many unknowns in this innovative project, which different from doing business as usual. We were doing this (transformation) for the first time with no recipe.*"

Identified Challenges in DES Model Deployment Phase

Challenges associated with the deployment of a DES model in support of production system design decisions were also present. These were linked to the limited use of DES in the industry. Model developers had to continuously show in what ways DES contributed to the design of production systems [9], as exemplified by the consultant in Case 2, "*There was a need to present simulation testing at very different levels (in the organization). Simulation is important, but it is really difficult to make a crisp conclusion for everyone to see. Especially when so little is known*." Further, communication of DES model results required the interpretation of experts, a situation that limited effective decision making by project team members [10]. Similarly, the low-reusability of DES models was linked to the lack of in-house resources with DES know-how that could modify or re-use developed models at later times.

Discrepancies Between Challenges in the Case Studies and Earlier Literature
Empirically not all challenges in DES use outlined in [1, 9, 11] were detected (see Table 1), and different levels of concurrence of challenges in DES use existed across cases. The absence of previously identified challenges (Table 1) does not indicate a disagreement with extant theory. The dearth of evidence on this matter is explicated by contextual circumstances. The absence of challenges regarding representation of production system dynamics and complexity, as well as modelling the combinatorial explosion of options in a production process was a consequence of the choice of what production system to model and how to model. DES models incurred in assumptions and simplifications that limited the representativeness of complexity and options. Challenges affecting simulation model maintenance were not discovered as DES models were not re-used after presentation of model results had taken place.

Also, case data show the presence of challenges additional to those specified in literature when DES supported production system design decisions. First, DES model objectives did not establish a direct connection to the high level objectives pursued by the manufacturing company. This constitutes a severe challenge to the characterization of a production system during its design and the decisions involved [21]. Second, DES use was severely limited by the absence of a rigorous production system design process with clearly defined milestones for DES use [10]. The project manager in Case 1 exemplifies, "*We could not specify an implementation (for DES) at the beginning. We had to investigate if it was a good idea first, look into this and start to generate ideas*," and a production engineer from Case 2, "*Of course we tried to look for benchmarking but there are not so many examples in this kind of industry for this type of a change. There is actually no case available where you can find something similar*."

5 Conclusion

This study revisited challenges of using DES when supporting decision in early stages of production system design, when significant changes are introduced. It was based on three real-time case studies performed at one manufacturing company during 2014–2016. Challenges were mapped to previous literature, pointing out discrepancies and highlighting two additional challenges, specifically related to issues in the early stages of the production system design process. The significant change introduced to the assembly system, and the early phases of evaluation put significant challenges to the use of discrete event simulation. Future research efforts are needed support manufacturing companies under significant change, with an established industrial structure and legacy systems including: (1) model design in terms of alignment to high level business objectives and knowledge, (2) input data and model validation during model development, and (3) model knowledge, reuse, and interoperability during model deployment.

References

1. Mönch, L., Lendermann, P., McGinnis, L.F., Schirrmann, A.: A survey of challenges in modelling and decision-making for discrete event logistics systems. Comput. Ind. **62**, 557–567 (2011)
2. Kleijnen, J.P., Pierreval, H., Zhang, J.: Methodology for determining the acceptability of system designs in uncertain environments. Eur. J. Oper. Res. **209**, 176–183 (2011)
3. Law, A.M.: Simulation Modeling and Analysis, 5th edn. McGraw-Hill, New York (2015)
4. Michalos, G., Makris, S., Papakostas, N., Mourtzis, D., Chryssolouris, G.: Automotive assembly technologies review: challenges and outlook for a flexible and adaptive approach. CIRP J. Manufact. Sci. Technol. **2**, 81–91 (2010)
5. Jahangirian, M., Eldabi, T., Naseer, A., Stergioulas, L.K., Young, T.: Simulation in manufacturing and business: a review. Eur. J. Oper. Res. **203**, 1–13 (2010)
6. Van Der Zee, D.J., Van Der Vorst, J.G.A.J.: A modeling framework for supply chain simulation: opportunities for improved decision making. Decis. Sci. **36**, 65–95 (2005)
7. Schluse, M., Priggemeyer, M., Atorf, L., Rossmann, J.: Experimentable digital twins - streamlining simulation-based systems engineering for industry 4.0. IEEE Trans. Industr. Inf. **14**, 1722–1731 (2018)
8. Ericsson, U.: Diffusion of discrete event simulation in swedish industry. Doctoral thesis, Chalmers University of Technology (2005)
9. Fowler, J.W., Rose, O.: Grand challenges in modeling and simulation of complex manufacturing systems. SIMULATION **80**, 469–476 (2004)
10. Heilala, J., Montonen, J., Jarvinen, P., Kivikunnas, S.: Decision Support Using Simulation for Customer-Driven Manufacturing System Design and Operations Planning. INTech Open (2010)
11. Wang, Q., Chatwin, C.R.: Key issues and developments in modelling and simulation-based methodologies for manufacturing systems analysis, design and performance evaluation. Int. J. Adv. Manuf. Technol. **25**, 1254–1265 (2005)
12. Skoogh, A., Johansson, B.: A methodology for input data management in discrete event simulation projects. In: Proceedings of the 2008 Winter Simulation Conference, Miami, FL, pp. 1727–1735 (2008)
13. Miles, M.B., Huberman, A.M., Saldaña, J.: Qualitative Data Analysis: A Methods Sourcebook. SAGE, Thousand Oaks (2013)
14. Yin, R.K.: Case Study Research: Design and Methods. SAGE, Thousand Oaks (2013)
15. Robinson, S.: Tutorial: choosing what to model—conceptual modeling for simulation. In: Proceedings of the 2012 Winter Simulation Conference, pp. 1–12. IEEE, Berlin (2012)
16. Parida, V., Patel, P.C., Frishammar, J., Wincent, J.: Managing the front-end phase of process innovation under conditions of high uncertainty. Qual. Quant. **51**, 1983–2000 (2017)
17. Randell, L.: On discrete-event simulation and integration in the manufacturing system development process. Doctoral thesis, Lund University (2002)
18. Barlas, P., Heavey, C.: Automation of input data to discrete event simulation for manufacturing: a review. Int. J. Model. Simul. Sci. Comput. **07**, 1630001 (2016)
19. Carrillo, J.E., Gaimon, C.: A framework for process change. IEEE Trans. Eng. Manage. **49**, 409–427 (2002)
20. Frishammar, J., Lichtenthaler, U., Richtnér, A.: Managing process development: key issues and dimensions in the front end. R&D Manag. **43**, 213–226 (2013)
21. Cochran, D.S., Foley, J.T., Bi, Z.: Use of the manufacturing system design decomposition for comparative analysis and effective design of production systems. Int. J. Prod. Res. **55**, 870–890 (2017)

Knowledge Management as an Important Tool in Participatory Design

Xiaoli Chen(✉), Ralph Riedel(✉), Michael Bojko, Mandy Tawalbeh, and Egon Müller

Chemnitz University of Technology, 09107 Chemnitz, Germany
{xiaoli.chen, ralph.riedel, michael.bojko, mandy.tawalbeh, egon.mueller}@mb.tu-chemnitz.de

Abstract. Innovation is a necessity for the survival in the dynamic and complex environment companies are currently in. Innovation is not only the result of a creative development process, but comes out also from the value adding process itself, and derives from the generation of knowledge, including the interaction and application of knowledge for market success. Therefore, the ability to collect all possible knowledge and trigger it for success is of great importance for being competitive. This is also the main focus of participatory design activities. In this work, with a special view on the importance of knowledge management, an approach using the analysis of relevant and available knowledge has been set up for the determination of suitable methods for participatory design activities. In detail, objectives of knowledge management are identified according to different requirements of the innovation lifecycle. Cognitive and technology gaps among participants are further analyzed to provide an in-depth view on the problem of participatory design. With the matching of problems with the potentials of possible participatory design methods, proper methods are further identified, which helps to realize objectives of knowledge management, in the end leading to the success of value adding.

Keywords: Knowledge management · Participatory design
Innovation lifecycle

1 Introduction

Ever increasing global competitive pressure, shrinking product lifecycles and fast changing technologies are driving companies towards innovation to remain in the competition [1]. Quite often, innovation is related to the occurrence of new products and technologies [2]. But currently, innovation is more and more seen as the process which results from various interactions among different participants. Especially, when it comes to new product development, innovation is particularly characterized by value adding, which derives from the generation of new knowledge and includes the interaction and application of knowledge for market success. It is the participation and interaction of all involved actors (e.g. designers, users, machine operators, suppliers/partners, logistic operators and customers), which finally leads to the success and competitiveness of companies. Therefore, participatory design for the full

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 541–548, 2018.
https://doi.org/10.1007/978-3-319-99704-9_66

encouragement of all potential knowledge and its interaction is highlighted as one of the most focused issues of company management. A suitable knowledge management within the participatory design is an alternative shortcut contributing to the success of value adding.

When it comes to the aspects of knowledge management, it is not only the content of knowledge, but also the way in which different knowledge pieces interact with each other is crucial to the success of value adding. The manners of knowledge interaction is highly related to how the approach of participatory design is established. However, question arising here is: How to find out and establish appropriate approaches for the realization of efficient participatory design? And derived questions that should be clear are:

– What is an efficient participatory design?
– Which approaches are existing for carrying out participatory design?
– With a view to the objectives of knowledge management and also the real conditions of participants, how to identify a suitable approach for participatory design activities?

With all these in mind, the purpose of this work is to provide an approach, which helps to setup an efficient participatory design model. General work begins with the introduction of the relevant background. Further work goes on with a vast review on the theoretical basis. Related participatory design approaches are investigated based on the state of art. With a view to the importance of knowledge management, a general logic is composed as the rule for determining suitable participatory design methods. A detailed model is further established for interpretation. An empirical study is conducted for validation purposes. A conclusion of the work is composed in the end.

2 Definition and Possible Methods of Participatory Design

2.1 Participatory Design and Knowledge Management

Participatory Design is "an emerging design practice" that involves different stakeholders within various co-design activities throughout the designing process [3]. Here, beside designers, stakeholders involve not only other discipline members from a development team (e.g. machine operators, project manager and general manager), but also external stakeholders within the supply chain (e.g. logistic operators, suppliers and partners). For better marketization, potential customers beyond the boundary of the company or industry would also be included during the design stages. Therefore, these stakeholders have usually "different backgrounds, experience, interests and roles within the project" [3]. For the full encouragement of participatory design activities, the consideration of the detailed contents of knowledge brought from the participants is of great importance. Moreover, the way how to trigger knowledge interactions dependent on the real situation is sometimes even more important and necessary. This brings special emphasis on the issues of knowledge management.

Knowledge management is a "planned, structured approach" to realize sharing, acquisition, refinement, distribution and application of knowledge as in the organizational asset [4]. With a view to the vast body of literature and practice, we see knowledge management has been widely used in many fields, e.g. new product development [4], organizational leaning, organizational innovation, project management [5], and so on. In this paper, while considering the relative advantages, knowledge management has been involved as an important tool in the development of efficient participatory design, which can help to access and structure the experience, knowledge and expertise of participants to create new competitiveness advantages, to enable better performance and in the end to increase value adding and customers' satisfaction [6]. And the establishment of an efficient participatory design requires not only the planning of knowledge pooled by participants, but also the structuring of knowledge for proper "collision", which leads to knowledge fusion and fission for creating new value [1].

2.2 Possible Methods Used for Participatory Design

The arrangement of an appropriate participatory design is, to some extent, a crucial determinant of innovation. Knowledge generation and value adding are all illusory scenarios if the knowledge from relative stakeholders could not be structured and formalized in a suitable way. Hence, studies of participatory design are highly emphasized both in theory and practice. Methods, such as LEGO® SERIOUS PLAY® [7], LEGO® MINDSTORMS®, scenario analysis, role plays, prototypes, Mind Mapping, morphological boxes, story-telling, persona, brain writing, diagrams and image schemes, contextual inquiry, ethnographic methods, participatory ergonomics [8], have come up during the past periods.

Numerous works can also be found dealing with the classification of participatory design methods [3, 9, 10]. Some focused on a basic understanding and tried to propose proliferation of theoretical foundation, e.g. in the works of Muller and Kuhn [9], more than 20 methods have been listed out, where two issues namely "position of activity in the development cycle or iteration" and "who participates with whom in what" have been concluded as the logics for the taxonomy. With the analysis of application cases in practice, others attempted to make a comparison among different participatory design methods, to help to list out the key features for the identification [10]. With the aim of combining theory and practice, works from Sander, Brandt and Binder [3] also tried to sort the situations of participatory design based on the purpose (for probing, priming, understanding or generating), group size and composition (individual or group) and manners of participatory design (face-to-face or on-line). Taken together, all these works contribute to the idea of the current work, yet two shortcomings can still be found: (1) the ignorance of knowledge management, though the compositions of knowledge and how the knowledge would be structured for collision are the core for the defining of an efficient participatory design; (2) the lack of a systematic approach, which can be used as a reference of application. Though a systematic method is of great importance for the decision support related to the participatory design activities, only partial theoretical and practical assets could be found separately. However, with a view to different objectives of knowledge management within various innovation stages, a bridge with an overall mindset to match the real conditions with the potential abilities of existing participatory design methods, is still a gap. Therefore, a more "contemplative and nuanced approach" is required [4], so as to answer "how to get appropriate approaches for the realization of efficient participatory design?"

3 Establishment of the Proposed Approach

3.1 Framework of Participatory Design

Based on the aforementioned analysis, a general framework of participatory design has been composed as shown in Fig. 1. As can be seen, three issues compose the initiate status of participatory design. Those are the *position in the innovation lifecycle*, the *team composition* and the *degree of prior knowledge* [8]. The general work of participatory design begins with the identification of the objectives of knowledge management. This is based on the analysis related to the *position in the innovation lifecycle*. Real conditions of knowledge, pooled by participants, are further analyzed with the consideration of the *team composition* and the *degree of prior knowledge*. *Cognitive gaps* and *technology gaps* among participants can also be identified according to the analysis of the real conditions. When taking into account both the objectives and real conditions, the logic of knowledge management plays the role of a bridge to match the existing gaps with the possible abilities of participatory design methods, which in the end leads to the identification of suitable methods.

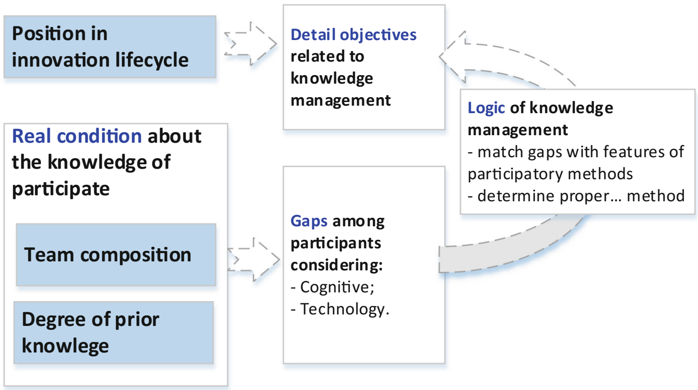


Fig. 1. General approach for the establishment of participatory design

3.2 Detailed View of the Approach

Based on the composition of the general framework, the proposed approach has been detailed as shown in Fig. 2. It can be seen, that the approach could be divided in three stages: (1) obtain detailed objectives of knowledge management; (2) analyze the real conditions of the knowledge pool to find gaps among participants; (3) match to determine a proper participatory design method, to realize the objectives of knowledge management.

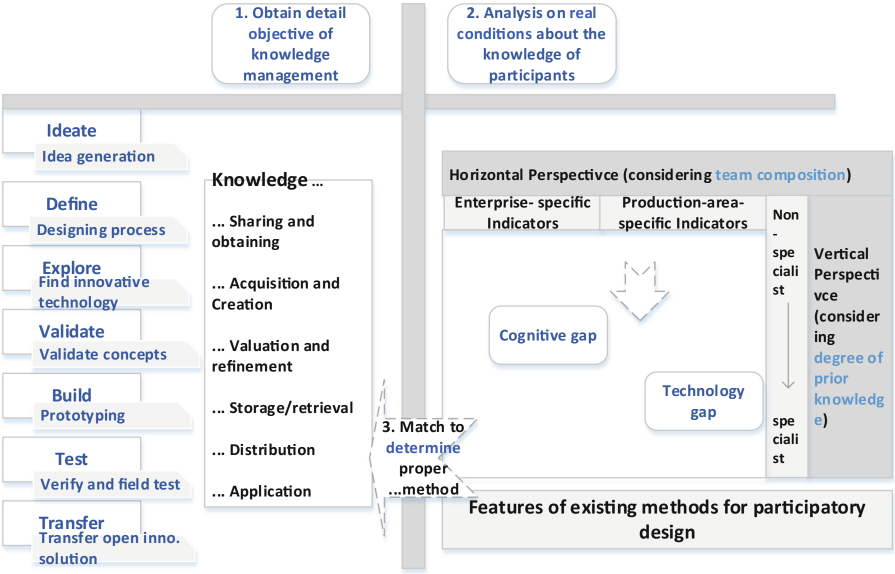


Fig. 2. Detail interpretation of the approach

(1) Obtain detailed objectives of knowledge management

Knowledge management is a “set of activities, initiatives and strategies” [11], which enables effective and efficient usage of knowledge and helps to create new value. Within different stages of the innovation lifecycle, the target of knowledge management varies differently, e.g. the idea generation stage requires more knowledge sharing and obtaining; the validation stage needs more valuation and refinement of knowledge. Based on the works of Plessis [4] and also Grant and Dumay [12], activities and detailed objectives of knowledge management have been gathered as: ***knowledge sharing and obtaining; acquisition and creation; valuation and refinement; storage and retrieval; distribution and also application***. Here, *knowledge sharing and obtaining* mainly refers to the engagement and participation of all stakeholders, communication to share ideas, which triggers the obtaining of information and interactions for new ideas. The *acquisition and creation of knowledge* is a more in-depth stage, which relates to reconstructing and synthesizing of knowledge and also the organization of knowledge for getting general concepts [12]. The *Valuation and refinement* is mainly connected with the set-up of metrics for evaluation and attempts to refine the knowledge accordingly; the *storage and retrieval* includes the codifying and documenting of knowledge for storage. The *distribution* is more the spreading of information in hope to get better effects for the existing knowledge pool [11]. The *application* refers to the usage of knowledge to realize value.

(2) Analyze the real conditions of the knowledge pool

According to Tawalbeh et al. [8], the real conditions about the knowledge pooled by the participants could be analyzed from both a horizontal and also a vertical perspective (see Fig. 2). Here, the horizontal perspective focusses on considering the team composition, where *enterprise-specific* or *production-area-specific indicators* would be used for the analysis. In detail, *enterprise-specific issues* include knowledge on cognitions, mindsets, norms, values, hierarchy, business process and other special characteristics of the company [1]; and the *production-area-specific items* are more focused on the technical know-how. Indicators, such as education background, previous work done in certain areas, or simply working with similar technologies or in the same type of industry would be used for interpretation. Beside the horizontal perspective, a vertical one, focusing on conditions regarding the degree of prior knowledge would also be taken into account. Different levels of the knowledge base of each participant can also be assessed accordingly. As a result, a knowledge distance, namely cognitive and technology gaps could be identified based on the above knowledge portfolio and their relative levels. Methods with multi-dimensional scaling analysis proposed for instance by Stuart [13] and Baum et al. [14] are suggested as the references for further work here.

(3) Match to determine a proper participatory design method

With the consideration of the objectives of knowledge management, and based on the knowledge gaps among participants, detailed requirements can further be gathered for the determination of a participatory design method. Detailed characteristics listed out for the identification and classification of participatory design methods from [3, 7–9] would be involved for the interpretation of each method's features. With the matching of requirements with potential features and abilities of participatory design methods, the target method (the most suitable one) could be identified as a result. This general idea is displayed in Fig. 3.

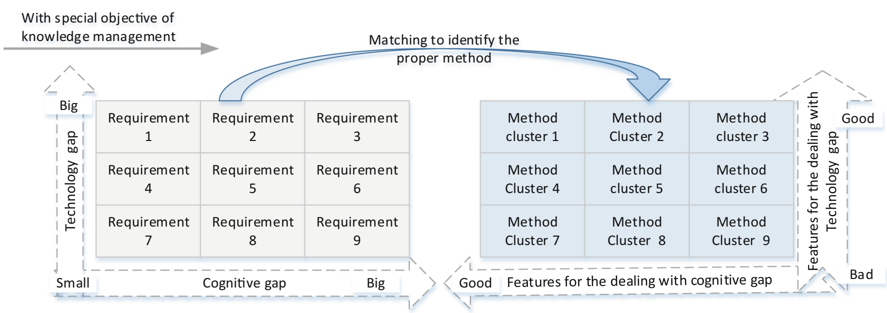


Fig. 3. Matching for the identification of a proper method

4 Empirical Study

The German initiative “Mittelstand 4.0-Agentur Prozesse” is a platform focused on the digitalization of resource and process management [7]. The main target of this initiative is to support the qualification of information multipliers, who are enabled to help small and medium-sized enterprises and also handicraft companies [8]. Here, the major activities of knowledge management are related to the distribution and transfer of digitalization knowledge. The participants have different backgrounds, experience and interests. As most participants come from different industries, a big gap exists both on cognitive and technology aspects. Therefore, as shown in Fig. 3, the requirements on the participatory design method are identified as “requirement 3”. To deal with this special condition, a method, which embodies the ability to deal with the big gap (on cognitive and technology related knowledge), should be considered for facilitating participatory design.

With these requirements in mind, a vast search through all possible methods has been conducted. In the end, LEGO® SERIOUS PLAY® has been identified as the proposed method. LEGO® SERIOUS PLAY® is “an innovative hands-on and minds-on method based on metaphorical thinking to improve the understanding of processes” [8]. In this case, a fictive company has been modelled as the objective of the investigation. Each of the participants has been pointed to a special role within this objective company. Via the establishment of the fictive company, problems with the gaps considering the special company and industry could be solved. As all participants were introduced to the same objective company, they were moved to the same knowledge level for a common understanding. With the introduction of the theory and warming up with Lego, all participants could feel free to design their view of the future versions of the objective company in the year 2020. Moreover, with the learning-by-playing approach, concrete actions for realization could be worked out suitably when considering the scenario of their working area within this fictive company and also with the consideration of external influences of the system’s environment. A joint model representing the common understanding of the digitalization has also been concluded. Taken together, with the logic of knowledge management, LEGO® SERIOUS PLAY® has been confirmed as an appropriate method within this project. Here, the problems with the cognitive and technology gap have been solved smoothly and the knowledge of the different participants has been fully shared and triggered under a common understanding. Therefore, the approach proposed as in this paper could be seen as to be validated to some extent.

5 Conclusion and Outlook

With a view to the importance of knowledge management, a new approach has been set up using knowledge analysis as a basis for the determination of participatory design methods. This helps to answer the question: How to identify appropriate approaches for efficient participatory design? With help of knowledge management, the participatory-design approach has been established in a general system. This helps to fill the gap between real conditions and existing participatory design methods. Moreover, with the detailed interpretation of three application stages, this approach also helps to build a bridge between theory and practice. Based on an empirical study, the proposed approach was validated. Considering that the research work is still in progress, the established approach has only been applied to one case. More empirical studies with quantitative analysis have been planned to be carried out in the following work. When it is well confirmed, the proposed framework could be used as a reference model for practice within different industries.

References

1. Chen, X.L.: Technological innovation capability evaluation and decision support for companies in innovation alliance. Doctoral thesis, Chemnitz University of Technology, Germany (2014)
2. Schulz, K.P., Riedel, R.: Innovation through process simulations and business games - considering the social aspects of innovating in networks. In: International Conference on Advances in Production Management Systems: Innovation in Networks, Helsinki University of Technology, Finland (2008)
3. Sanders, E.B., Brandt, E., Binder, T.: A framework for organizing the tools and techniques of participatory design. In: PDC 2010 Proceedings of the 11th Biennial Participatory Design Conference, Sydney, Australia, pp. 195–198 (2010)
4. Plessis, M.D.: The role of knowledge management in innovation. J. Knowl. Manag. **11**(4), 20–29 (2007)
5. Liao, S.H.: Knowledge management technologies and applications-literature review from 1995–2002. Expert Syst. Appl. **25**, 155–164 (2003)
6. Gloet, M., Terziovski, M.: Exploring the relationship between knowledge management practices and innovation performance. J. Manuf. Technol. Manag. **15**(5), 402–409 (2004)
7. Schneider, H.: Mittelstand 4.0 - Agentur Prozesse. http://www.prozesse-mittelstand.digital/. Accessed 20 Feb 2017
8. Tawalbeh, M., Riedel, R., Horler, S., Müller, E.: Case studies of participatory design: comparison of methodologies in factory planning. In: Lödding, H., Riedel, R., Thoben, K.-D., von Cieminski, G., Kiritsis, D. (eds.) APMS 2017. IAICT, vol. 514, pp. 159–167. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-66926-7_19
9. Muller, M.J., Kuhn, S.: Participatory design. Commun. ACM **36**(6), 24–28 (1993)
10. Berthet, E.T., Barnaud, C., Girard, N., Labatut, J.: How to foster agroecological innovations? A comparison of participatory design methods. J. Env. Plan. Manag. **59**(2), 280–301 (2016)
11. Donate, M.J., Pablo, J.D.: The role of knowledge-oriented leadership in knowledge management practices and innovation. J. Bus. Res. **68**, 360–370 (2015)
12. Grant, K., Dumay, J.: Leading Issues in Knowledge Management, 2nd edn. Academic Publishing International, Japan (2011)
13. Stuart, T.E.: Interorganizational alliances and the performance of firms: a study of growth and innovation rates in a high-technology industry. Strateg. Manag. J. **21**(8), 791–811 (2000)
14. Baum, J.A., Cowan, R., Jonard, N.: Network-independent partner selection and the evolution of innovation network. Manage. Sci. **56**(11), 2094–2110 (2010)

Using Serious Gaming to Discover and Understand Distributed Ledger Technology in Distributed Energy Systems

J. W. Veeningen and Nick B. Szirbik(✉)

University of Groningen, Groningen, The Netherlands
j.w.veeningen@student.rug.nl, n.b.szirbik@rug.nl

Abstract. This paper provides an extension to a family of games that are in the theme of distributed energy systems. This extension of the family of games is a direct result of developing a derived type of game, that is, an energy trading and investing game that involves the infrastructural usage of a new technology, in this particular case, blockchain (a type of distributed ledger technology). The game's novel architecture is explained succinctly, and some results are discussed. Shortly, the extensions of the generic architecture are listed, and special emphasis is put on the idea that such a game must have a two-phased play – one with the novel technology not active and one with it activated. Finally, some insights in game architecture development and the necessary next steps are posited.

Keywords: Serious games · Blockchain · Renewable energy

1 Introduction

To keep up with the latest innovation trends and remain competitive, companies should continuously be aware of novel technologies that can impact their processes and decide whether they should adapt and use those emerging technologies. Nevertheless, technology-driven trends are sometimes irrelevant for certain industrial domains. One of the researcher's challenge is to make an early context-dependent distinction between new valuable technologies from irrelevant ones for specific and generic cases of application. Many times, new technologies have often had quite different effects that initially expected. A classic example is the steam machine, initially envisaged an applied to pump water out of mines; creative people adapted it quickly for transporting goods and people. Another relevant example is the early digital DARPANet which was intended for military command, control, and intelligence (C2I); nowadays the civilian version of the Internet and its applications are used to bring people close for personal and social goals, business and commerce, entertainment and politics. However, the stakeholders who are responsible of taking the decision to use the novel technologies with positive disruptive potential are not always convinced of the benefits of their adoption. In some cases, a healthy skepticism is welcome, because more than many technology-driven "silver-bullets" did not deliver, leaving stakeholders burdened with huge investments that never paid off. A relatively recent (2012) example is Google

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 549–556, 2018.
https://doi.org/10.1007/978-3-319-99704-9_67

Glass and its promise to revolutionize how social networks will work in the future. Although the technology itself was working and up to the promised task, concerns about the privacy of others (nobody likes to be recorded without their knowledge), price (around $1500) and copyright infringement (in movie theaters), kept the device from going mainstream, though it is still used in some professional applications. A simple way to make the stakeholders in a certain domain aware about the implications of a new technology is to show the impact of this technology on the business processes via a serious game. This paper shows how a novel technology trend can be included in the architecture of serious games, and how such games can be used to make players/stakeholders aware and understand these technologies. The next section presents the novel technology trend, Sect. 3 presents how a serious game can be used to increase stakeholder trust in certain aspects of a complex business process, Sect. 4 illustrates the application of a novel technology to energy markets, Sect. 5 explains how an existing generic architecture for serious games was extended, Sect. 6 comments on the preliminary results, and Sect. 7 concludes the paper.

2 Distributed Ledger Technology as a Novel Trend in Various Domains

A technology trend that is currently in its ascent phase is the distributed ledger technology (DLT) called blockchain [1], which enables some currently popular (albeit controversial) cryptocurrencies like Bitcoin. DLT is a technology that entails a record of information (a database), that is shared across a network. In a blockchain-based system, all transaction data is multiply stored in blocks that are attached to each other to form a chain. The transactions in the system are continuously reviewed by a fixed number of independent members, which opens the possibility that intermediaries who are centrally organized and trusted are not any more necessary. For example, in processes like payments, clearings, and settlements, blockchain technology offers a decentralized solution for storing data in a secure, verifiable, and trustworthy way [2]. Due to the hype it generated, many different businesses are interested in the technology, but they do not understand the possibilities of the technology or are wary or even afraid to invest for its implementation. In Europe, various industries like finance, education, logistics, the energy industry and also individual companies are exploring the possibilities for applying DLT in their business [3]. For example, the European Central Bank published an exploratory paper [4] about possible use cases in security markets, suggesting several scenarios, and recognized that DLT holds potential for the financial industry. Another immediate and already adopted application is in supply chains of products that are sensitive to tampering, like second-hand cars, where the mileage and maintenance status of the car is essential for trust [5]. Researchers also point out that one of the biggest potential application of blockchain technology is in the area of smart contracts, that is a self-executing contract that can be used as an alternative to enforcement, and does not need the intermediaries like e-commerce sites, credit card companies, or courts [6]. This raises the possibility to have peer-to-peer contracts in a decentralized energy market, where consumers are sometimes producers and vice-versa. To see where DLT can be of an added value requires a better understanding and more awareness of the potential applications of DLT. The authors of this paper consider that serious games can be one of the solutions that can bring awareness, understanding, and the ability to think of new applications for a specific technology in a given industrial context.

3 Raising Stakeholders' Trust and Understanding with a Serious Game for Peer-to-Peer Distributed Energy Systems

The authors' previous research involved the building of and experimenting with serious games in relation to various infrastructural inception problems like the development of a bio-gas infrastructure in the Netherlands, and also the development of local small-scale demand and supply infrastructure for wind power. The need to quickly prototype games led to the development over years of a game generic architecture and the guidelines to apply it for a given context [7]. This architecture is considered a constant work in progress, as an artefact of design science at work, trial and error, and refinement. This generic architecture has a primary purpose for the games developed from it, that is, to convince stakeholders that investing in a multi-player inception infrastructure brings rewards in the long term. Typically, there is a blockage in this kind of investments, because all stakeholders wait for the others to make the first move. For example, in an variant of the game where LNG-powered truck-refueling infrastructure was envisaged, the truck fleet owners waited for the stations owners to develop new stations, and station owners waited that truck fleet owners acquire more LNG-powered trucks. Stakeholders like investors, LNG distributors, customers who wanted a "green logistic" image were not even factored in this "chicken and egg" problem mitigation. The game could bring together all these stakeholders and show them that various long term scenarios can be discovered via game playing, where all stakeholders ended in a win-win outcome. A new step forward towards the extension of the generic architecture of this kind of games that was done recently, via implementing a new kind of game, i.e. the "blockchain within local energy" game. Here, the main purpose of the game is not the discovery of win-win scenarios of investment and return of investment. The goal is to make stakeholders adopt a novel technology. The previous experiences with the afore mentioned games hinted that serious gaming is potentially helpful in understanding possibilities of new technologies. In the bio-gas game [8], the main goal was to gain insights in the factors that contribute to success or failure in the complex and difficult investment processes for the gas and bio-gas infrastructure in The Netherlands. Nevertheless, the players (who were technical and non-technical stakeholders in the gas industry) became aware and understood the finer points related to the technological details of the infrastructure. In a mere presentation of the technologies involved, the stream of information was unidirectional and the listeners often forget what was presented. With serious gaming, the technology was "experienced" and discussed between the players engaged in the game. Extant literature also supports this finding, it has been confirmed that a game is beneficial for learning knowledge that is considered outside the normal expertise of a player [9].

4 Distributed Ledger Technology in Distributed Energy Systems

A promising use case for DLT is in the energy industry. This is because the popularity of distributed energy resources (DERs) is rising. This is enforced by the fact that solar and storage technology is decreasing in price and becoming more available for households. Blockchain, by its nature, allows that the systems can be organized and coordinated in a decentralized manner. Thus it fits the decentralized organization of the energy infrastructure discussed. There are many systems in the energy industry where the infrastructure is organized in a decentralized manner, some already supported by blockchain technology. In Brooklyn, NY, an initiative [10] was taken by a community which organized a local market where electricity is exchanged. In this community, households owning solar panels are able to sell electricity to other members of the community, so they can keep trading profits within the community. This incentivizes and simplifies the process of investing in now solar panels, wind turbines, or local energy storage, simply because the community members no longer have to pay for the service of an intermediary. The transaction system is based upon blockchain technology, where the participants pay each other with a local cryptocurrency. Another example, which is a global initiative, where incentives facilitated by DLT are provided for solar powered energy is SolarCoin [11, 12]. This is a special kind cryptocurrency that since January 2014 is distributed amongst owners of solar panels that are located anywhere in the world, even off-grid. The goal of the creators of the coin is to incentivize generating renewable energy and to that end, they give 1 SolarCoin to people for every MWh that they produce with their solar panels. Later, these producers will be able to exchange SolarCoins as consumers of other green and ethical goods made available for trading with this currency, invest in new production capacity created by SolarCoin buyers, donate for charity, etc. At the time of writing this text, there were 6,980,342.4 SolarCoins granted to solar energy producers in 59 out of the world's 215 countries. Nevertheless, the application of the blockchain technology in energy can be segmented in local, private blockchain applications – which can interact with cryptocurrencies like SolarCoin (but not necessarily). In the Netherlands, in Amsterdam, a pilot project [13] was initiated by a collaboration between De Ceuvel, Alliander, and Spectral. In this project, locally produced renewable energy is distributed in a community supported by blockchain technology. Participants of the system can trade energy from peer to peer and handle transactions via a specially created cryptocurrency. These examples show that companies are actively searching for blockchain technology applications in redesigning energy infrastructures. To make potential participants in such a complex system more aware of the benefits of DLT, it was considered that a serious game could make them discover the benefits. Moreover, playing this game together with the participants, new use cases could be discovered. What the initial attempts for gaming also show is that there are numerous parties that are very willing to deploy such a blockchain enabled micro-grid. However, some of these stakeholders are not yet convinced, and the intention is that the game playing helps them to get in touch with the blockchain technology and its usefulness in the DER context.

5 The Specific Features of the DLT Energy Game

The blockchain energy game is designed simulate an energy exchanging community that consists out of households of which some own solar panels or wind power micro-plants. The owners of the electricity producing units may consume the output themselves, however when they have a surplus they want to sell it to the existing grid. The main problem in this scenario is that price they get for their produced electricity is fixed and quite lower than the two fixed prices (peak and through prices) that are currently offered in the energy retail contracts. Moreover, the selling price can be perceived by these prosumers as ridiculously lower in comparison with the volatility prices that appear on the higher level spot-market managed by the grid (energy prices can go 100 times over the average when the demand is high). However, retail contract participants cannot play on this spot-market, which is only for specialized traders who trade on the supply and demand of high-volume producers and users (trading kilowatts vs trading megawatts) This inability to participate in the higher level market where prices are dynamic, and profit can be made during high demand period, reduces the incentive to invest in extra producing capacity. The grid operator has the responsibility to maintain grid stability and provide a reliable power supply. Traditionally, the electricity supply was a one-way stream, but nowadays distributed reusable energy resources are gaining popularity. However, solar and wind produced electricity which puts power back on the grid creates instability and it becomes nowadays a challenge for grid operators. The game is to be played in two distinct phases: the first phase is the current real-world situation with limited selling prices for produced electricity to the grid and increasing instability of the grid due to DERs. In the second phase the blockchain technology is introduced and this enables an energy exchanging community. Peer-to-peer trading, smart contracts, and transactional transparency are introduced. In both phases, households have the option to invest in solar panels, wind micro-plants, and also electricity storage units. In the first phase, the households with solar panels will consume their own produced electricity and they will want to sell their surplus to the utility company. However, they will receive a very low fee for every kWh they want to sell. Thus, investing in a collection of solar panels that has a capacity that is higher than their own consumption is not attractive. The attractiveness of (extra) production capacity and eventual storage is linked to the consumption of the households and to the producing capacity. The higher the consumption of the household and its storage capability, the higher the capacity needed to meet this demand – and the potential to sell energy to the grid, albeit this is constrained by un-attractive low and fixed prices.

When the second phase begins, the ability to sell energy to neighbors at dynamic prices will be given to the households that own production capacity. A solar panel owner without storage can sometimes sell its surplus to neighbors at a better price than selling it to the grid. This incentivizes investment in extra solar panels in the energy exchanging community. The equilibrium of such a community would be when there are enough solar panels to be self-sufficient within the community. The grid instability that arises with the increasing nationwide popularity of DERs can be diminished by establishing such a community. That is, within the community the frequency and load of the network will be managed separately from the normal grid. This enables further an increasing number of DERs, while maintaining stability. When the self-sufficiency of the community increases, the distance that power has to travel before it can be consumed also decreases significantly. Investment in local storage allows players to choose the right time to sell the excess energy, for a better price. The game is purposefully designed to show the difference of the situation ex-ante and ex-post blockchain implementation. Players will notice that the price they are able to sell their energy for is much higher than before. The payback period of the return of the investment in producing units for solar and wind decreases significantly and investing in more power capacity is therefore incentivized. The previous papers [7, 8] showed games where an infrastructure is developed to enable local exchanges between producers, transporters, storage owners, and consumers of electricity or biogas. In this novel game, exchanges of electricity are also played, but now these exchanges are supported by blockchain technology which allows for a novel manner to register and manage transactions. The new game extends the existing generic architecture of energy trading games with a new set of functions and guidelines, that will be applied when the game should include the adoption of a new technology (which is not blockchain necessarily). There are a few new aspects that appear in the upgraded architecture. First, the main goal of the game is that a new technology is communicated via the game. The balance between showing the application and the inner workings has to be carefully thought of. Too much showing the inner workings of blockchain would not serve the purpose of understanding the applications of the new technology on a more meta level. In this particular example, the possibility to record in a trustworthy and immutable manner all the transactions between participants explains actually how the price calculations and settlements between participants can be done securely and fair for all. Second, the game has first to be played without the novel technology to show the status quo and only then starting the game over from the initial situation – but now with the technology "enabled". This shows clearly to the stakeholders the difference in the outcomes with and without the technology. Finally, all the "commercial" information is communicated to a "blockchain" and this is used to enable visual feedback for the players and control against cheating. This last aspect is less generalizable, but the idea for the generic architecture is that visual tools should be used to show the impact of the technology and also give hints about how it works and how it is applied in the context.

6 First Results and Next Steps

After the first test run of the game, feedback was collected for improving the game and the guidelines for serious game creation. The game showed to be able to start up conversation and thought about the new technology and how it can be applied in society. Understanding and awareness of the application of blockchain in distributed energy systems were both increased. The players could clearly see how solar panel owners in the current situation are not incentivized to invest in more solar capacity because of the low profits realized by selling their solar power. When DLT was enabled, the community of households could exchange energy internally. This showed that DLT can act as a catalyst for the energy transition by incentivizing DER investments. For the next steps in developing the game, a second technology, that is, energy storage should be included not a as mere investment, but as an enabling technology (like blockchain in the first experiment). Efficient and long lasting electric power storage at its current prices ($400 per installed kWh) is considered not attractive economically to invest in, even in a community setting. However, the costs per installed kWh storage are expected [14] to drop significantly in the coming years – especially due to economies of scale, which is also simulated in the game. Positive practical examples are seen in Texas [15], where storage is now continuously installed to balance the intermittency of the fast-growing local wind power generation, and in Australia, where recently Tesla exceeded expectations with a large-scale storage project [16]. This opens the expansion of the generic architecture of this kind of games to not only one technology in a game setting, but to two or more technologies that enable the investments or even catalyze the use and expansion of each other in a cascading effect.

7 Conclusions

The game sessions played strongly support the assertion that beside the well-known results, a serious game can also be used to increase the understanding and awareness of new infrastructure system stakeholders about new technologies, such as blockchain. This is an interesting finding, even more stringent today, as companies need to keep up with new ideas, innovations, and technologies that appear and evolve at an increasing pace – like for example, the Physical Internet [17]. The main message of this paper is that a new game can be built easier based on the generic architecture proposed and expanded to increase understanding to enable discovery of new applications of technologies or how they can be applied in certain industries. The paper has shown through the example of the two distributed energy system games that it is possible to develop a generic game architecture. The two successive development of novel games, on top of the same generic architecture, helped to further this architecture into a new dimension, that is, the technological one.

References

1. Johansen, S.K.: A comprehensive literature review on the Blockchain as a technological enabler for innovation. Technical report preprint, Mannheim University (2018)
2. Mills, D.C., Wang, K., Malone, B., et al.: Distributed ledger technology in payments, clearing, and settlement (2016). https://www.federalreserve.gov/econresdata/feds/2016/files/2016095pap.pdf
3. Pilkington, M.: Blockchain technology: principles and applications, Chapter 11. In: Research Handbook on Digital Transformations, p. 225 (2016)
4. Pinna, A., Ruttenberg, W.: Distributed ledger technologies in securities posttrading revolution or evolution? (2016). https://www.ecb.europa.eu/pub/pdf/scpops/ecbop172.en.pdf
5. Brousmiche, K.-L., Heno, T., Poulain, C., Dalmieres, A., Hamida, E.B.: Digitizing, securing and sharing vehicles life-cycle over a consortium Blockchain: lessons learned. In: IFIP NTMS Blockchain and Smart Contracts Workshop (2018)

6. Koulu, R.: Blockchains and online dispute resolution: smart contracts as an alternative to enforcement. SCRIPTed: J. Law Technol. Soc. **13**, 40–69 (2016)
7. Veeningen, J.W., Szirbik, N.B., Blokhuis, M.P.: A generic architecture for quickly-deployable, flexible, scenario-oriented serious games. In: Lödding, H., Riedel, R., Thoben, K.-D., von Cieminski, G., Kiritsis, D. (eds.) APMS 2017. IAICT, vol. 514, pp. 287–294. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-66926-7_33
8. Huitema, G., Szirbik, N., Wortmann, H., Ittoo, A., Dzousa, A.: Embedding flexibility in combined gas and electricity infrastructures. In 4th Research Day EDGaR (2012)
9. Wenzler, I.: Is your simulation game blue or green. In: de Caluwé, L., Hofstede, G., Peters, V.: Why Do Games Work: In Search for the Active Substance. Kluwer, Alphen aan den Rijn (2008)
10. Mengelkamp, E., Gärttner, J., Rock, K., Kessler, S., Orsini, L., Weinhardt, C.: Designing microgrid energy markets: a case study: the Brooklyn microgrid. Appl. Energy **210**, 870–880 (2018)
11. Johnson, L.P., Isam, A., Gogerty, N., Zitoli, J.: Connecting the Blockchain to the sun to save the planet (2015)
12. Gogerty, N., Zitoli, J.: DeKo: an electricity-backed currency proposal (2011)
13. Pilot project: Jouliette at De Ceuvel, Amsterdam (2018). https://jouliette.net/blockchain.html
14. International Renewable Energy Agency: Electricity Storage and Renewables: Costs and Markets to 2030 (2017)
15. https://www.bloomberg.com/news/articles/2017-12-07/u-s-energy-storage-surges-46-led-by-big-project-in-windy-texas (2017)
16. https://www.nytimes.com/2017/11/30/world/australia/elon-musk-south-australia-battery.html (2017)
17. Sternberg, H., Norrman, A.: The physical internet – review, analysis and future research agenda. Int. J. Phys. Distrib. Logist. Manag. **47**(8), 736–762 (2017)

University Education as a Networked Service for Competence Co-creation

Riitta Smeds[1(✉)], Rita Lavikka[2], and Miia Jaatinen[1]

[1] School of Science, Aalto University, Helsinki, Finland
{riitta.smeds,miia.jaatinen}@aalto.fi
[2] School of Engineering, Aalto University, Helsinki, Finland
rita.lavikka@aalto.fi

Abstract. Our societies need game changers that have the competencies to develop emerging business ecosystems based on digital data. We claim that these competencies can be taught through a networked education service process between students, companies of the emerging ecosystem, and university teachers. We present a case study of two university courses in Industrial Management that deal with networked business process development and management, and co-development intervention methods. Both courses include student assignments on an emerging ecosystem case. The assignments were integrated into the studying process through co-creative workshops with the case representatives. According to the results, all actors in the networked education process received value. First of all, the students accumulated competencies and expertise in developing business ecosystems. Facilitated by the students, the company representatives co-created in the workshops a shared understanding of their collaborative service process and service model, which triggered real-life innovations. The teachers realized their new roles and tasks as the "process owners" of the education service. - The results support the networked service approach in university education for competence co-creation. More experimental case and action research applying this approach is clearly worthwhile in all disciplines where students need to co-create competences in interaction with external actors that represent the field in practice.

Keywords: Ecosystem · Competence · Education · Service · Co-creation

1 Introduction

Our societies are currently transforming, with digitalisation as a key driving force. Through collecting, sharing, and exploiting data, companies, as well as public sector and third sector bodies, can cooperate efficiently in novel ecosystems with each other and the end users of the new products and services they provide – nationally and more and more also globally. Digital data opens up enormous possibilities for new business, but organisations lack the necessary collaboration competencies for turning the possibilities into value-adding business model innovations. Universities are in a central role in the national and global innovation systems. How can they answer to the request for new competencies to develop and manage emerging business ecosystems?

I. Moon et al. (Eds.): APMS 2018, IFIP AICT 535, pp. 557–565, 2018.
https://doi.org/10.1007/978-3-319-99704-9_68

In this paper, we show how universities can educate game changers that have the capabilities needed to develop business ecosystems. We claim that the competencies are taught through a networked education service process between students, companies of the emerging ecosystem, and university teachers. We present a case study of two university courses in Industrial Management that collaborated with an emerging company ecosystem. Following the service-dominant logic [1], we analyze how this education service created value to all its actors: the students, the business ecosystem, and the university teachers.

2 Theoretical Background

2.1 Education as a Networked Service

Following the service-dominant logic [1], education can be conceptualised as a service process, where the students as "consumers" and the teachers as "producers" co-create in interaction the core value of the service, i.e., learning [1, 2]. If external actors, such as company representatives, participate in the process, we can speak of a *networked education service* (Fig. 1).

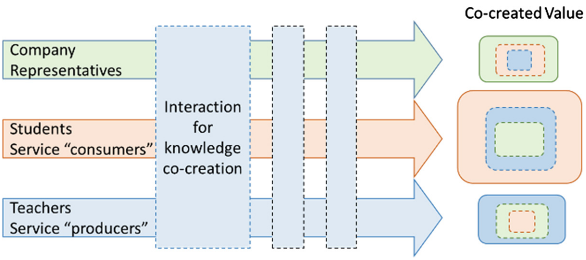


Fig. 1. A course as a networked, interactive service process.

In networked education service, the teachers are the process owners, but the students are responsible for their own learning. The teachers integrate into the students' studying processes the external actors' operant resources, to enhance the students' learning. In the interaction between the students, the company representatives, and the teachers, an innovative knowledge community emerges where all actors co-create knowledge [3, 4]. The students as participants gain *new knowledge and expertise;* the company representatives gain *shared understanding* about their collaborative operations and business, which can even lead to *innovations* in real-life. Moreover, the teachers gain ideas for improving the *networked education service process*, as well as for empirical *research*.

Our case study explores the interaction of teachers, students, and company representatives in two university courses. How was company interaction integrated into the studying process of the students in these courses? What value did the students co-create for their learning? Did they develop expertise? Moreover, what value did the companies and the teachers receive from the networked education service process?

2.2 Process and Business Model Innovations in Ecosystems

Innovation can be defined as an idea or invention that is implemented and creates added value [5]. A central principle of successful implementation is the participation of the users in innovation. It has two roots: one is the law of requisite variety, the other is the principle of empowerment. According to the law of requisite variety [6], to achieve its goal against a set of disturbances, the system's degree of internal specialisation must be at least as high as the environment's variety. Applying this law to innovation, the team should possess enough variety of knowledge to cover the complexity of the problem [7]. Thus, for process innovation, the employees who have the operational process knowledge should participate in innovation to ensure the quality of the innovation.

The principle of empowerment is key to implementation and thus for the final success of the innovation [8, 9]. The employees are the key actors in realising the developed process ideas into practice, i.e., in implementation. Employees that participate in innovation develop a shared understanding, commitment, and "ownership" of the change. Therefore, they further the implementation instead of resisting it.

In emerging ecosystems in the era of digitalisation, business model innovations are based on the business potential of data sharing and inter-organisational value co-creation. Thus, based on the law of requisite variety and the principle of empowerment, these innovations cannot be developed by one company. The new processes and business models have to be innovated in collaboration with all potential ecosystem actors that share the joint objective for value creation. The participants in innovation have to represent both the operational process knowledge and strategic business knowledge, as well as knowledge about the companies' ICT systems and new digital technologies.

Empirical evidence of real-life experiments for business model innovation in companies is scarce [10]. In company networks, learning quickly from business model failures and successes are hardly possible. Therefore, experiments for innovation should be arranged in a "laboratory setting," as a series of participative knowledge co-creation workshops with all relevant ecosystem actors [11, 12]. In workshops, neutral facilitators should apply experimental co-creation methods such as process simulation, gaming, and value network co-creation methods [12]. The successive workshops can provide a temporary governance structure for the implementation of joint business model innovations in real-life ecosystems [11, 12].

Specific new competence for business innovation in emerging ecosystems is the *facilitation of inter-organisational co-creation of business processes and business models*. The two university courses that we analyse include assignments that have been developed to answer precisely to this request. They allow the students to develop and apply facilitation skills for inter-organisational business co-creation in a laboratory setting. The courses as a whole teach the development of emerging inter-organisational business, focusing on business processes and business models, coordination, and knowledge co-creation, as well as co-development methods and management of developmental intervention projects.

3 Case: Two Courses in Networked Business Innovation

Our study concerns two Master level courses at Aalto University, Industrial Engineering and Management: "Management of networked business processes" (the autumn course), and "Co-development interventions in business networks" (the spring course). Following the idea of education as a networked service, the courses were designed to include student assignments with companies forming a business network. The selected company network consisted of a service business company and its two partners with whom it had realised its first business case. This business case was used as a pilot case in the student assignments on both courses. The assignments were integrated into the teaching and studying processes of the courses for the first time in the study year 2017–18, with 33 students in the autumn, and nine students in the spring.

The unit of analysis in this case study is the education service process in the two courses. Our research design combines a case study approach [13] with participatory action research since the authors acted as teachers in the courses [14].

Our data consists of (1) Documents of the education service process: the teachers' notes from planning meetings with the company, e-mails with the company representatives, and two collaboration contracts; (2) Teaching material of the two courses, student assignment presentations, and reports; (3) Video recordings and photos from workshops; (4) Ex-post interviews with four representatives of the pilot network companies (April 2018); (5) Open student feedback from the two courses. The data in 1, 2 and 3 was used to describe the collaborative teaching process. The feedback data in 4 and 5 was used to evaluate the co-created value of the education.

4 Findings

4.1 Description of the Networked Education Process

In spring 2017, based on former research contacts, the pioneers from the company contacted the teachers, seeking for collaboration potential. This led to negotiations about collaboration in student assignments of the two courses. The objectives and schedule of the assignments were planned together. Agreements on the study projects, separately for the two courses, were signed between the University, the company, and the students. For the company, the confidentiality of business-critical information was crucial.

In the assignments, the tasks of the student teams were to plan, facilitate and analyze the co-creation of the company and its network partners in workshops, two in the autumn and three in the spring. In the autumn, the focus of co-creation was on the pilot service process and its challenges, whereas in the spring the students could continue from the autumn results. First, they facilitated the co-creation of solutions to the process challenges, thereafter they continued with the networked service concept, and finally with the emerging service ecosystem (Table 1).

Table 1. Description of the co-creation workshops

Workshop	Goal	Participants	Methods	Activities	End-result
I 20.10. 2017 3 h	Model the service process	26 students; 11 from the pilot network; 3 teachers	Process interview; Process modelling	Student teams interviewed the pilot companies on their joint service process	A draft of an inter-organisational process model
II 1.12. 2017 2 h	Develop the service process	18 students; 7 from pilot network; 3 teachers	Facilitated process discussion with visual process models	Students facilitated the discussion on the modeled process. The pilot companies co-created further process ideas	A refined process model. Process ideas and challenges
III 9.3. 2018 3 h	Create ideas for solving identified process challenges; Create ideas for the service concept	8 students; 5 from pilot network; 3 teachers	Two games as triggers of facilitated discussions. Role play by students in discussions, substituting missing pilot network people	Students prepared the workshop and the games, guided by the teachers. Students facilitated the games and discussions of the pilot network representatives	Service concept ideas put on the related phases of the service process model. Ideas on revenue generation. Ideas of the service ecosystem
IV 16.3. 2018 3 h	Enlarge the service concept to ecosystem level	9 students; 6 from pilot network; 1 from larger ecosystem; 3 teachers	Modelling the value network and the ecosystem	Students prepared and facilitated the workshop guided by the teachers. Students visualised the value network and the ecosystem map	Service concept for the ecosystem level. Visualized value network of the future service
V 23.3. 2018 2 h	Developing the service concept	9 students; 4 from pilot network; 3 teachers	Facilitated discussion of the results, using visual models	Students presented the end report of the spring assignments and facilitated the discussion on key findings	Converging of the ideas for the networked service concept

The teachers supported the students via lecturing about theories and methods, guiding the preparation of the workshops, rehearsing with the students the facilitation and co-creation methods, and participating in the workshops as their background support.

The teachers also communicated with the company representatives during the course, to keep up their motivation to participate in the workshops. The representatives of the company and its partners participated actively in all workshops, according to the demanding course schedule. They also prepared some background material for the autumn and a presentation for the last workshop in spring. The company and its partners experienced co-creation in a “course laboratory setting”.

The students received additional operant resources into their studying process via the integrated interaction with the companies in the co-creative workshops: applying the theories and methods taught at the lectures, and guided by the teachers, the teams prepared the workshops, facilitated the workshop discussions, analyzed the results, wrote the reports, and presented and discussed the results again in workshops with the companies. They were “learning by doing” and developing expertise in *facilitating inter-organisational co-creation of business processes and business models*.

4.2 The Value of the Networked Education Service to the Companies

The end report of the students in March 2018 provided the company and its partners important new knowledge that had been co-created in the workshops, concerning the emerging ecosystem’s service model and future development potential. The report included the roles and relationships of the actors; a specified value proposition; clarification of customer needs, service offering and the service delivery channels; a modular service pricing model; and principles of brand management for the service.

We were also interested in the added value to the pilot case network: did the ideas co-created in the educational service process get implemented into innovations [5]?

The preliminary findings from the interviews with four representatives of the companies, conducted in April 2018, give some positive evidence of implementation.

The CEO of the company stated in the interview that the process modelling in autumn 2017 was a turning point in the development of the company and its networked service. After the workshop in December 2017, the company board decided that the company was not yet ripe for the development of a formal strategy. Instead, they developed an operational program for the following year.

According to the CEO, it was crucial that key representatives from all partners participated in the process workshops. “Only then can the core of the service be revealed.” “You do not imagine what the customers and partners think in the service process, but they tell it and bring their knowledge into the co-creative process development in a focused way.” The process modelling and discussion helped the company to understand its role as the integrator of the networked service. It realised that it has to keep the ownership of the networked service process. The co-created process understanding became a central tool for marketing and sales. It helped the company to crystallise and to communicate their service offering. This understanding was instrumental also in formulating the web communication of the company.

The spring assignments on developing the service concept and the broader service ecosystem were beneficial as well. The games helped to create applicable knowledge. One practice developed in the game was implemented in customer relationship management. According to the CEO: “Yes, it started with the game!”- A significant result was the modular pricing model of the service that students created as a result of the fourth co-creative workshop. The company applied the model immediately in its sales process.

According to the CEO, the assignments as a whole gave confidence in the new networked service. The discussions in the workshops "lifted the hidden knowledge of the entrepreneurs into focused use for knowledge co-creation". As an overall result, the company's service concept is now way ahead of its competitors.

The two partners of the company do not report as many concrete results from their participation in the assignments. However, the business development manager of one of them stated that the neutral facilitation of the students was an essential trust-building element: the collaboration in teaching had no vested interests, except learning. Listening to the questions and answers of the other partners in the facilitated process discussions in the workshop strengthened his insights about the potential to productize his company's competencies. In February 2018, the new brand and the new name of the company were published, and according to the interviewee, the ideas from the service process discussion were "triggers and important accelerators of this change".

4.3 The Value of the Networked Educational Service to the Students

Through the case assignments that were integrated into the courses, the students assimilated the practical skills of facilitating networked business co-creation. In the autumn course, they became proficient in collaborative business process modelling, in the spring course in facilitating the co-creation of business models and ecosystems.

The autumn course students evaluated their learning in the assignment positively:

> "The case-based group assignment was one of the things where I learned the most. It was motivating that we were able to give improvement suggestions to real companies, and know that they would possibly actually benefit from it."

> "It was super to learn to make a process model which is a skill that I will need later on as well."

> "It supported my learning well. However, I would use more time to go through how process maps are drawn."

> "In the beginning, it seemed like it is very easy to model the process. We realised that it is not as easy as it seems and this was my biggest learning here."

Some autumn students felt unsure at the beginning of the assignment. According to their feedback, they would have needed more support from the teachers at the very start:

> "I liked the task to develop a business process. However, the interview session was quite challenging because so many non-process-related topics were discussed."

> "Hands-on doing always supports learning. For the interview session I think I'd not let everyone interview, preferably everyone would formulate the questions together, but only some 2–4 students would interview. Or maybe students would be in the audience, learning by watching the teachers do the interview?"

> "It helped to use the (theoretical) topics in a real case. There could be clearer instructions."

The spring course students continued in their assignments from the autumn results, which gave them a smooth start. Their feedback was very positive; one student was even employed by the company right after the course ended. The students appreciated the interaction and knowledge co-creation with the companies for their learning:

> "The subject and contents were great and well thought. The real-life case assignment supported greatly my learning, as well as the hands-on experience of workshop facilitation."

> "This course was refreshing since we got to work with an actual client on an actual case. Writing lecture diaries was more effective than having an exam on theoretical aspects."

> "The practical group work and discussing the articles supported learning; the diaries did not."

> "The final project experience and class discussion were very useful."

> "… It was nice to get feedback from the company people concerning the work done during the course."

4.4 The Value of the Networked Educational Service to the Teachers

The university teachers experienced their new roles as "process owners" of the networked education service, and will manage their courses similarly in the next school year. Their first task is to recruit fruitful case networks for the student assignments. For this, their former research partners and alumni provide an invaluable case "resource pool". When planning and running the courses, the teachers collaborate with the company network and integrate the assignments into the course objectives and timetables, and into the studying processes of the students. To familiarize the students with facilitation of inter-company knowledge co-creation, the teachers facilitate with the students the very first workshop, and support the facilitation in the latter workshops if needed.

The teachers are also active researchers in the field, and the case network that participated in the education process can potentially become an object for future research.

5 Discussion

The case study shows that the two courses created value for all their actors. The students developed expertise as facilitators of inter-organisational process and business model innovation and ecosystem development. The company actors co-created a shared understanding of their service process, service model, and ecosystem, and implemented the ideas into innovations in the business world. The teachers realized their new roles and tasks as the "process owners" of the education service. As researchers, they gained access to a potential research case. - The results give support to university education as networked service for competence co-creation. More experimental case and action research applying this approach is worthwhile in all disciplines where students need to co-create competences in interaction with external actors that represent practice.

References

1. Vargo, S.L., Maglio, P.P., Akaka, M.A.: On value and value co-creation: a service systems and service logic perspective. Eur. Manag. J. **26**, 145–152 (2008)
2. Smeds, R., Huhta, E., Pöyry-Lassila, P.: Using process simulations to co-design future school networks. In: Taisch, M., Cassina, J., and Smeds, R. (eds.) Experimental Learning in Sustainable Management, Economics and Industrial Engineering. Proceedings of 14th Workshop of the Special Interest Group on Experimental Interactive Learning in Industrial Management of the IFIP Working Group 5.7, pp. 196–205. Poliprint - Politecnico di Milano, Milano (2010)
3. Hakkarainen, K., Palonen, T., Paavola, S., Lehtinen, E.: Communities of Networked Expertise: Professional and Educational Perspectives. Elsevier, Amsterdam (2004)
4. Smeds, R., Pöyry-lassila, P.: Co-designing value networks in process simulations. In: Smeds, R. (ed.) Co-designing Serious Games. Proceedings of the Special Interest Group on Experimental Interactive Learning in Industrial Management of the IFIP Working Group 5.7., in Collaboration with the EU Network of Excellence GaLA, pp. 115–136. Aalto University publication serie, Espoo (2011)
5. Urabe, K.: Innovation and the Japanese management system. In: Urabe, K., Child, J., Kagono, T. (eds.) Innovation and Management, pp. 3–25. De Gruyter & Co., Berlin (1988)
6. Ashby, W.R.: Variety, constraint and the law of requisite variety. In: Buckley, W. (ed.) Modern Systems Research for the Behavioral Scientist, pp. 129–136. Aldine Publishing Company, Chicago (1968)
7. Van de Ven, A.H.: Central problems in the management of innovation. Manag. Sci. **32**, 590–607 (1986)
8. Mumford, E.: Participative systems design: structure and method. Syst. Object. Solut. **1**, 5–19 (1981)
9. Nonaka, I., Takeuchi, H.: The Knowledge-creating Company - How Japanese Companies Create the Dynamics of Innovation. Oxford University Press Inc., Oxford (1995)
10. Chesbrough, H.: Business model innovation: opportunities and barriers. Long Range Plan. **43**, 354–363 (2010)
11. Lavikka, R., Hirvensalo, A., Smeds, R., Jaatinen, M.: Transforming a supply chain towards a digital business ecosystem. In: Lödding, H., Riedel, R., Thoben, K.-D., von Cieminski, G., Kiritsis, D. (eds.) APMS 2017. IAICT, vol. 514, pp. 295–301. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-66926-7_34
12. Smeds, R., Suominen, S., Pöyry-Lassila, P.: Co-creating networked educational innovations via process simulations. In: Meijer, S.A., Smeds, R. (eds.) ISAGA 2013. LNCS, vol. 8264, pp. 140–147. Springer, Cham (2014). https://doi.org/10.1007/978-3-319-04954-0_17
13. Yin, R.: Case Study Research: Design and Methods. Sage Publications, Newbury Park (1989)
14. Gummesson, E.: Qualitative Methods in Management Research. Sage Publications, California (2000)

Author Index