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ORIGINAL PAPER

THE IMPACT OF LEAN & GREEN SUPPLY CHAIN PRACTICES ON SUSTAINABILITY: LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

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ABSTRACT. Background: The adoption of lean and green practices, sequentially or simultaneously, in the context of supply chain management has been recommended by researchers and practitioners as strategies to gain a sustainable competitive advantage while reducing negative social and environmental impacts. Hence, there is a growing interest in this topic. This attention is evident through the increased number of publications on lean and green supply chain practices. However, only a few studies have listed and classified these practices according to the different levels of the supply chain. Moreover, there is a restricted number of research papers that have highlighted the specific practices that impact each measurement of sustainable performance. Thus, this research aims to contribute to the literature in the field of supply chain management by presenting, in a simple and structured way, the different lean and green practices that have been studied by previous researchers, focusing on their impact on sustainable performance measurements.

Methods: A rigorous literature review in seven steps was followed, based on the study and analysis of 23 research articles dealing with lean and green practices and their impact on the supply chain's sustainable performance.

Results: The novelty of this research is that it presents, at the same time (i) a review of lean and green practices used in the context of supply chain management, and classified based on their citation frequency and level of use (upstream, internal and downstream), (ii) a focus on the practices that have been empirically studied as having an impact on supply chain's sustainable performance, as well as highlighting the indicators that are directly influenced by these practices, and (iii) a development of a conceptual framework, to present in a simplified way the lean and green practices that have an impact on one or more sustainable performance dimensions. The results of the study indicated that regarding the different levels of the supply chain, there is a dominance of practices used internally, with a greater number of lean practices compared to green practices. In addition, the majority of the practices identified have a positive impact on sustainable performance, except for some practices, namely « Cooperation with suppliers », « JIT philosophy », « Total Productive Maintenance », « Small lot-sizing » and « Reverse logistics », that have shown a disagreement between previous studies. It was concluded that the supply chain's environmental performance aspects are the most studied, followed by economic performance, then social performance

Conclusions: Numerous recommendations are provided to help managers and decision-makers in their choices of lean and green strategies according to their sustainability objectives, and to guide academics in their future studies on this field.

Key words: Lean Practices, Green Practices, Supply Chain Management, sustainable performance, Conceptual Framework

INTRODUCTION

In a period of global environmental degradation, resource depletion, and climate change, sustainable practices evolved as a strategy for maintaining balance within enterprises' three pillars of sustainable performance, by addressing stakeholders' requirements while maintaining market competitiveness. In this setting, lean and green paradigms have emerged as critical solutions for sustainability. These approaches, implemented together, may increase corporate and supply chain performance while generating social, economic, and environmental benefits. With the lean paradigm, waste is seen as being reduced, and thus costs as well, quality and productivity improved, and better utilization of resources

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ensured so that consumers receive more value. By reducing waste at every stage along the product lifecycle, including manufacturing, process, and supply chain management, lean has the potential to enhance sustainable performance [Abualfaraa et al. 2020, Cherrafi et al. 2019, King & Lenox 2001]. On the other hand, green paradigm aims to eliminate environmental effects while increasing ecological efficiency. Companies may be able to cut their expenses in the long run by maximizing the use of resources and minimizing waste [Cherrafi et al. 2019, Farias et al. 2019, Kovilage 2020, Singh et al. 2020].

In the context of supply chain management, combining lean and green paradigms in one integrated approach has gained popularity among scholars and practitioners, for instance, Abualfaraa et al. [2020] carried out a systematic literature review and identified similarities, differences and the main success factors to integrate lean and green to achieve sustainability. Cherrafi et al. [2019] proposed a model for integrating lean and green through the use of Gemba-Kaizen approach to improving firms resources consumption and environmental performance. Farias et al. [2019] developed a framework to assess the performance, practices and relationships between green and lean paradigms. Leong et al. [2019] conducted a literature review that presented the application, benefits and synergies of lean and green paradigms in the manufacturing industry. Notwithstanding, these growing research efforts toward lean and green subsequent or simultaneous implementation and their link with sustainability, only a limited number of studies have addressed the integration of the two strategies in the supply chain and their influence on different dimensions of sustainable performance [Galeazzo et al. 2013, Huo et al. 2019, Rodrigues et al. 2020, Sharma et al. 2021]. Thus, there are several research gaps that require further investigation; empirical results vary from negative to positive outcomes, leading to ambiguous and contradictory conclusions. Moreover, many studies have dealt with the supply chain as an integrated concept, failing to investigate whether green and lean practices in each component of the supply chain, i.e., upstream, internal, and downstream levels, would have a different impact on sustainable performance aspects. [Abualfaraa et al. 2020, Campos & Vazquez-Brust 2016, Dües et al. 2013, Engin et al. 2019, Farias et al. 2019, Galeazzo et al. 2013, Garza-Reyes 2015, Huo et al. 2019, Rodrigues et al. 2020]. Therefore, this paper aims to review the extant literature, identify and classify the most important lean and green practices within the upstream, internal and downstream levels of the supply chain, also clarify the relationships between lean and green practices and the three dimensions of sustainable performance from a supply chain perspective, highlighting the performance measurements that are most impacted by these practices. This study proposes, as well, a conceptual framework linking lean and green practices to sustainable performance three dimensions. This paper is prepared as follows: Section 2 presents a literature review. Section 3 illustrates the followed research methodology. The findings and discussion are presented in section 4. Finally, Section 5 presents the summarized conclusion and future research directions.

LITERATURE REVIEW

Lean and Green Supply Chain Management

Lean management is a cost-cutting and flexibility-based strategy that focuses on process improvements by reducing or eliminating unnecessary operations and wastes. Whereas the green approach has arisen as an organizational concept based on decreasing the environmental impact of operations while boosting resource efficiency [Azevedo et al. 2012]. Several authors claim that the adoption of the lean system has well demonstrated a better use of resources when successfully implemented, thus, improving operational performance [Farias et al. 2019, Galeazzo et al. 2013], while the implementation of green practices may help to enhance the efficient use of resources, thus improving environmental performance [Dües et al. 2013, Galeazzo et al. 2013, Kovilage 2020].

In the context of supply chain management, regardless of the fact that their drivers, tools, and practices diverge, these two paradigms serve together to improve the different dimensions of supply chain management, hence, they are frequently employed as complementary strategies. When it comes to the company's internal level, lean management can be used to increase process performance and product quality and to optimize the flow of different materials, through several tools such as Just-in-time (JIT) or Pull flow, Quality Management Systems (QMS), Total Productive Maintenance (TPM) and Value Stream Mapping (VSM) [Campos & Vazquez-Brust 2016, Carvalho et al. 2010, Engin et al. 2019, Govindan et al. 2013, Sharma et al. 2021, Singh et al. 2020, Wu et al. 2015]. While green paradigm focuses on reducing resource consumption and environmental impacts using a variety of tools including Environmental Management System (EMS), Reduce, Reuse and Recycle (3R) and Green technology [Campos & Vazquez-Brust 2016, Carvalho et al. 2010, Duarte & Cruz-Machado 2019, Engin et al. 2019, Govindan et al. 2013, Hussain et al. 2019]. Regarding the upstream and downstream levels, lean management aims essentially to develop long-term collaborations and partnerships at the operational scale between the company and its suppliers and customers, using many practices, e.g., Geographic concentration from suppliers [Campos & Vazquez-Brust 2016, Carvalho et al. 2017, Engin et al. 2019, Sharma et al. 2019] and Delivery time reduction to customers [Alqudah et al. 2020]. Green supply chain management also supports the improvement of suppliers and customers alliances through transferring and spreading green awareness by means of green practices, e.g., Environmental Management System mandatory for suppliers and Reverse logistics [Alqudah et al. 2020, Azevedo et al. 2011, Campos & Vazquez-Brust 2016, Carvalho et al. 2010].

Lean-Green supply chain management practices and sustainable performance

Through waste reduction and resource efficiency, the synergy between lean and green paradigms has been highlighted, resulting in improved environmental, social and economic performances. Several studies of how green and lean strategies can impact supply chain sustainable performance are provided in the literature. However, there is a number that specifies the influence of each practice on a given economic, social or environmental performance measurement. Sawhney et al. [2007] have proposed a framework called En-Lean, to help companies in developing the relationship between a set oflean practices and their environmental impact. It also takes into account some measures of social performance such as employees' health and safety. Afterwards, this framework was applied to a metal cutting industry in order to highlight the overall environmental and social impacts of lean practices for this specific process. The results indicate that many of the lean principles if properly implemented, have a positive impact on the environmental and social indicators; « mistake-proofing » and « employee involvement and empowerment » are considered as best lean practices that represent an opportunity for improving environmental and social parameters. However, the case study shows that there is a conflict between lean production and environmental performance. Furthermore, it should be borne in mind that the framework developed in this paper and its results only concern a particular production process. Based on a literature review, Carvalho et al. [2010] have developed a conceptual model linking the different lean and green practices with the economic, environmental and operational performance measures of the supply chain, while highlighting the nature of the impact that each practice has on each performance measure. It has been found that lean practices taken into account in the model contribute poorly to the environmental performance of the supply chain, only the relationships with suppliers contribute to the reduction of the company's waste. When it comes to green practices, they have a minimal effect on the operational and economic performance of the supply chain. This study has great importance to discover the impact of each practice on supply chain performance. However, the conceptual model was developed based only on empirical data available in the literature, without any validation. After having collected a very significant number of green practices and classifying them into upstream, focal company and downstream categories, Azevedo et al. [2011] have developed a theoretical framework to understand the influence of these practices on the economic, environmental and operational performances of the supply chain. Then, they have conducted five case studies from the Portuguese automotive supply chain, in order to empirically test the influence of green practices on the supply chain performance. They have concluded that automotive companies implement green practices to manage their supply chains, as they consider the implementation of these practices to be essential to achieve the highest levels of environmental performance, especially when it comes to cooperation with suppliers. These companies consider some measures to be more appropriate than others for properly assessing the impact of these practices on the supply chain performance; the most important one is « environmental cost », however, it is the least used measure by companies. They also consider that specific green practices have a greater potential influence on some performance measures, such as « waste minimization », « reverse logistics », « environmental collaboration with customers » and « environmentally friendly packaging ». Azevedo et al. [2012] have proposed a theoretical framework aiming to analyse the influence of upstream lean and green supply chain management practices on companies' sustainable performance. They have then carried out a case study at a Portuguese car manufacturer in order to test the validity of this framework. As a result, it has been highlighted that the implementation of lean upstream supply chain practices, such as « just-in-sequence », « deliveries directly to the point of use » and « geographical concentration », enables the improvement of the economic, social and environmental performance. Regarding the green upstream supply chain practices, their implementation has a positive impact on social and environmental performances. However, it has a minor impact on economic performance, especially when it comes to some practices like « mandate for a first-tier supplier to have environmental management systems », « monitoring suppliers' environmental performance » and « using green purchasing guidelines and sourcing from environmentally responsible sources ». This study has contributed to the identification of lean and green practices that impact the three dimensions of sustainability, but it has only focused on the upstream supply chain level. In addition, the results could not be generalized since only one company in the automotive industry was studied. Govindan et al. [2013] have used the interpretive structural modelling approach to identify the inter-relationships among lean, green and resilient practices and different elements of the Portuguese automotive supply chain performance, namely: operational cost, business wastage, environmental cost and customer satisfaction. They have concluded that the most important practices that the top management should focus on to manage the automotive supply chain are « just-in-time », « flexible transportation » and « environmentally friendly packaging », which together contribute to the improvement of « total quality management », « strategic stock », « ISO 14001 », « operational cost », « business wastage » and « environmental cost ». Then, all of these practices and performance enhancement lead finally to « customer satisfaction ». Hence, this study has recommended the lean, green and resilient practices, that make the automotive industry ready to meet customers' requirements, providing eco-products with short lead times and high-quality levels, thus achieving the economic and environmental objectives. Nonetheless, social performance has not been taken into account by this study. Martínez-jurado & Moyano-fuentes [2013] have reviewed the existing literature related to the relationships between lean management, supply chain management and sustainability. After having analysed 58 articles, they have highlighted that the impact of lean practices on environmental performance is inconclusive since both positive and negative relationships were reported from the literature, especially when it comes to « JIT » practice, which is undergoing a great debate as to its impact on « environmental pollution ». Furthermore, many studies have stated that the use of lean practices is important in promoting and facilitating the adoption of green practices, thus enabling to reinforce the effect of lean practices on environmental performance. Cherrafi et al. [2018] have proposed a conceptual model linking lean, green and process innovation practices with green supply chain performance. They have then conducted a questionnaire survey of 374 industrial companies from 13 different countries all over the world and used the SEM method to analyse the data collected with the aim of understanding the impact of the practices studied on selected green performance measures, such as « economic efficiency », « cost », « value creation » and « sustainability ». The results of this research have highlighted the best practices that manufacturing companies can use to improve the green performance of their supply chains. Regarding lean practices, the best ones to implement are « JIT », « set up time reduction », « cellular manufacturing » and « waste elimination ». For green practices, the best ones to be employed include « eco-design », « life cycle assessment », « green manufacturing », « reverse logistics », and « waste management ». Nevertheless, it has been argued that process innovation practices do not have a direct impact on the improvement of green supply chain performance. They do however reinforce the effect achieved by lean and green practices. Zhan et al. [2018] have developed a research model in order to examine how business and environmental performances of Chinese organizations are affected by lean and green practices, and also to analyse the moderation role of « guanxi » in this relationship, which is a Chinese concept based on strong networks with the organization' business partners. Through the application of structural equation modelling on 172 questionnaires' responses, it has been concluded that the adoption of lean and green practices is beneficial to improve the supply chain business and environmental performances. Some of the indicators improved by these strategies include « reduction of air emissions », « reduction of wastewater », « decreased consumption of hazardous/harmful/toxic materials » and « sales improvement ». In addition, it has been found that the use of guanxi initiatives is very essential as a preliminary step, which precedes the adoption of lean and green practices, in order to achieve positive results in terms of business and environmental performances. Despite the contribution of this study concerning the existence of a positive effect of lean and green practices on performance, it remains limited as it deals with this relationship in a general way, not specifying which practices are at the origin of this effect. Farias et al. [2019] have conducted a systematic literature review of 65 articles in the field of lean and green, then they have developed a conceptual framework that includes lean and green practices for assessing operational and environmental performances. The framework also illustrates how the practices and performance measures can be combined for performance assessment purposes and how lean and green practices can be used in a synergic way to improve each of the performance measures. For example, « energy consumption » can be reduced using lean practices such as « value stream mapping », « setup time reduction », « 5S », « kaizen », « total productive maintenance », « cellular manufacturing », « JIT » and « standardized work », as well as green practices such as « environmental management system », « design for environment », « environmental emission control » and « 3R ». The strength of this assessment framework is that it is considered to be an integrated system, as it treats lean and green practices as having the same objectives in terms of improving specific performance measures, whereas it only assesses the operational and environmental dimensions of performance, without taking into account economic and social aspects.

RESEARCH METHODOLOGY

For the purpose of expanding the scope of knowledge in the field, an in-depth literature review was carried out. As initially stated, the main objective of this research is to clarify the relationships between lean and green practices and the three dimensions of sustainable performance. Thus, the examination of the literature on lean and green practices implemented in the context of supply chain management and their link with sustainable performance has been done using different databases. Numerous journal papers, conference proceedings have been chosen. We have started with the extraction of lean and green practices used in the context of supply chain management, then we have classified them into three categories: upstream, internal and downstream practices. Afterwards, in order to identify the impact of lean and green practices on supply chain sustainable performance, we have been most interested in the studies that have specified the practices that directly influence each measurement of the economic, social and environmental aspects. The steps below were followed:

1. **Research purpose:** Identify and classify the most important lean and green practices within the upstream, internal and downstream levels of the supply chain, and

clarify the impact of these practices on the three pillars of sustainable performance (economic, social and environmental).

2. **Keywords used:** Lean, Green, Supply chain management, Sustainable performance, Sustainability, Environmental performance, Social performance, Economic performance
3. **Inclusion criteria:** Qualified international scientific publications (journal papers and conference proceedings), in English, on the adoption of lean and green supply chain management practices in an integrated way and analysing the impact on one or several aspects of sustainable performance.
4. **Exclusion Criteria:** Books, reports, essays and theses were all excluded.
5. **Literature Searches:** Research on electronic databases: Scopus, Emerald, Science Direct (Elsevier), Web of Science and IEEE Xplore. We have also done complementary research on Google Scholar.
6. **Data extraction:** 23 papers were selected to be examined
7. **Synthesis and added value:** The creation of two synthetic tables. The first identifies and classifies the lean and green practices used at different levels of the supply chain management, according to their frequency of citation in the literature. The second focuses only on studies that have clarified the impact of these practices on each of sustainable performance measurements, allowing us to develop a conceptual framework to better perceive these relationships.

RESULTS AND DISCUSSION

Classification of lean and green practices used in the SC context

Table 1 outlines the main lean and green practices that are used jointly in the supply chain management, grouped according to the three levels of the supply chain: upstream, internal and downstream. Within each of these categories, we have three types of practices: lean practices, green practices, and L&G practices that belong to both the lean and green approaches. Upstream practices are used to manage and improve the relationships between a corporation and its suppliers. A number of 8 upstream practices was gathered from the literature. Based on the frequency of citation, « Geographic concentration from suppliers » is the most identified lean practice in previous research and « Environmental Management System (EMS) mandatory for suppliers » has been found as the most important green practice. Moreover, only one practice « Cooperation with suppliers » has been found as shared between lean and green approaches at the upstream level. Afterwards, internal practices are used within the company in order to improve its operational processes and efficiency. These are the practices that exist the most in the literature. According to the papers reviewed, 27 internal practices were found, 20 of them belong to the lean paradigm headed by « Just-in-Time (JIT)/ Pull philosophy », while 6 other practices are part of the green paradigm with « Life cycle assessment (LCA) » as the most significant one. « Waste minimization » is the only internal practice shared between lean and green. The final category includes downstream practices, which are used by the company in order to develop and maintain long term and fruitful relationships with its customers. « Distribution network configuration » is the only lean practice found at this level, « Reverse logistics » is the most weighted one as a green practice, and « Cooperation with customers » is the only lean-green practice found as well. On a final note, while classifying the different practices, we have found that « Information spreading through the network » is a common practice that can be part of all categories (Upstream, Internal and Downstream). This practice has a significant weight in the literature, and it is considered very important to manage all the levels of the supply chain. In conclusion, the literature on supply chain management focuses more on the internal practices with a strong emphasis on the lean paradigm, followed by the upstream practices, then the downstream practices that are not sufficiently addressed by the previous papers.

Table 1. Classification of lean and green practices used in the supply chain

Category	Type	Practices	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Fequency
Upstream	Lean	Geographic concentration from suppliers				√		√		√				√	√				√							6
		Just-in-Time (JIT) delivery				√		√		√				√					√							5
		Reducing number of suppliers						√		√				√	√											4
	Green	Environmental Management System (EMS) mandatory for suppliers						√			√	√		√	√			√						√		7
		Green purchasing		√		√			√					√	√									√		6
		Green/less packages from suppliers						√		√					√				√							4
		Environmental risk sharing with suppliers						√															√			2
	L&G	Cooperation with suppliers	√			√		√			√	√		√	√		√	√			√		√	√		8
Internal	Lean	Just-in-Time (JIT)/ Pull philosophy	√	√	√	√	√	√				√		√	√	√		√	√		√	√		√		15
		Inventory minimization		√	√	√		√	√				√	√		√	√								√	10
		Human Resources Management (HRM)				√		√	√		√			√			√			√	√	√			√	10
		Quality Management Systems (QMS)	√			√		√	√			√		√		√		√				√				9
		Total Productive Maintenance (TPM)	√			√		√	√					√						√	√	√				8
		Shorter lead times		√	√	√		√						√	√	√										7
		Kaizen/ Continuous Improvement						√	√		√									√		√			√	6
		Value stream mapping (VSM)		√			√	√			√									√						5
		Set-up time reduction			√	√		√						√				√								5
		Cellular manufacturing			√	√								√							√	√				5
		Total time reduction				√		√						√				√				√				5
		5S				√		√			√									√						4
		Kanban				√		√														√		√		4
		Quick changeover				√								√							√	√				4
		Small lot sizing				√								√							√	√				4
		Work standardization							√		√			√						√						4
		Sustainable VSM (SVSM)		√		√		√																		3
		Poka-yoke/ Mistake proofing				√															√					2
		Six sigma				√		√																		2
		Innovation management	√																							1
	Green	Life cycle assessment (LCA)		√	√	√		√	√			√	√	√		√	√		√					√		12
		Reduce, Reuse and Recycle (3R)				√		√			√	√		√	√	√		√	√			√				10
		Environmental Management System (EMS)				√		√	√		√	√		√		√		√	√					√		10
		Cleaner production				√		√				√		√				√		√		√		√		8
		Green technology				√		√	√					√												4
		Efficiency of resource consumption		√		√		√			√			√												3
	L&G	Waste minimization		√	√	√		√	√		√			√	√	√	√	√		√		√		√	√	15
Downstream	Lean	Distribution network configuration				√																				1
	Green	Reverse logistics		√	√	√		√						√									√	√		7
		Environmental risk sharing with customers						√															√			2
	L&G	Cooperation with customers	√			√		√			√	√		√	√					√		√	√	√		8
Common	Lean	Information spreading through the network		√	√	√		√		√	√		√	√	√		√						√			11

References 1-Singh et al. (2020); 2-Dües et al.(2013); 3-Cherrafi et al. (2018); 4-Engin et al. (2019); 5-Martínez-Jurado and Moyano-Fuentes (2013); 6-Campos and Vazquez-Brust (2016); 7-Hussain et al. (2019); 8-Sharma et al. (2019); 9-Duarte and Cruz-Machado (2019); 10-Zhu and Sarkis (2004); 11-Kainuma and Tawara (2006); 12-Carvalho et al. (2010); 13-Azevedo et al. (2012); 14-Govindan et al.(2013); 15-Duarte and Cruz-Machado (2014); 16-Hajmohammad et al. (2013); 17-Carvalho et al. (2017); 18-Verrier et al. (2016); 19-Sawhney et al. (2007); 20-Wu et al. (2015); 21-Espadinha-Cruz et al. (2011); 22-Azevedo et al. (2011); 23-Zhan et al. (2018)

Impact of lean & green practices on sustainable performance

Relationships between lean and green practices and sustainable performance of the supply chain are shown in Table 2, linking each practice to the performance measurement it is able to influence. These results are very useful to identify the performance measurements that are more sensitive to various lean and green practices, in the context of supply chain management.

In fact, the majority of the practices presented in this table impact positively the different performance measurements, hence, we will focus more on those that disagree with performance results. Starting with the upstream practices, « Cooperation with suppliers » is one of the most important practices to be used to manage supply chains, however, according to Sawhney et al. [2007], its impact on LCA and employee's health and safety may be positive or negative depending on materials purchased. When it comes to internal practices, the adoption of « JIT philosophy » based on a pull system is the most influential one. This practice is undergoing a great debate in the literature, especially with regard to environmental aspects. According to the articles reviewed, JIT has a positive impact on green image [Azevedo et al. 2012, Farias et al. 2019], business wastage [Azevedo et al. 2012, Govindan et al. 2013], cost [Azevedo et al. 2012, Carvalho et al. 2010, Govindan et al. 2013], ROA, cash-to-cash cycle and efficiency [Carvalho et al. 2010], as well as employee's health and safety [Sawhney et al. 2007]. However, disagreement is about LCA, which allows the quantification of energy, water and materials usage and environmental releases. Thus, while Sawhney et al. [2007], Farias et al. [2019] and Cherrafi et al. [2018] stated that JIT impacts positively the LCA measurement, Azevedo et al. [2012] and Martínez-jurado & Moyano-fuentes [2013] outlined that this may have a negative impact on supply chain's environmental performance. Along the same lines, « Total Productive Maintenance » is also a vital practice to improve supply chain's performance in terms of green image [Farias et al. 2019], cost, ROA, efficiency [Carvalho et al. 2010] and employee's safety [Sawhney et al. 2007]. Nevertheless, this lean practice can have a negative impact on LCA due to more wastewater, energy use, packaging materials, plastic wraps and paper used during frequent maintenance operations [Sawhney et al. 2007]. Another practice under conflict in the literature is « Small lot-sizing », which causes increased air pollution, more energy use and increased wastages, impacting negatively LCA measurement and employee's health [Sawhney et al. 2007]. Furthermore, « Reverse logistics » is a downstream practice that has several positive impacts on LCA, benefits and LCA measurements [Azevedo et al. 2011] as well as business wastage, however, it may also have negative impacts because it represents an additional environmental cost for the organization [Carvalho et al. 2010]. Finally, we can notice that the supply chain's environmental performance aspects are the most studied by previous research, followed by economic performance, then social performance.

Conceptual framework

In order to simplify the identification of lean and green practices impacting each dimension of sustainable performance, we have developed the conceptual framework (Fig. 1). Thus, from this conceptual framework, we can identify the lean, green and L&G practices that have an impact on:

- Environmental performance alone,
- Economic performance alone,
- Economic and environmental, performances
- Environmental and social performances, and
- Economic, environmental and social performances

Table 2. The impact of lean and green practices on the supply chain's sustainable performance

Category	Type	Practices \ Measurements	Environmental performance				Economic performance				Social performance				
			Environmental costs	Green image	Business wastage	Life cycle assessment (LCA)	Cost	Return on Assets (ROA)	Cash to cash cycle	Efficiency	Corruption risk	Supplier screening	Local suppliers	Employee's health	Employee's safety
Upstream	Lean	Geographic concentration from suppliers		2	2	2	2						2		
		Reducing number of suppliers					2								
	Green	Green purchasing	1	2	1 ; 2	1 ; 3	2				2	2			
		EMS mandatory for suppliers		2	2	2	2					2			
	L&G	Cooperation with suppliers	1		1 ; 5	1 ; 4	1							4	4
Internal	Lean	JIT/ Pull philosophy		2 ; 6	2 ; 3	2 ; 4 ; 6 7 ; 8	1 ; 2 ; 3	1	1	1				4	4
		TPM		6		4 ; 6	1	1		1					4
		QMS			3		3	1		1					
		Set-up time reduction				7	1	1	1						
		Cellular manufacturing				4 ; 6 ; 7								4	4
		Poka-yoke				4								4	4
		Quick changeover				4								4	4
		Small lot sizing				4		1						4	
		VSM		6		6									
		Kaizen		6		6									
		5S		6		6									
		HRM				4									
		Work standardization				6									
	Green	EMS	1	3 ; 6	1 ; 3	6	3								
		Green packaging	1		1 ; 3	1	3			5					
		Reduction of toxic materials	2 ; 5		1	1 ; 5	5								
		3R		2 ; 6	2	6	2								
		Eco-design			5										
	L&G	Waste minimization	1 ; 5		1 ; 3 ; 5	1 ; 5 ; 7	1 ; 3 ; 5			1 ; 5					
Downstream	Green	Reverse logistics	1 ; 9		1	5	5			5					
	L&G	Cooperation with customers	1 ; 5		1 ; 5	1 ; 5	5			1 ; 5					
Common	Lean	Information spreading through the network			2		2								

References 1-Carvalho et al. (2010); 2-Azevedo et al. (2012); 3-Govindan et al. (2013); 4-Sawhney et al. (2007); 5-Azevedo et al. (2011); 6-Farias et al. (2019); 7-Cherrafi et al. (2018); 8-Martínez-Jurado and Moyano-Fuentes (2013)

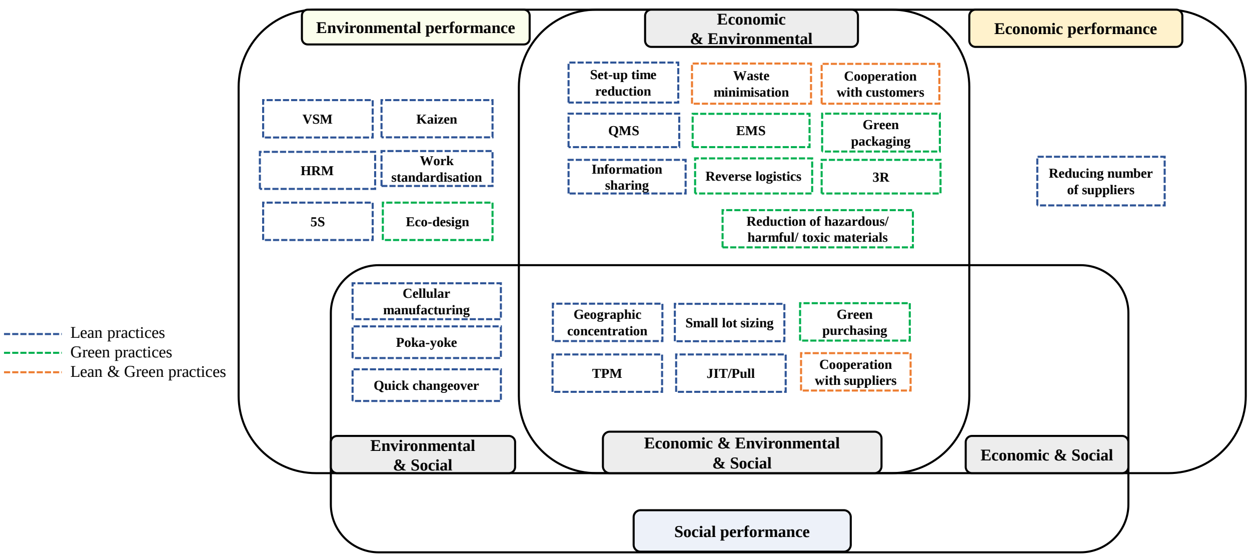

Fig. 1. Conceptual framework of lean & green practices and their impact on sustainable performance

It can be noticed that, based on the papers examined, there are no practices that impact either the social performance alone or the economic and social performances together.

CONCLUSION

Successful integration of lean and green practices within firms supply chain levels requires a complete understanding to determine the set of practices that have the most important contribution to improve each component of sustainable performance. This was the reason behind this research paper, which aims to review the extant literature in the field of lean and green supply chain management.

This research is important and relevant to other scientists in the same field since it identified and classified the most important lean and green practices within the upstream, internal and downstream levels of the supply chain. It also clarified the relationships between lean and green practices and the three dimensions of sustainable performance from a supply chain perspective.

In addition, the conceptual framework developed by this paper is a very important tool, allowing to focus on lean and green practices that have an impact on one or more sustainable performance dimensions. This might be helpful for managers and decision-makers concerned with supply chain management, in several ways. Our results can help companies looking for new solutions to improve their supply chains, by showing the powerful outcomes of combining lean and green practices on sustainability results, especially when it comes to the environmental side. Thus, this paper proposed to these companies the most important lean and green practices, enabling them to meet the requirements of their stakeholders, by enhancing their profitability, while being socially and environmentally responsible. On the other hand, if the company is already using lean and green practices, our results help to make an assessment in order to identify which practices to keep, which to eliminate, and which to add, depending on sustainability objectives. It would also be preferable to be careful with lean and green practices that have shown conflict in the literature. For example, if the company aims to improve economic, environmental and social results at the same time, it would be recommended to focus on the following practices: « Geographic concentration from suppliers » and « Green purchasing », while being vigilant towards the practices « Cooperation with suppliers », « JIT », « Total Productive Maintenance » and « Small lot-sizing », in an effort to take advantage of their positive impacts and avoid any potential negative effects.

However, this study has certain limitations that might be transformed into further possibilities for future research. Particularly, a systematic literature review and an empirical evaluation of lean and green supply chain management practices on a firm's sustainable performance, with a focus on the social aspect which has not yet been sufficiently studied. Therefore, this study will be extended into an empirical investigation in order to identify the most used lean and green practices within the supply chain and their classification according to the degree of importance.

We would also like to point out that the results of this paper are based on previous empirical studies. Nevertheless, there are a very large number of lean and green practices that have not been empirically tested in terms of their impact on sustainable performance. It is for this reason that we recommend that more practices be the subject of future empirical studies, in order to identify other lean and green practices that may be advantageous for sustainability improvement. Also, synergies and trade-offs between lean and green paradigms in the supply chain perspective have not been considered in this research. Therefore, future research might be conducted in this area.

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ORIGINAL PAPER

GREEN CONCEPTS IN THE SUPPLY CHAIN

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ABSTRACT. Background: Reducing negative environmental impacts has become a significant managerial issue. It includes also supply chain participants, e.g., by introducing such concepts as green supplier evaluation or green supplier development.

The goal of this paper is to identify concepts aimed at reducing negative environmental impacts in the supply chain (the "green concepts") and to determine their scope of use.

Methods: The research method used in this paper is the review of the existing literature. The reviewed literature is related to the area of reducing negative environmental impacts in supply chain.

Results: The results concern the classification of green concepts in supply chain and determining their scope of use, including green supply chain management, green purchasing and green supplier development.

Conclusion: The main research implication is providing a basis for further research related to reducing negative environmental impacts in supply chain. It includes also identifying relationships between these concepts and observable trends in the global economy, such as sharing economy and circular economy. The results might also contribute to implementing the green concepts in companies interested in reducing negative environmental impacts in their supply chains. The originality of this work lies in taking into consideration various concepts aimed at reducing negative environmental impacts and discussing them in the context of the supply chain.

Keywords: green supply chain management, green purchasing, green supplier development, green concepts, supply chain management, environmental impacts

INTRODUCTION

Reducing negative environmental impacts is becoming increasingly important in management. This also applies to supply chains. The importance of reducing negative environmental impacts in the supply chain was described, among others, by R. Sroufe [2006, p. 12]. Environmental issues relevant to the supply chain include location and method of extraction of raw materials, energy and material capacity of the business, environmental performance, emission level, mode of transport, mode of packaging, reusability, technologies and methods of production and eco-innovations [Rudnicka, 2011, p. 165].

The goal of this paper is to identify concepts aimed at reducing negative environmental impacts in the supply chain (the "green concepts") and to determine their scope of use.

NEGATIVE ENVIRONMENTAL IMPACTS IN SUPPLY CHAIN

Different areas of the supply chain have different environmental impacts. These include emissions of solid waste, wastewater and atmospheric pollutants. During the extraction of non-renewable natural resources, the landscape degrades, and soil, water and air are polluted. During production, material goods and energy are consumed. Furthermore, packaging and hazardous substances are used. In addition, emissions of solid waste, wastewater, gas, vibration and noise emissions occur. Energy is

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also consumed during transport. On the other hand, one of the effects of using a finished product is the production of waste associated with this product, which can contaminate the soil, water or air. The different types of negative environmental impacts, considering the related areas of the supply chain, are presented in Table1.

Table1. Types of negative environmental impacts

Supply chain area	Types of negative environmental impacts in the supply chain
All	Emissions of solid waste; atmospheric emissions (including CO_2)
Extraction of natural resources	Depletion of non-renewable raw materials; energy consumption; water consumption; landscape degradation; reducing biodiversity; soil, water and air pollution (including chemical pollution); eutrophication; vibrations; noise
Transport and distribution	Leaks; energy consumption; vibrations; noise
Production	Manufacturing and use of dangerous substances; resource consumption; energy consumption; water consumption; waste generation; the use of packaging; heat emissions; wastewater emissions; vibrations; noise; use of chemicals in consumables
Use of the finished product	Excessive consumption; emissions associated with improper use of the finished product; lack of (or improper) management of waste; soil, water and air pollution (including chemical pollution); exposure to dangerous substances; returns of finished products
Stage after the end of use	Pollution of soils, water and air (including chemical pollution) by waste

Source: own study based on: Kalinowski et al., 2019, pp. 144–145; Preuss, 2006, pp. 218–221.

Researchers also identify a significant role for environmental management in the supply chain. C. Y. Wong et al. describe the inclusion of environmental management in the supply chain as a way to build a green supply chain [Wong et al., 2015, pp. 59–60]. M. Urbaniak, on the other hand, points to the essential role of environmental management in building a competitive advantage [Urbaniak, 2018, p. 139]. Furthermore, S. Y. Lee and R. D. Klassen described the essential importance of environmental management in building a green supply chain, and stressed the importance of monitoring and collaborating with suppliers for the development of environmental management capabilities among suppliers [Lee and Klassen, 2008, p. 583].

ENVIRONMENTAL MANAGEMENT IN SUPPLY CHAIN

As defined by R. D. Klassen and C. P. McLaughin, environmental management means, in all efforts, to minimise the negative environmental impact of products throughout their life cycle [Klassen and McLaughlin, 1996, p. 1199].

Environmental management is also influenced by the supply chain actors: suppliers, clients, employees and competition. Suppliers have a negative impact on the environment and their clients decide whether and how they will respond to such impacts: whether they apply environmental criteria for assessment or environmental evaluation of suppliers (green supplier evaluation), or take other actions related to environmental cooperation or collaboration with them [Sosnowski, 2019, pp. 333–334].

The motivation for supply chain actors is provided by their clients and their competitors. For clients, this includes, but is not limited to, environmental requirements for products, services and processes related to their production and provision. In the case of competition, this includes, but is not limited to, competing by meeting the environmental requirements of consumers. In turn, employees of supply chain companies are involved in activities that have an impact on reducing negative environmental impacts [Rudnicka, 2016, p. 70]. The impact of supply chain actors on environmental management is described in Table2

Table2. Impact of supply chain actors on environmental management

Supply chain actors	Impact on environmental management
Suppliers	Generation of pollutant emissions and consumption of material goods and energy affecting product life cycle assessment; impacting environmental risk levels
Clients	Placing environmental requirements on products and services and processes related to their production and provision; participating in the life cycle of the product; deciding on the degree of acceptance of implemented eco-innovation
Employees	Participation in actions affecting the reduction of negative environmental impacts
Competition	Meeting the environmental requirements of your audience, which motivates you to take similar action

Source: own study based on: Rudnicka, 2016, p. 70.

Supply chain actors are an intermediate link between their clients and suppliers. In the context of environmental management, this means, on the one hand, meeting the environmental requirements of its clients and, on the other hand, placing environmental requirements on its suppliers. Employees who work to reduce negative environmental impacts in their company and competitors who meet the environmental expectations of their clients are also important. thus provide an incentive for other market actors to compete in this area.

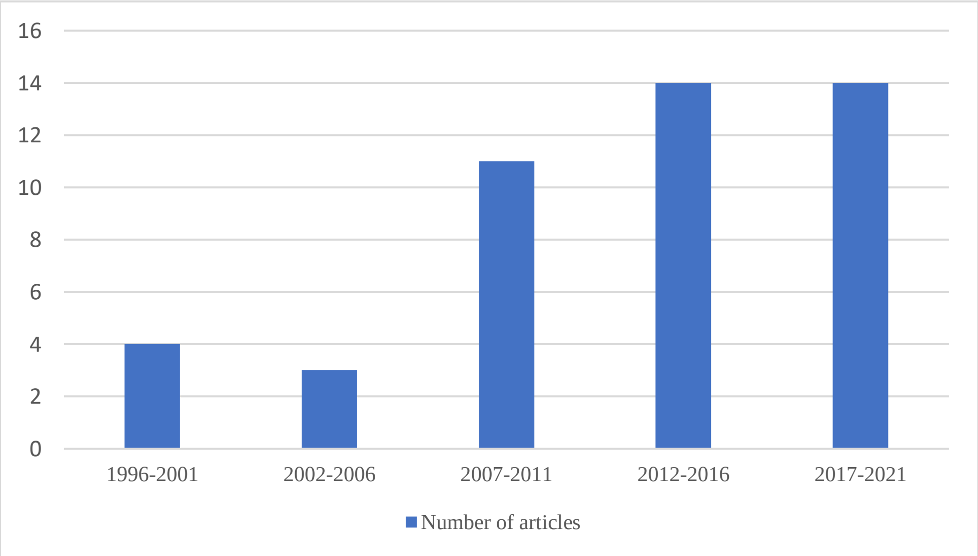

Figure 1. The bibliometric analysis timeline

THE OVERVIEW OF GREEN CONCEPTS IN SUPPLY CHAIN

Green concepts that relate to the supply chain can be distinguished. Some of them relate to elements of supply chain management, such as purchasing process management, supplier relationship management, supplier development or the implementation of environmental innovations in the supply chain [Ocicka, 2014, p. 7276]. These include such concepts as green purchasing [Bai and Sarkis, 2010, p. 1201; Dubey et al., 2013, pp. 188–189], green supplier development [Bai and Sarkis, 2010, p. 1201] and reverse logistics [Rogers and Tibben-Lembke, 2001, p. 130].

The bibliometric analysis timeline is presented in Figure 1.

The literature review was conducted in July and August of 2021. There was no criterion related to the time of publication. Articles taken into account were published between 1996 and 2021. It should be noted that the relative majority of reviewed sources (28 out of 46) were published during the last decade. It points out the increasing significance of the focal topic in management science.

Some green concepts concern the supply chain as a whole. This includes the creation of closed-loop supply chains. Furthermore, a green concept that is particularly important in the context of this dissertation is green supply chain management. It combines environmental management and supply chain management, considering the use of tools such as green supplier evaluation. Other green concepts concern specific elements of supply chain, e.g. green manufacturing [Malek and Desai, 2020, p. 9].

Green concepts in the supply chain can also include concepts related to sustainable development that concern not only environmental issues but also economic and social issues. In this approach, green concepts in the supply chain also include sustainable purchasing, sustainable supplier management, sustainable supplier management and sustainable supply chain management. An overview of green concepts in the supply chain is presented in Table3 It can be observed that the above-presented concepts can provide a link not only with the relevant area of the supply chain but also with sustainable development. This is important because one of the dimensions of sustainability is the environment. In addition, all the above concepts, except for green manufacturing, are directly related to cooperation with suppliers. This demonstrates the indirect link between these concepts and buyer-supplier relationships. It should also be noted that the concepts presented above are not disjointed. Some of them are even treated as elements of other concepts, such as green purchasing, which can be considered both as a separate green concept in the supply chain and as part of the green supply chain management concept.

Other concepts that are more indirectly related to reducing negative environmental impact in supply chain include: sharing economy [Govindan et al., 2020, p. 2], circular business models (circular economy) [Bocken et al., 2019, p. 4].

FINDINGS AND DISCUSSION

There are several green concepts included in the overview. Some of them are related to the concept of sustainability (sustainable supply chain management, sustainable purchasing sustainable supplier development and sustainable supplier management). Hence, these concepts are focused not only on environmental issues but also economic and social issues. In the case of sustainable supply chain management, it includes sustainable aspects of all supply chain actors [Karaosman et al., 2020, pp. 660–661].

Also, three described concepts are related directly both to building relationships in the supply chain (hence, building a supply chain) and reducing negative environmental impacts: green supply chain management, green purchasing and green supplier development.

Table3. Overview of green concepts in supply chain

Concept	Description
Reverse logistics	The process of planning, implementing and controlling the efficient, cost-effective movement of raw materials, stocks, finished products and related information from the place of consumption to the place of origin with a view to recovery or production of value or proper disposal
Closed-loop supply chain management	Design, control and operate the system to maximize value creation throughout the product lifecycle with dynamic value recovery with different types and magnitudes of returns over time
Green supply chain management	Integrating environmental thinking into supply chain management, including product design, sourcing and raw material selection, manufacturing processes, final product delivery to end-users, and post-use product management
Green distribution*	Distribution management including measuring and reducing negative environmental impacts
Green logistics*	Efforts to measure and reduce the negative environmental impact of logistics activities
Green manufacturing*	Production management including measuring and reducing negative environmental impacts
Green purchasing, green procurement, green supply management, environmental purchasing, environmental purchasing and suppliermanagement*	Management of the purchasing process including measuring and reducing negative environmental impact, including the inclusion of environmental criteria in supplier selection and evaluation of suppliers in terms of the results of their environmental activities
Green supplier development*	Supplier development aimed at increasing supplier environmental performance
Sustainable purchasing	Integrating environmental, social, ethical and economic issues into the management of the organisation's external resources in such a way that the supply of all the goods, services, capabilities and knowledge needed to run, maintain and manage the core organisation and support actions provide value not only to the organisation but also to society and the economy
Sustainable supplier development	Supplier-oriented development focused on achieving their environmental and social objectives
Sustainable supplier management	Economic, environmental and socially efficient supplier management
Sustainable supply chain management	Managing the flows of goods, information and capital and working with other actors in the supply chain integrating the three dimensions of sustainable development: economic, environmental and social

* also mentioned as green supply chain management practices

Source: own study based on: Bai and Sarkis, 2010, p. 1201; Dubey et al., 2013, pp. 188–189; Foerstl et al., 2010, p. 118; Guide and Van Wassenhove, 2009, p. 10; Pagell et al., 2010, p. 58; Rogers and Tibben-Lembke, 2001, p. 130; Sancha et al., 2015, p. 95; Seuring, 2013, p. 1514; Sosnowski and Bojanowska, 2018, p. 128; Srivastava, 2007, pp. 54–55; Tate et al., 2012, p. 174; Wilding et al., 2012, p. 489; Zsidisin and Siferd, 2001, p. 69.

GREEN SUPPLY CHAIN MANAGEMENT

The first green supply chain management studies were produced in the last years of the 20th century to characterise environmental management activities in the supply chain [Sarkis, 1998, pp. 162–163]. According to some scholars, e.g. A. Maryniak and S. Laari, green supply chain management combines supply chain management with environmental management [Laari et al., 2017, p. 1304; Maryniak, 2017, p. 13]. In this respect, green supply chain management can be defined as the implementation of environmental management in the supply chain [Srivastava, 2007, pp. 53–54] This is important given the indications that the development of supply chain management is related to green supply chain management [Nelson et al., 2012, p. 33].

To discuss the concept of green supply chain management, it is necessary to establish the meaning of the term 'green supply chain'. According to J. Witkowski and A. Pisarek, the green supply chain distinguishes the traditional supply chain from the traditional one, among others, by its purpose. The traditional supply chain aims to maximise profits and minimize costs throughout the supply chain. The green supply chain, on the other hand, aims to reduce resource consumption and negative environmental impacts throughout the supply chain. In addition, the green supply chain is operating to build a closed-loop supply chain, and all stakeholders of the company are focused on end-users [Witkowski and Pisarek, 2017, p. 18].

The management of the green supply chain should consider not only flows of goods, services, information and capital but also waste [Sarkis, 2012, p. 209]. It is also indicated that the implementation of the green supply chain management concept can be a step towards the implementation of sustainable supply chain management concepts which take into account, in addition to the economic and environmental dimension, the social dimension, in line with the principles of sustainable development [Tundys, 2018, p. 99].

GREEN PURCHASING

The green purchasing concept incorporates the reduction of different types of negative environmental impact in the management of the purchasing process [Dubey et al., 2013, pp. 88–89]. This is an element of green supply chain management that is directly related to the green supplier evaluation [Sarkis, 2014]. The implementation of the green purchasing concept may be motivated by end-user requirements, applicable regulations and expected economic benefits [ElTayeb et al., 2010, p. 224].

Green purchasing practices are an instrument for the implementation of green purchasing practices. These include, but are not limited to, activities related to the green supplier evaluation, such as the environmental audit of suppliers, the environmental certification of suppliers by an independent body, the assessment of the life cycle of the material good purchased, the requirement for the supplier to implement and maintain an environmental management system not necessarily certified by a third party, and the requirement for suppliers to disclose the specific characteristics of the material good purchased, e.g. in the form of environmental labels or declarations [Bowen et al., 2006, p. 159]. Green purchasing practices also include the use of environmental checklists [Chien and Shih, 2007, p. 384] to conduct environmental activities [Bowen et al., 2006, p. 159; Sarkis, 2014, p. 15].

It should be noted that the company's commitment to environmental issues translates into its purchasing opportunities [Large and Gimenez Thomsen, 2011, p. 181] and implementing the concept of green purchasing translates into economic efficiency [Green et al., 2012, p. 299]. In addition, positive links have been demonstrated both between the implementation of green purchasing and the increase in the efficiency of purchasing management understood as a function of the company and between the implementation of green purchasing and the increased purchasing efficiency if the company maintains a partnership with suppliers [González-Benito et al., 2016, p. 319]. Furthermore, there is a positive correlation between taking environmental considerations into account in the purchasing process and increasing the effectiveness of environmental activities and the competitive advantage of the company [Ferri and Pedrini, 2018, p. 886].

GREEN SUPPLIER DEVELOPMENT

Supplier development incorporating environmental activities, referred to as green supplier development or environmental supplier development, means the efforts to increase the effectiveness of the environmental activities of suppliers [Bai and Sarkis, 2010, p. 1201]. This is done primarily by interacting with them, the use of supplier evaluation and taking into account the type of relationship with [Sarkis, 2014, pp. 19–21; Urbaniak et al., 2021, p. 2]. Overall, supplier development is influenced by factors such as effective communication, partnership approach, mutual involvement of the supplier and the client in cooperation and support of top management [Sillanpää et al., 2015, pp. 230–231]. The partnership approach implies the possibility of the importance of the type or duration of the relationship between the supplier and the client in terms of carrying out supplier development activities [Wagner, 2011, p. 281].

Among the areas of green supplier development activities are exchange and communication of knowledge on environmental issues (green knowledge), exchange of resources and management practices [Bai and Sarkis, 2010, p. 1202]. The first area includes knowledge exchange and communication activities aimed at reducing the negative environmental impact of the supplier, such as the training of suppliers in this field and the evaluation of suppliers taking into account environmental criteria. In turn, the exchange of resources and investments takes into account the sharing of material goods and capital with the supplier for the same purpose. Management and organisational practices, on the other hand, include all other organisational and management activities aimed at reducing the various negative impacts of suppliers on the environment, such as the implementation of green practices, environmental contracting and green supplier development, eligibility criteria for suppliers to implement green supplier development.

CONCLUSION

To summarize, there are several concepts directly related to related directly to building relationships in the supply chain and reducing negative environmental impacts. They are related either to the supply chain as a whole (green supply chain management) or to specific areas of the supply chain. Despite of limiting the scope of use, some of them affect directly more than supply chain link, e.g., green purchasing and green supplier development.

However, results reducing negative environmental impacts by introducing these concepts depend, among alia, on management approach. Possible factors affecting effectiveness of introducing green concepts in supply chain are performance measurement system and cooperation and collaboration with other supply chain actors.

It should be noted that the essential element of both green purchasing and green supplier development is green supplier evaluation, which can provide a basis for environmental cooperation between buyer and supplier. However, the scope of practical implementation of these concepts in a company may vary (see: Implication for business practice).

IMPLICATION FOR FUTURE RESEARCH

All the identified green concepts in the supply chain are related directly or indirectly to reducing the negative environmental impacts. The main recommendation for future research is a study of relationships between these concepts and observable trends in the global economy, such as sharing economy and circular economy.

The results might provide a way of introducing identified green concepts in the context of an economy based on either (or both) shareability and/or circularity.

IMPLICATION FOR BUSINESS PRACTICE

Implementation of concepts described in this paper may result in reducing negative environmental impacts in companies. The profitability of such action depends on the region of operations, targeted market, business sector, and legal regulations related to business processes and products.

Hence, the introduction of such concepts as green purchasing should be preceded by the research of these areas.

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ORIGINAL PAPER

CURRENT TRENDS IN THE GERMAN PACKAGING INDUSTRY

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ABSTRACT. Background: Germany is the largest plastic consumer in Europe. On average some 400g of plastics are used by its citizens. Despite promoting circular economy (CE) systems almost 60% of plastics are burned, recovering the thermal energy, however leaving an additional CO_2-Footprint. This increased emission does not only negatively contribute to climate change but also translates to poor sustainability metrics, lacking behind industry trends. The objective of this article is to review and provide an overview of the current trends of the German packaging industry with a focus on sustainability. This is important to understand the future opportunities and risks concerning the industries' economic development.

Methods: This review article is based on a primary literature review of key authors within the respective field. As an additional criterion, only articles published not before 2013 have been included.

Result: The German packaging industry is experiencing decreasing production rates and prices between 2018 and 2021. While general trends are shifting towards sustainability and responsible consumption, the majority of plastics are used for energy recovery. Following that the German packaging industry is driven by three key trends, (i) Packaging Materials, (ii) Packaging Design and (iii) Smart Packaging. Improving sustainability can be identified as the leading driver in all the mentioned trends. The industry is rapidly shifting towards circular systems giving high importance to social value and well-being.

Conclusion: This study analyses and contributes to our understanding of the German packaging industry. It provides a deeper insight into the current market, its challenges and discusses overall key trends.

Keywords: Circular Economy, Sustainable development, Packaging Industry, Trends

INTRODUCTION

The plastics and packaging industry is a growing concern to the public, worldwide. Hence the industry faces increasing pressure from the public and legislation to reduce plastic waste, emission and its carbon footprint, thus to becoming more sustainable. Energy recovery, waste management and recycling are just a few examples of current challenges. Global relevance is given as the plastic industry is contributing about 19% of the total remaining carbon budget before reaching the 1.5°C goal [Bailey et al., 2021; Fuhr et al., 2019].

Germany is the largest plastic consumer in Europe, responsible for over 24% (12Mt p.a. in 2019). The German consumer uses about 400g of plastics a day. The amount of packaging material is increasing in past years given the retail development and logistics, accelerated by COVID at the Business-to-Customer (B2C) market.

Over 40% of plastics are manufactured for packaging materials [*Plastics - the Facts 2020*, 2020]. The second-largest consumer of plastic is construction with 20%. Polyethylene (HD/LD PE) and polypropylene (PP) are the two most common polymers used in 40% of all materials [*Plastics - the Facts 2020*, 2020].

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Notably, the majority of plastics is used in energy recovery once their primary purpose (e.g., packaging) has been completed. Almost 60% of plastics in Germany are used for energy recovery, compared to the European average of 43% [*Plastics - the Facts 2020*, 2020]. Thirty-nine percent are recycled (vs. 32% in EU) and less than 1% disposed (vs. 25% in EU) [*Plastics - the Facts 2020*, 2020]. Whilst production of plastic in Germany decreased by 5% between 2018 and 2021, prices declined by 11% during the same period [Herrmann et al., 2021].

These recent developments and increasing social focus led to a renewed interest and pose disruptive threats to the German packaging industry. Sustainability e.g., a revised product life cycle, product innovation and socially responsible consumption are believed to be the main industrial domains.

The purpose of this paper is to review current trends in the German packaging industry and to highlight their effects on climate change. The remaining part of the paper proceeds as follows: The next chapter will lay out the fundamentals in the packaging industry based on a recent survey, followed by a discussion of the implications for the future.

TRENDS IN THE PACKAGING INDUSTRY

The German packaging industry is under continuous development. The large number and variety of its customers led to a multifactorial market environment for this industry. Nevertheless, general trends can be seen and described. Based on a recent survey performed by Blass et. al in 2021 with 108 Industry representatives, key trends could be identified [Blass and Feeß, 2021], presented in Table 1.

Table 1. Trends in the packaging industry highlighting their impact areas.

Trends	Impact areas
Packaging Material	Circular Economy
	Increased use of Recycled material
	Mono materials
Packaging Design	E-Commerce optimized design
	Ecologically optimized design
	Brand experience
Smart Packaging	Quality Control
	Watermark
	Track & Trace

PACKAGING MATERIAL

The Packaging Material and chemical composition is the key element defining characteristics [Dobrucka, 2019]. Sustainable development starts with the selection of the proper material. Climate change and resulting legislation thereof emphasize the importance to consider a products life cycle, with Circular Economy (CE) as the leading area of influence in the industry, being supported by the increased use of recycled material and the use of mono materials. The latter two facilitate a transition towards CE sharing the "4R" (Reduce, Reuse, Recycle, Recover) discussed by Kirchherr et al. [Kirchherr et al., 2017; Potting et al., 2017; Reike et al., 2018]. CE has the goal to establish a closed loop supported by the economic system.

Kirchherr et al. defined CE by analysing and combining 114 definitions derived from the linear economic model [Kirchherr et al., 2017]. Linear economy suggests recovery. The energy will be recovered once having fulfilled the primary purpose [Kirchherr et al., 2017; Potting et al., 2017]. This is the case for 60% of plastics in Germany. Extending the lifespan of products and/ or their parts increases circularity. Recycling is the next step towards the circular economy. It is defined by the processing of material to obtain a comparable product quality [Kirchherr et al., 2017; Potting et al., 2017]. This goal can be reached through the incorporation of new materials. Reusing materials and products by other consumers supports the extension of the life span [Kirchherr et al., 2017; Potting et al., 2017]. Continuous innovation, reduced use of materials and higher efficiency reduction of materials should be sought in a CE system [Kirchherr et al., 2017; Potting et al., 2017; Wolf et al., 2021].

Korhonen et al. conclude that circular systems have three elements in common. Such systems are (i) closed cycles, use (ii) renewable energy and follow a (iii) system thinking approach [Korhonen et al., 2018a]. This definition is close to other researchers arguing that (iv) social inclusiveness is also a key element of circular economy [Korhonen et al., 2018a, 2018b].

Closed cycles are defined through zero waste, as all residual streams, including both materials or energy, are the feedstock of new products. To reach this goal high material quality needs to be maintained and the life cycle conceptualized [Geissdoerfer et al., 2020; Korhonen et al., 2018b].

The required energy in circular systems is also subject to a waste-free generation minimizing the impact on external systems such as but not limited to the environment using renewable sources [Korhonen et al., 2018a]. However, following the laws of thermodynamics energy cannot be recycled and closed loops established.

The circular economy is based on a full life cycle analysis of materials. Thus, connecting and requiring a high level of collaboration across all levels. This includes packaging design, production, use, reuse, recycling and recovery [Kirchherr et al., 2017; Korhonen et al., 2018a; Reike et al., 2018].

Social inclusiveness can be seen as an intrinsic factor of circular systems. In contrast to linear systems circular systems facilitate a transition towards a shared economy increasing interdependencies among all actors [Geissdoerfer et al., 2020; Korhonen et al., 2018a]. This empowers self-organized social systems fostering the importance of social value rather than personal gains.

The implementation of CE systems in the food or beauty industry is challenging. On the one hand, these industry faces strong regulations associated with product safety. Additionally, there is only limited recycled HD/ LD PE or PP are available [Blass and Feeß, 2021]. On the other hand, the economic cost benefits of new "virgin" plastic materials often outweigh the sustainable benefit of recycling [Blass and Feeß, 2021].

This is often the case as complex composite Packaging Materials are used and desegregated waste collection is in place significantly decreasing recycling efficiency thus increasing costs. Moreover, international product standards need to be established to provoke sustainability and circularity across the entire value chain throughout country borders [Blass and Feeß, 2021; Coelho et al., 2020]. This has to be analysed and reviewed for each material individually. The case of fully recycled PET clearly demonstrated the feasibility.

PACKAGING DESIGN

Packaging Design is an important area having a direct influence on used materials, logistics and lifespan, translating to sustainability. In the light of recent years especially e-commerce, optimized Packaging Design and brand experience developed in the industry.

E-commerce is a key area of influence and the main driver within Packaging Design. The positive development and the significant increase of B2C packages between pre covid 2019 and 2020 support this [Esser and Kurte, 2021]. Unboxing videos and other publicity through various channels are used to increase the audience and reach. E-commerce is antimonic to sustainability. Research into the environmental impact compared to traditional in-store shopping revealed, that GHG emissions can be up by the factor of 3 - 6 [Carling et al., 2015; Escursell et al., 2021; van Loon et al., 2015].

The ecologically optimized design tries to reduce environmental impact by light-weighting, using mono materials, simplifying recyclability and extending the life span. According to the Ellen MacArthur Foundation, 80% of the environmental impact of packaging are defined within its design phase ["Ellen MacArthur Foundation," 2021]. Optimized Packaging Design has become a value for consumers. Blass and Feeß demonstrated the consumers' willingness to pay for sustainable design [Blass and Feeß, 2021].

Nowadays, Packaging Materials have become a multipurpose product being integrated into the customer journey and brand experience. The package has developed towards a marketing instrument.

SMART PACKAGING

Product digitalization is one innovation area in the packaging industry. In the context of this article Smart Packaging refers to active and intelligent functionalized packaging systems. Active packaging systems interact with transported goods by releasing or absorbing substances [Chen et al., 2020; Drago et al., 2020; Kuswandi and Jumina, 2020]. Intelligent packages are able to monitor conditions of the good, providing information without interaction [Chen et al., 2020; Drago et al., 2020; Kuswandi and Jumina, 2020]. Smart packages interact with the good based on the provided information, extending product life span and maintaining quality standards [Chen et al., 2020; Drago et al., 2020; Kuswandi and Jumina, 2020].

Such smart packages are of significant benefit in the food or pharmaceutical industry. These systems do not only extend shelf life, therefore increasing product life span, minimizing waste and the environmental impact, but also support product safety [Chen et al., 2020; Drago et al., 2020; Kuswandi and Jumina, 2020]. In the pharmaceutical industry, intelligent packages allow tracking of storage and transportation as well as medical regimes. This is accelerated based on consumer needs and as technology becomes more available and affordable [Dobrucka, 2013].

Product security goes beyond the above-mentioned quality control and regulating systems. The pharmaceutical and food industry is highly sensible against counterfeit. Micro text, debossing, customized varnishes and the latest RFID allowing track & trace [Pareek and Khunteta, 2014]. It is currently believed, that by 2023 90% of pharmaceutical deliveries will be using track & trace systems [Blass and Feeß, 2021].

Focus on the environmental impact and efforts towards increased sustainability can be supported by Smart Packaging. One important pillar in CE is efficient recycling. Segregated processing of individual materials is key and leads to better sorting of post-consumer waste while increasing yield quality. A digital watermark - the holy grail promotes the development and unifies recycling efforts.

CONCLUSION

The aim of this present research was to examine current trends in the plastic and packaging industry.

Within Europe, Germany is driving the plastic and packaging industry. In 2019 more than 24% (12Mt p.a.) of plastics in Europe have been used in Germany, primarily for packaging materials and construction. Most commonly polyethylene and polypropylene can be found. At the end of its lifetime, Germany uses almost 60% of its plastics for energy recovery (vs. 43% of the European average).

Yet climate change, environmental action and public concerns led to industry changes provoking innovation and product development. Despite the inhomogeneous nature of its products and customers similarities in form of trends became evident. These trends can be summarized to the trends Packaging Materials, Packaging Design and Smart Packaging.

Packaging Materials are driven by sustainability. The most obvious finding to emerge from this study is that there is a strong focus on shifting the currently linear industry into a circular economy. The overall goal is to increase sustainability across the packaging's life span. Key areas of concern are simplified Packaging Materials, facilitating recycling with an extended design life span.

Packaging Design partially supports the above-mentioned sustainability efforts. Packages are ecologically designed using methods such as but not limited to light-weighting. In contradiction to this e-commerce and increased shipping show negative effects on the environment.

Smart Packaging shows the added value of packaging systems across various industries throughout functionalization within logistics or quality control. The development of affordable technologies is key to further promoting these trends. Smart Packaging is expected to grow in the food and pharmaceutical sector.

Considering these developments, the packaging industry is in the process of revolution. Established linear systems accelerating consumption are being replaced by circular processes and an increased social valuation. Sustainability and increased functionality of packaging materials and enhanced life cycle assessments add value to packaging design.

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ORIGINAL PAPER

SUPPORTING OF MANUFACTURING SYSTEM BASED ON DEMAND FORECASTING TOOL

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ABSTRACT. Background: Enterprises' decision-making could be facilitated by properly creating or choosing and implementing demand forecasting systems. Currently, there are more and more advanced forecasting algorithms based on sophisticated technologies such as artificial neural networks and machine learning. The following research paper focuses on a case study of an automotive manufacturer. The main research aim is to propose the proper demand forecasting tool and show the prospects for implementing the mentioned solution.

Methods: The research paper contains the statistical analysis of a chosen time series referring to the demanded quantity of the manufactured products. To create forecasts, models based on the following forecasting algorithms were created: ARIMA, ELM (Extreme Learning Machine), and NNAR (Neural Network Autoregressive). All algorithms are based on the R programming language. All algorithms are run in the same time series where the training and testing periods were established.

Results: According to the forecasts ex-post errors and FVA (forecasts value-added) analysis, the best fitting algorithm is the algorithm based on ELM. It yields the most accurate predictions. All other models fail to add value to the forecast. Specifically, the ARIMA models damage the forecast dramatically. Such significant magnitudes of negative FVA values indicate that choosing not to forecast and plan based on the sales of the same period of the previous year is a better choice. However, in the case of the ELM model, the forecasts can be worth the time, finance, and human resources put into preparing them.

Conclusion: The increased accuracy of ELM forecasts can contribute to optimizing the process of reaching consensus forecasts. While unconstrained statistical forecasts tend to be overridden, not only to produce constrained forecasts incorporating various variables such as calendar events, promotional activities, supply capacity, and operational abilities, they are also overridden by planners to reflect their foreseeing of demand. The proposed solution could also be easily implemented in the resource planning process to improve it. The proposition of the resource planning process supported by the proposed forecasting system is also shown in the following paper using a BPMN 2.0 (Business Process Modelling Notation 2.0) map.

Keywords: demand forecasting, R Studio, ARIMA model, Neural Network model, Machine learning model, manufacturing system

THEORETICAL BACKGROUND

Forecasting is the process of analyzing and utilizing available information in the form of historical data and knowledge of the future to predict potential future events. It is crucial to distinguish forecasting from prediction, forecasting is a type of prediction, and it bases the future outcomes on temporal recorded data. In contrast, the prediction has three sub-disciplines. They are the prediction of the future, which attempts to predict the state of the future; prediction to the time of reference, which is an attempt to predict what is happening at the time of the making prediction, and prediction to the past, which attempts to predict the occurrence of the past. In essence, every forecast is a type of future prediction; however, not all future predictions are forecasts, as forecasts focus on not only a future occurrence but also the time of the occurrence. While some future predictions bluntly predict an occurrence without any insight into the timing of the occurrence or other parameters such as errors and confidence intervals. Furthermore,

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forecasting is a prediction based on quantitative or qualitative methodologies, and in the case of quantitative forecasts, the models have measurable errors. In comparison, a prediction might be subjective and based solely on gut feeling. In forecasting literature, generally, forecasts refer to the process of predicting future values, while predictions refer to the values themselves [Gische et al., 2020].

A successful demand forecast facilitates decision-making and improves final decisions regarding the scheduling of production, transportation, and personnel, and provides a guide to long-term strategic planning. [Hyndman and Athanasopoulos, 2018] In order to forecast demand accurately, an enterprise needs to have sufficient historical data to capture a bigger picture of the characteristics of demand. Despite the fact that the availability of sufficient data is the very first requirement of demand forecasting, the value needs to be extracted from the time-series data through the selection and use of compatible forecasting methods that are capable of taking trends, seasonality, and randomness of the data into account. Following the method selection, the parameter(s) of the method needs to be tweaked to enhance the model in order for it to mimic the behavior of the data more accurately and precisely. Additionally, demand prediction depends on the comprehension of contributive factors such as volatility and uncertainties involved. Demand volatility is unpredictability and rapid changes in demand.

Forecasting is considered as one of the risk categories in material flows [Szozda and Werbińska-Wojciechowska, 2013] also in production. Mentioned risk factors are imprecision, seasonality, product differentiation, short product life cycle, insufficient customer database, and information deviation. Demand fluctuations could imply supply management problems and create a tendency to keep excessive stocks as a buffer to production systems. Using flexible and precise forecasting procedures gives possibilities to gain good results even in capricious markets where the ordering practice of middleman distorts the demand of ended participants [Vokhmyanina et al., 2018]. The main features of demand on flowing goods are [Chandra and Grabis, 2007; Malladi and Sowlati, 2018]: the size of orders (it is the average quantity of orders); demand predictability (defines the error in forecasting); demand variability (it is the relation between demand pattern and average demand); market size (it is a rate of penetration for the specific products categories) and domestic market strength (in comparison to the global demand of a company).

In consideration of the meaning of forecasting in companies' activities, special attention should be paid to incorrectly created forecasts. Demand revaluation could cause for example high costs of excessive stocks and high marketing costs to get rid of them. Underestimation, on the other hand, could cause for example lost sales, lost reputation, and underestimated levels of sales tasks [Krzyżniak, 2017]. Forecasting has a special meaning especially in the context of manufacturing because the manufacturer forecasts usually influence whole supply chains [Mesjasz-Lech, 2011]. Through using proper forecasting methods as a part of demand planning there is a possibility of reducing the bullwhip effect [Dujak et al, 2019; Vokhmuanina et al, 2018] and also have a strong influence on the whole decision-making process [Czwajda et al, 2019].

Forecasts are created by strategists to identify business threats and spot emerging opportunities in the market [David, 2011] and for the purpose of predicting the future demand in order to plan ahead to meet demand and reduce risks arising from uncertainty. Through accurate forecasts and planning, enterprises can reduce working capital and other associated costs by manufacturing the optimum quantity of products and stocking the optimum amount at the right location at the right time. The accuracy of forecasts directly affects those variables and corrective action tends to be expensive and time-consuming in case of higher lead times. Failure to forecast can result in the failure of a business. Demand forecasting, along with demand planning constitute demand management. Demand forecasting and management form the foundation for all planning processes. Demand management is also one of those areas that companies continue to struggle with. Regardless of how good the demand management of an enterprise is, there still appears to be room for potential improvement [Chase, 2016]. Being able to meet demand optimally, leads to cost reduction, increasing profit, customer retention, and meeting corporate social responsibility expectations. The high availability of computers and their increased capabilities have facilitated the implementation of mathematical models for forecasting [Hughes and Morgan, 1967; Niazkar et al., 2020]. Furthermore, Computers have facilitated forecasting through data aggregation and visualization. Forecasting without computers takes dramatically longer, might be prone to higher error, and in some cases, it is impossible such as in using artificial neural networks. Forecasting methods are vast in quantity and specific; different behaviors of data might be grasped by different methods. Quantitative forecasting can be automated, for instance, the Box-Jenkins model, Autoregressive Integrated Moving Average (ARIMA), which can be automated in many forecasting tools and software.

Automated forecasting models are able to achieve optimal results as they are not based on human trial and error, rather than following a programmed sequence of action; however, the level of freedom they offer is significantly low, for instance, according to Hyndman, auto.arima() in R sets the AIC of some models to Inf, despite the real AIC of that model not being infinity, when the same model is rebuilt in the normal arima() function, it will have a defined AIC value. The reason that auto.arima() sets the AIC to infinity is to avoid it from being chosen based on that criterion as it does not meet other criteria such as having roots near the unit circle, which essentially means not being stationary. Another limitation of automated forecasting tools is that despite being statistically sounder, their results might not always be intuitive, for instance, in business analysis, it is necessary to check the findings of automated model selections, assess them and modify them if necessary.

More evolved and advanced forecasting models include Artificial Neural Networks (ANN), which rely on machine learning for time-series modeling. An ANN is typically composed of three types of layers, input layer, hidden layer, and output layer, each layer has neurons, essentially simplified neurons. In a single layer ANN, there is only an output layer, and the inputs are directly fed into the output neurons. while multilayer ANN is composed of all three types of layers, and the neurons can have multiple connections across the neurons of the other layers. In terms of the direction of outputs, ANN can be feedforward-based or recurrent-based. In a feedforward-based ANN the outputs of neurons can only be input for the neurons of an upper layer, whereas, in recurrent ANN, the output of neurons can also be fed back into the same neuron or neurons of a lower layer. Prior to achieving satisfactory results from an ANN, it has to be trained, which determines correct weights and biases. In forecasting, a time series is the input of the ANN, and forecasted values are the outputs. The input (time-series) has to be divided into two subsets, a training subset and a testing subset, the former one is used for training the neural network to assign weights that yield a lower overall error, while the latter one is used for measuring and assessing the abilities of the ANN [Zhang et al., 1998; Khandelwal et al., 2015]. Thus, the evolution of forecasting has a wide horizon, and quantitative forecasting can be as simple as the Naïve method, or as complex as artificial neural networks.

A limitation of forecasting arises from the need for increasing the granularity of forecasts for short-term planning. The basic issue of short-term prediction is the selection of the optimum time granularity, which directly affects the accuracy of forecasts [Li et al., 2019]. While some enterprises can manage demand on long-term low granular forecasts due to longer lead times, others cannot. For certain industries, low granular forecasts cannot be used for planning, such as in those industries where product lead times and shelf lives tend to be shorter and risks of spoilage or obsolescence could be high, such as in the fast-moving consumer goods (FMCG), technology, and fashion industries. In such industries daily or even weekly forecasts are more valuable than monthly forecasts. AI-based demand forecasting solutions surpass traditional statistical forecasting methods in accuracy for short-term forecasting, as a result reducing safety stock and stockouts at points of sale, thus, increasing profitability [Tarallo et al., 2019].

Another limitation of forecasting is its tedious process of carrying out. One workaround is aggregate forecasting, also known as top-down (TD) forecasting. In some industries, aggregating forecasts by product groups, divisions, and subsegments is possible due to the similarity of the products and a nearly constant historical relativity. Aggregate forecasts are developed for all products at once and through individual historical relative demand frequency, the demand of each individual product is allocated. [Dangerfield et al., 1992] Forecasting the demand of a group of products yields more accurate results than forecasting the demand of an individual product within the group [Narasimhan et al., 2007] this, is due to the fact that summing the individual forecasts up results in a large variance, hence, forecasting the demand of all products at once is better [Fogarty et al., 1994]. However, when the aggregate forecast is allocated to individual products, the accuracy is less compared to the accuracy of disaggregate forecasts with individual models [Dangerfield et al., 1988]. This is due to the top-down approach having many disadvantages, among those is the substantial information loss resulting from the aggregation of data [Orcutt et al., 1968]. The application of the top-down approach can be in the dairy industry, a farm can use an aggregate forecast of dairy products to plan future milk production, then based on historical relativity, the demand for individual products such as homogenized milk, yoghurt, and others can be allocated.

The main research problem of the following research paper is the comparative analysis of the accuracy of machine learning based forecasting models and traditional statistical forecasting models in the example of the selected production enterprise. To create and compare forecasting solutions were chosen the algorithms from the R programming environment were. R is a programming language for statistical analysis of the data which is chosen willingly in universities research as presented in Figure 1.

Tested algorithms in the conditions of machine learning will be ELM, MLP, and NNAR algorithms from the R programming environment. On the opposite side, there will be ARIMA and an automated ARIMA algorithm also calculated in R.

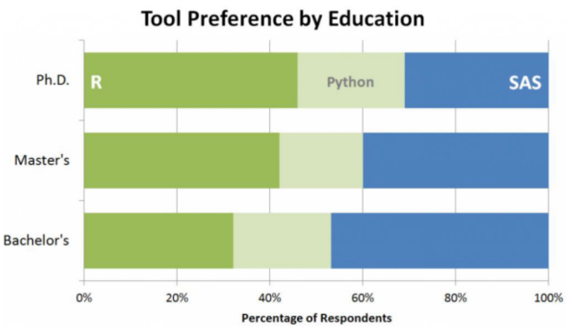

Fig 1. Preferences of predictive analytics tools across different levels of education

source: [Burtch, 2016]

The forecast package contains functions for manual and automated forecasting methods, and the artificial neural network tool in this package is Neural Network Autoregression (NNAR) which puts to work a single hidden layer feedforward neural network to forecast univariate time-series (figure 2). It is called through the function nnetar(). The NNAR model uses the lags of the time-series as inputs to the neural network, and it is important to note that it does not restrict its parameters to ensure stationarity. This artificial neural network uses a backpropagation algorithm to update the weights to obtain the minimum sum of squared errors. Artificial neural network methods are proven to give better results when there is volatility in demand [Mahbub and Paul, 2013].

Extreme Learning Machines (ELM) is a function from the package nnfor which serves as an automatic, semi-automatic, or fully manual modeling of artificial neural networks for time-series forecasting. What sets ELM aside is that it can only have one hidden layer, and furthermore, the learning algorithm, which was first proposed by G, -B Huang, et al. It sets out to solve one limitation of artificial neural networks, which is high time consumption in the training process. Instead of iterated learning through backpropagation, ELM uses simple inverse operation to find the output weights analytically. [Huang, et al, 2004; Liu et al., 2018].

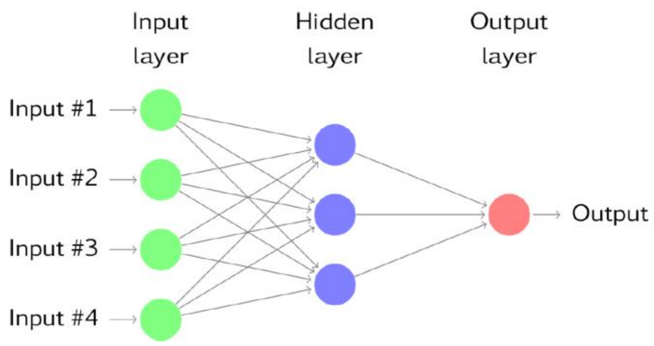

Fig. 2. A sample ANN
source: [Hyndman and Athanasopoulos, 2018]

Another function from the nnfor package, MLP, fits a multilayer perceptron neural network to a time-series for forecasting. MLP function creates a multilayer perceptron and trains it. MLPs are fully connected feedforward networks and probably the most common network architecture in use. Training is usually performed by error backpropagation or a related procedure [Rdocumentation, 2021].

AI is increasingly adopted as a problem-solving tool in business [Davenport and Ronanki 2018; Gunasekaran et al. 2017; Lee 2018; Phan et al. 2017] and the unsurpassed learning capabilities of AI can aid demand management in emergency situations as well. The COVID-19 pandemic forced many enterprises to transform and remodel their supply chains [Ivanov, 2020]. Artificial intelligence as a solution addresses issues associated with supply chain resilience and offers potential approaches to promote long-term sustainability [Modgil et al., 2021]. AI encompasses big data, machine learning, and deep learning technologies [Gupta et al., 2021; Wamba et al., 2020; Dwivedi et al., 2019]. It can empower the procurement strategy of the organization through automation of contractual agreements with suppliers and avoid redundancy of a supply chain through improved decision-making capabilities. [Baryannis et al., 2019; Dubey et al., 2020]. Furthermore, AI is capable of developing genetic algorithms and agent-based systems to facilitate demand planning, inventory planning, and network design in conjunction with supplier systems [Muniz et al., 2020]. While AI can have a broad range of applications in demand management, specifically for demand forecasting, AI offers demand sensing, which is the utilization of upstream data within a value chain to generate a more accurate unconstrained demand forecast [Chase, 2009]. The COVID-19 pandemic caused many manufacturing plants to halt production due to supply chain disruptions. The surge of demand following the low demand for many products lead to a bullwhip effect. A potential solution could be drawing insights from data directly related to the cause of the event or the state of the event. In other words, to incorporate historical sales data with other correlated data.

Other than forecasting demand for managerial and operational planning and controlling, accurate demand planning can be used for strategic planning. For instance, existing knowledge can be devalued by turbulence, also, ongoing turbulence may devalue investments in exploration aimed at the generation of new knowledge [Posen, et. al, 2012], and high accuracy AI-powered demand forecasting could predict the frequency of turbulence, thus, justifying strategic decisions such as exploration or exploitation.

Currently, more and more entities are taking advantage of contemporary technological achievements. It is popular especially in the activity of automotive enterprises which are the basic enterprises involved in the Industry 4.0 development. Nowadays, automotive enterprises are striving with the issue of demand planning necessity and Big Data common occurring in their environment. All the mentioned issues started the considerations of supporting the manufacturing process by highly technological advanced demand forecasting tool.

MANUFACTURER AND PRODUCT DESCRIPTION

The historical data used in the empirical part of this thesis is the sales of the lineup of pickup trucks manufactured and marketed by an American automotive manufacturer. The mission statement of the manufacturer shows that it wants to leave its fingerprint everywhere and provide people with its vehicles at affordable prices to make improvements in people's lives. The company has a vision of rapid development for their products to provide vehicles with high-end technology to the whole globe, and it wants to gain the trust of customer loyalty. The manufacturer serves the market across the globe.

The manufacturing strategy of the company is based on the flexibility strategy. It abandoned the dedicated assembly lines, which were capable of manufacturing only one model, in favor of flexible plants. The flexible plants have reprogrammable body tooling and a common final assembly line that can seamlessly shift the production of different models. The pickup truck lineup, which is the subject of this research, comprises eight distinct models, and the lead time for their production is in the range of 16 to 26 weeks, depending on the model. The relatively long lead time of roughly a half-year-long requires resilient demand management to avoid underproduction and overproduction.

Overproduction has been a major theme in the American automotive industry. Many states prohibit manufacturers from selling directly to end-users. Thus, the dealers are not owned by the manufacturer. To minimize the losses resulting from overproduction, the manufacturers force the dealers to take more and more cars, this activity is known as "channel stuffing," and it causes substantial financial loss for the dealers, yet the manufacturers regard this as revenue even though the cars are parked in the dealership without real demand from an end-user. A cause of overproduction is associated with manufacturing more units to spread out the fixed costs, which is essentially an outcome of overcapacity and its utilization. As a result, the supply of the products is greater than the market demand. Therefore, in demand forecasting, the first step to take is to make sure the data truly represents the demand, if not so, regardless of how efficient the forecasting model is, the forecasted values cannot capture the true future demand.

The manufacturer has faced limitations in production and supply. After the dramatic decrease of demand in the fourth quartile of 2019 and the first quartile of 2020 due to the COVID-19 pandemic, the sales in 2021 are recovering back to their normal level, and the demand is high. Meanwhile, the limited supply of semiconductor chips at the beginning of February 2021 pushed the manufacturer to lay off shifts at their truck assembly plants. Thus, unable to match supply and demand, damaging the earnings.

The product, essentially a lineup of trucks, is marketed using a product differentiation strategy along with a low-cost leadership strategy; thus, the company manufactures products that are different from those of its competitors at lower costs. The company uses Caterpillar logistics services and SAP as enterprise resource planning (ERP) software, as well as SAS for data analysis. SAS is used for customer relationship management (CRM) as it has access to its customer relationship database, and it can produce predictive models. The historical data available for analysis and forecasting spans from January 2005 to January 2021, resulting in a total of 193 monthly observations. While this monthly data is of the whole lineup, The manufacturer needs to adjust the forecasts according to the market share of each eight individual models. Failure to accurately estimate the market shares of the individual models results in adding no value from the forecasts derived from these data.

The visualizations of the historical sales data and decomposed elements of the time series show that the sales data exhibits seasonality, and there is no persistent trend over the whole span of the historical data; however, the sales experience long periods of rising and fall. There is an overall negative trend from 2005 to 2009 and an overall positive trend from 2009 on. The seasonal plots suggest that the sales are generally peaking in December and troughing in January.

The lineup has experienced abrupt changes and deviations in sales which cannot be explained by the trend and seasonality, thus referred to as outliers. After running an in-depth outlier detection, the following outliers were found:

Fig. 3. Decomposition of the time series.

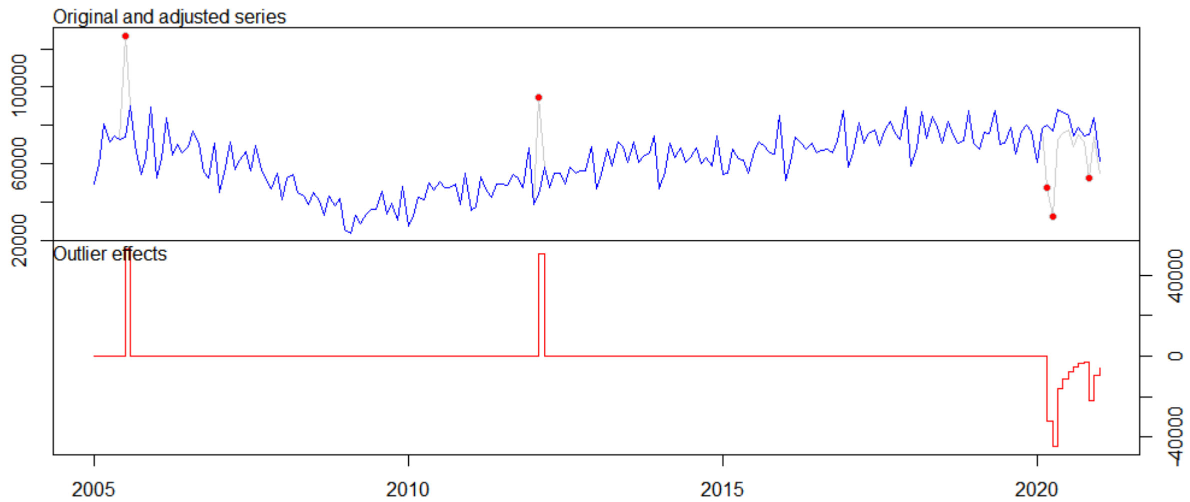

Fig. 4. Outliers of the time series and their effects.

Table 1. Outliers and their specifications.

Type	Index	Date	Coefficient	T-stat
AO	7	07.2005	52897.90436	11.24752354
AO	86	02.2012	50630.10018	13.06091663
TC	183	03.2020	-32335.06991	-6.705837541
AO	184	04.2020	-22138.05043	-4.833218304
IO	191	11.2020	-20358.05615	-3.516511451

The first outlier, located at index 7, is of type additive, and it is the result of sale promotion. While the second outlier at index 86 is also additive and it is due to the success in achieving high sales figures in 2012. The last three outliers are all negative and are caused by the supply chain disruptions and decrease in demand due to the COVID-19 pandemic-related events.

PROPOSED DEMAND FORECASTING MODEL

The studied models consist of a manual and an automated autoregressive integrated moving average (ARIMA), an extreme learning machine (ELM), a multilayer perceptron (MLP), and a neural network autoregressive (NNAR), of which the last three are machine learning based. The procedure to test their performance is divided into four main steps—namely, model studying, training, forecasting, and analysis of the results. In the first step, the models are studied both in terms of their mathematical algorithm, as well as the functioning of the models in the certain tool used, i.e., R. By studying algorithms, one can understand the roles and effects of the variables in the algorithms and studying the function and operation of the models of the tool helps in setting the models for the best possible results. In the second step, the time series is split into two new sets, the training, and the test set, at the ratio of 80:20. Then, the optimal inputs to be passed into the functions are determined through gaining intuition from the time series, such as its autocorrelation and partial autocorrelation function plots, and then they are fine-tuned through systematic experimentation. The algorithms of the artificial neural network (ANN) based models involve starting with random weights, thus, prior to systematic experimentation, the usage of the same randomly generated weights is ensured. Before proceeding to the third step, the models are tested for the maximum achievable accuracy. While for the simpler forecasting methods like the naive method, weighted moving average, and winter's method, the best model is determined through calculating the ex-post errors and choosing the minimum one. This model selection criterion is not a good measure of the performance of the models in predicting the future; in fact, the forecasting methods used in this paper achieve negligible ex-post errors, overfitting the data, which is best to be avoided in forecasting demand. Therefore, instead of relying on hyperparameter tuning to minimize the in-sample ex-post errors, the hyperparameters are tuned to build models which have the best residuals, neither overfitting nor underfitting, but capturing the essence of the time series. In the third step, the models are run, and the in-sample and out-of-sample ex-post errors are recorded. In the fourth step, the forecasts are compared based on their accuracy as well as a forecast value added (FVA) analysis.

The forecasting procedure starts with importing the data into Rstudio and converting it into a time-series format. The time series is then split into the training and test set. The training set is checked for skewness, and the optimal lambda (λ) value of Box-Cox transformation is found if it needs power transformation.

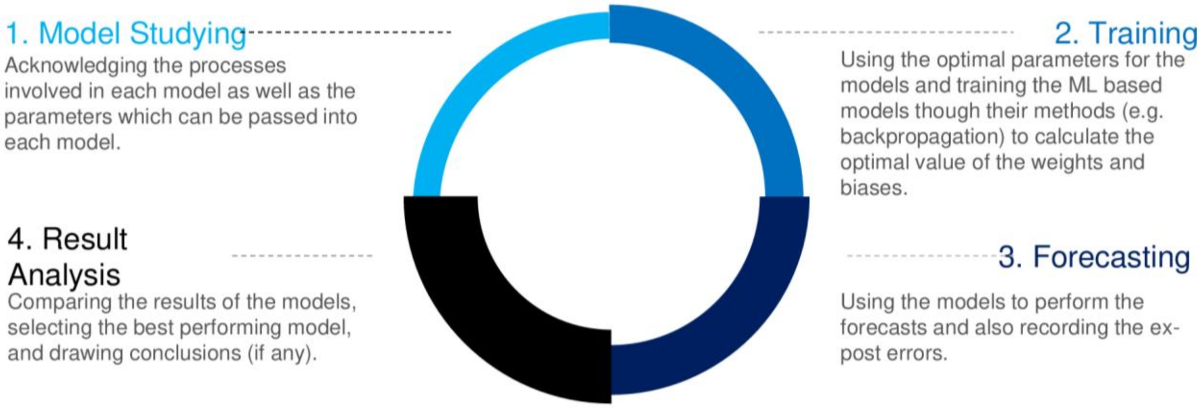

Fig. 5. Methods of the research.

After that, augmented Dickey-Fuller (ADF) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests are performed to check for stationarity of the training set, if not stationary, the optimal number of differencing is found to make it stationary. Then the training set along with the hyperparameters are passed into the forecasting model. After forecasting, a Ljung-Box test is performed on the residuals of the forecast to check for any autocorrelation left, if there are any, the hyperparameters of the model are tuned to eliminate the autocorrelation. Next, the out-of-sample forecasting ex-post errors, namely, MAPE and RMSE, are calculated from the actual values (i.e., the test set) and the forecast values. Finally, the forecast value added (FVA) is calculated using the ex-post errors of a seasonal naive forecast. Among the artificial neural networks used, the extreme learning machine (ELM) and the multilayer perceptron (MLP) functions do not natively support Box-Cox transformation, thus as a workaround, the models are trained on a transformed version of the training set, and after being trained, the models forecast the non-transformed training set without retraining the networks.

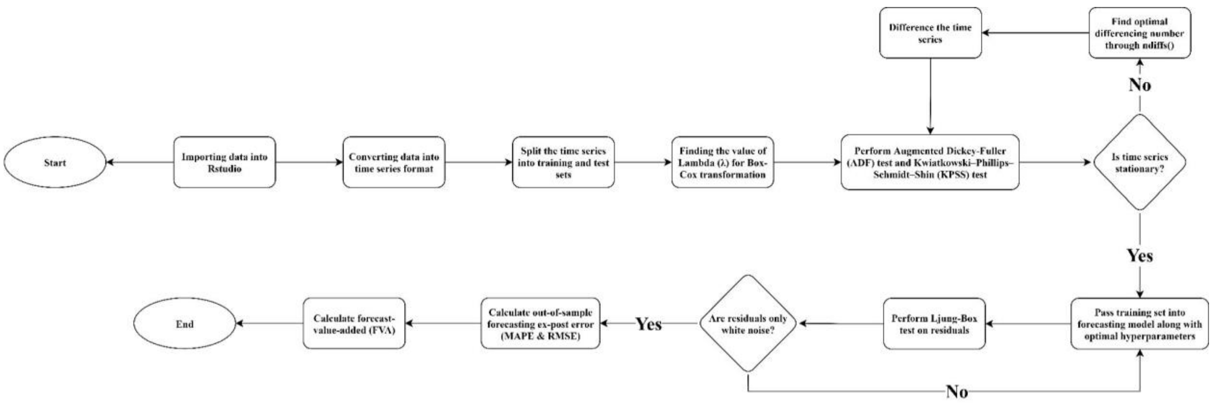

Fig. 6. Forecasting procedure.

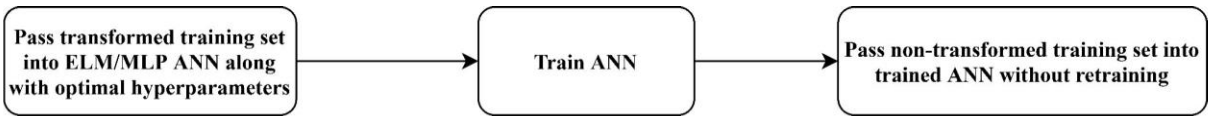

Fig. 7. Training procedure of ELM and MLP neural networks

The presented method offers the opportunity to the manufacturer to improve demand planning by using advanced demand forecasting algorithms, but it also has some limitations. The method and proposed algorithms with data analysis fit only the products with sales history. Also, the training period is stated in the same level of time series, in every calculation, the same percentage part of historical data is used for algorithm training.

RESULTS & CONCLUSION

The accuracy of the forecasting models is calculated in terms of Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE). While the former is scaled and measured in terms of actual units sold, the latter is a percentage that is more comprehensible. While both metrics describe the ex-post errors of the forecasts, they are not necessarily proportional, and they can be sensitive to different situations.

The ex-post errors of the models are as the following:

Table 2. Accuracy of the models.

Model	MAPE	RMSE
ARIMA	22.18%	16750.82
Auto RIMA	22.63%	17100.36
ELM	11.71%	9752.33
MLP	13.85%	10310.30
NNAR	13.98%	10553.63

The ARIMA models were outperformed by the artificial neural networks. While the ARIMA and automatic ARIMA models had a MAPE of 22.18% and 22.63%, respectively, the MLP and NNAR models achieved a MAPE of 13.85% and 13.98%, respectively. The manual ARIMA model performed better than the automatic one. The forecasts of the ELM model resulted in an outstanding MAPE of only 11.71%, almost half the MAPE of the ARIMA models.While in the particular industry of automotive manufacturing, the lead times tend to be long, it is worth looking at the short-term forecasting performance of the models. While both MLP and NNAR models outperformed the two ARIMA models in the long run, taking only the first five forecasted periods into account, in the short run, it was quite the opposite as the ex-post errors of the MLP model were unstable, fluctuating between greater extrema. While the NNAR model performed better than the MLP model, it did not manage to perform as well as the ARIMA models. Also, unlike the long-term forecast, in the short-term forecast, the automatic ARIMA performed marginally better than the manual ARIMA. The ELM model had the most accurate short-term forecast, and the ex-post errors were increasing without fluctuations, almost linearly. While comparing the ex-post errors of different forecasts is a method of determining which is superior, it cannot alone justify the value it adds, it is rather a relative measurement. For that purpose, the Forecast Value Added (FVA) analysis is performed to calculate the value each model's forecast adds. An FVA analysis compares the accuracy of forecasts to the accuracy of a basic forecast from either the naive method or the seasonal naive method, since the sales of the subject of this study are highly seasonal, the seasonal naive method is used as a benchmark. While an FVA analysis can incorporate judgmental forecasts, such as an analyst's override, this FVA analysis does not contain judgmental forecasts, and its sole purpose is to examine the added value from the forecasts of the individual models.

According to the FVA analysis, the only model capable of adding value to the forecast is the ELM model, as its forecast has a MAPE value that is less than the MAPE of the seasonal naive forecast. Meanwhile, all other models fail to add any value to the forecast, specifically, the ARIMA models damage the forecast dramatically. Such great magnitude negative FVA values indicate that choosing not to forecast and planning based on the sales of the same period of the previous year is a better choice. However, in the case of the ELM model, the forecasts can be worth the time, finance, and human resources put into preparing them.

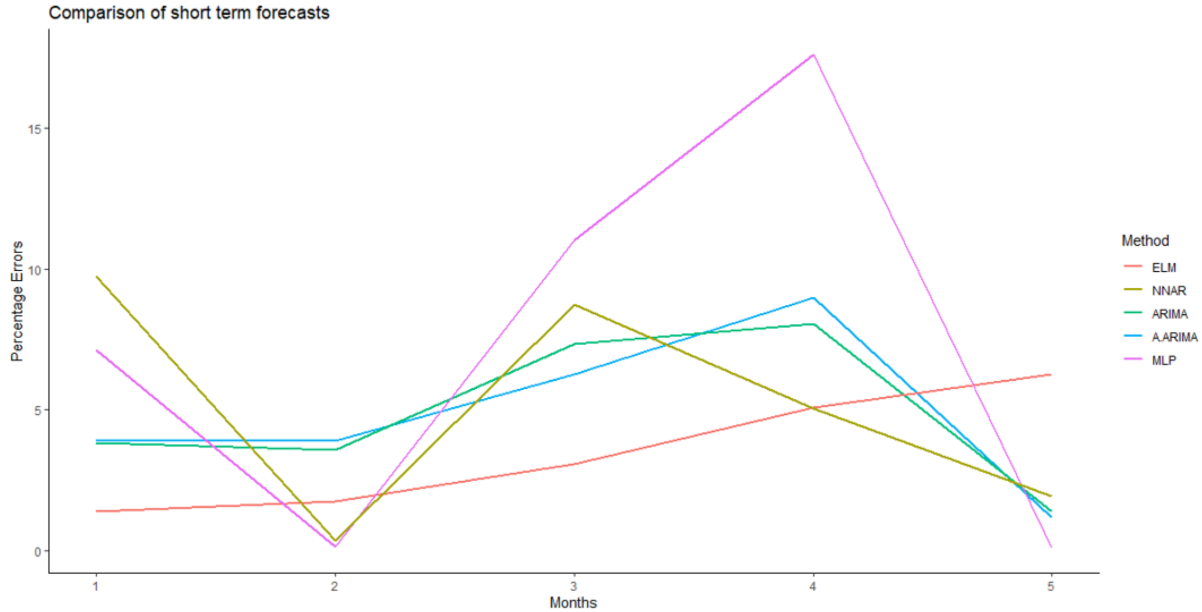

Fig. 8. Short-term forecast accuracy comparison.

Table 3. Percentage errors of the short-term forecasts.

	ARIMA PE	A. ARIMA PE	ELM PE	MLP PE	NNAR PE
1	3.92%	3.83%	1.37%	7.13%	9.74%
2	3.89%	3.56%	1.73%	0.13%	0.34%
3	6.25%	7.35%	3.08%	11.04%	8.72%
4	8.98%	8.05%	5.06%	17.63%	5.03%
5	1.19%	1.39%	6.26%	0.08%	1.93%
MAPE	4.85%	4.84%	3.50%	7.20%	5.15%

Table 4. Results of the FVA analysis.

Model	MAPE	RMSE
S. Naive	13.06%	-
ARIMA	22.18%	- 9.12%
Auto ARIMA	22.63%	-9.57%
ELM	11.71%	+1.35%
MLP	13.85%	-0.80%
NNAR	13.98%	-0.93%

The increased accuracy of ELM forecasts can contribute to optimizing the process of reaching consensus forecasts. While unconstrained statistical forecasts tend to be overridden not only to produce constrained forecasts incorporating various variables such as calendar events, promotional activities, supply capacity, and operational abilities, they are also overridden by planners to reflect their foreseeing of demand. The increased accuracy reduces the need for overriding, thus cutting on the planning time as well as the management costs. As the ELM model can predict both the far and near future of demand more accurately, it can reduce inventory costs and working capital through better optimization of inventory such as safety stock management. Furthermore, the planning horizon can be shortened as an increase of accuracy allows increasing the granularity of the forecasts without reducing the accuracy to an unacceptable level. Lastly, the benefits of the more accurate ELM forecasts result in less uncertainty and better risk management. The discussed benefits are the potential outcomes of switching to or adopting a more accurate forecasting method on its own, like the ELM network. However, the machine learning based forecasting models can be furthermore developed to meet the forecasting and planning requirements of different enterprises across different industries. What could be valuable, the analysis shows that one of the popular forecasting methods based on ARIMA has relatively low accuracy. Using machine learning or neural network based methods could bring the opportunity of preparing better demand plans, reduce the bullwhip effect in the distribution networks and also create the possibility of reducing the fluctuations and disruptions in a production system.

The proposed tool could be used, after a few modifications, to support the manufacturing system in the push strategy. The main modification will focus on increasing the automation level of the proposed solution and on integrating with the information systems of the manufacturer. Additionally, it could distinguish the data connected with sales done in push and pull systems. Using algorithms based on neural networks and machine learning gives the opportunity of finding some connections and correlations between these two kinds of data which could support the forecasting activity. Properly created and automated forecasting systems could also support the manufacturer in realizing their strategy connected with Industry 4.0. As a first step, the authors proposed to test the forecasting system as a tool for supporting manufacturing resource planning (figure 9).

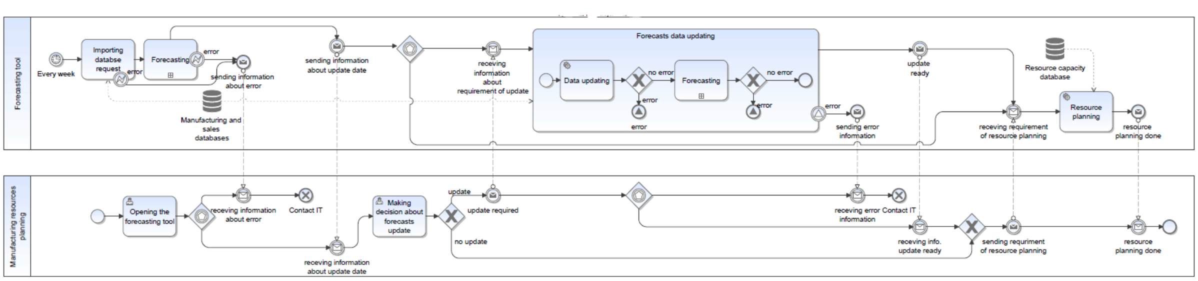

Fig. 9. Usage a demand forecasting tool for resource planning automation.

The proposed solution assumes the integration of the mentioned forecasting algorithm with databases of manufacturers. These databases consist of data connected with manufacturing, sales quantity, and capacity of particular resources. Resource planners could choose between the faster way, which is based on generated forecasts, or choose the option of updating the forecasts and sending the information of updating requirements to possess the current data from databases. Forecasts will be calculated automatically once per week with a one-month horizon. After forecasts calculation or forecasts data updating and calculation, there is automatic resource planning needed to the future values of sales predicted by the proposed algorithm.

Besides this solution, there is also a prospect for using the proposed tool to improve the level of stocks in the distribution network and to receive information about disruptions in advance. So, the proposed tool gives a lot of opportunities to improve the manufacturing system. There is also a possibility to improve the algorithms based on machine learning and neural networks by adding additional layers and trying to possess more data from the enterprise environment. The authors are also aware of the weaknesses of the proposed solution in the current state. For now, there is no possibility to use a different source data and the solution is strictly dependent on input data. Besides this, there is also a necessity of improving the collaboration between different nodes in the distribution network and supply chain, and the inclusion of the suppliers and retailers in the collaborative forecasts. These areas seem to be solvable before proper analysis which gives the opportunity to develop the following research.

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ORIGINAL PAPER

INFLUENCE OF REVERSE LOGISTICS ON COMPETITIVENESS, ECONOMIC PERFORMANCE, ECOLOGICAL ENVIRONMENT AND SOCIETY

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ABSTRACT. Background: Today, companies operate in an environment that is significantly affected by the forces of transformational changes, which create problems for logistics. Reverse logistics is a relatively new topic for businesses. Therefore, the purpose of this article is to study the relationship between reverse logistics and competitiveness, economic performance, the environment, and society.

Methods: The research methodology includes general scientific and special methods, such as synthesis and analysis, logical generalization, correlation and regression analysis. The hypotheses were empirically tested using sample data from 37 countries of the Organization for Economic Co-operation and Development (OECD). The analysis period ranged from 2000 to 2019, which corresponds to an unbalanced group of 591 observations.

Results: Eight different models were developed to analyse the proposed hypotheses. It was confirmed that reverse logistics has a positive effect on competitiveness, economic performance, environmental performance and society.

Conclusions: Therefore, companies should pay attention to reverse logistics, as it will promote their development and benefit during their activities. The aspects highlighted in the article will help to understand the development and scientific substantiation of logistics management measures. The conclusions of this document can serve as a guide for leadership and management.

Keywords: Reverse Logistics, Competitiveness, Economic performance, Ecological environment, Society
JEL Classification: F63, L23, O14

INTRODUCTION

The spread of globalization, growing consumer demand, the production of "special" products, lean management, shortening production cycles or the rapid development of information technology are placing increasing demands on businesses. These trends affect and form the logistics systems of enterprises.

Research conducted on the territory of some countries examined the issue of reverse logistics implementation only at the state level [Huang and Yang, 2014; Maheswari et al., 2018]. Regarding research into the experience of large corporations in reverse logistics, they were conducted by Zhang et al. [2016]; Alnoor et al. [2019]; Cricelli et al. [2021]. For small and medium-sized enterprises the implementation of reverse logistics for them was studied by Lopes et al. [2014]; Satyanarayana and Venugopal [2019]; Strong, et al. [2019]; Yang et al. [2019]; Pawar et al. [2021] and others. However, none of these studies has taken into account a comprehensive study of reverse logistics and its impact on competitiveness, economic performance, the environment, and society. There has also been insufficient research on reverse logistics in OECD countries. This study is important because it will allow making the right management decisions on reverse logistics and implementation of some strategies at the enterprise level.

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The other sections of this article are organized as follows. The next section is a review of the scientific literature on reverse logistics. The conceptual framework is then outlined, and hypotheses formulated. Then comes the section on the methodology of the study. The following is a test of the hypothesis. The article concludes with discussions, also offering suggestions for future research conclusions.

LITERATURE REVIEW AND HYPOTHESES

This section briefly reviews the scientific literature on the concepts used in this study. These are reverse logistics, competitiveness, economic performance, environment and society.

Reverse logistics and competitiveness

The implementation of reverse logistics strategy can effectively help modern manufacturing enterprises to improve the competitiveness of enterprises [Gao, 2018]. Job et al. [2020] recommend that implementation of reverse logistics should be guided by a process that requires identifying the uniqueness of resources the organization has and strategically utilizing these resources in a manner that builds comparative advantage. Studies by Mwanyota et al. [2017] have shown that the adoption of reverse logistics can lead to a sustainable competitive advantage for firms.

Reverse logistics and economic performance

When the organizations competently manage their reverse logistics, it results in positive economic performance outcomes and maintains the competitive situation in the industry, as it can reduce the use of resources [Phoosawad et al., 2018]. Results from analysis Mutingi [2014] indicate that reverse logistics may have an impact on economic performance. Reverse logistics has a positive and significant impact on economic and environmental performance [Huang et al., 2012].

Reverse logistics and the ecological environmental

Nowadays, there has been a growing interest in reverse logistics in both theory and practice due to ecological benefits [Aksoylu and Demirel, 2018]. Reverse logistics is an alternative that reduces negative impacts on the environment associated with the recovery of materials [Peña-Montoya et al., 2015]. Mangla et al. [2016] considered reverse logistics as a systematic approach to improve environmental impacts and to ensure sustainability in business.

Reverse logistics and the society

The research results of Hong and Yue-Jun [2021] show significant correlations between reverse logistics and social impact. As a result of research, Barky [2016] indicates a significant impact of reverse logistics on customer satisfaction in terms of the remanufactured product price, quality and a lower impact done by the service representatives and acquisition processes. Mohamed et al. [2015] in the work have shown that the application of reverse logistics has a significant impact on customer satisfaction.

Figure 1 presents our conceptual research model.

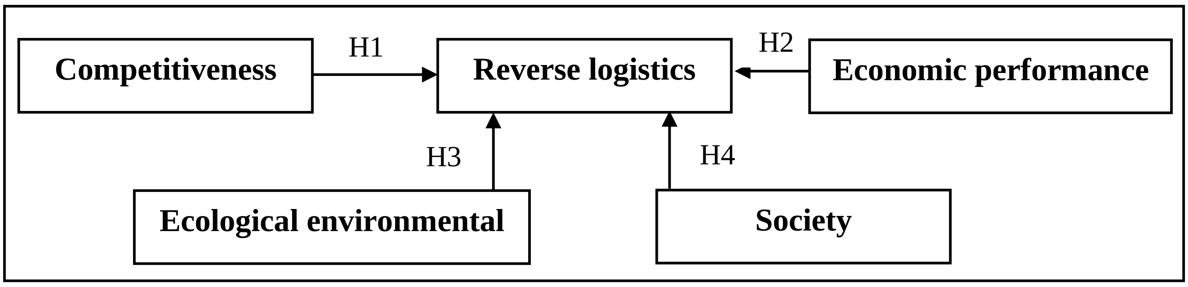

Fig. 1. Conceptual Model

AIMS

This paper aims to extend the literature by advancing research into the influence of reverse logistics on competitiveness, economic performance, ecological environment and society in the OESD countries.

The following research hypotheses were identified:

Hypothesis 1: Reverse logistics has a positive impact on the competitiveness of the enterprise.

Hypothesis 2: Reverse logistics has a positive impact on the economic performance of the enterprise.

Hypothesis 3: Reverse logistics has a positive impact on the ecological environment of the enterprise.

Hypothesis 4: Reverse logistics has a positive impact on society.

METHODOLOGY

Data

In the study, the reverse logistics impact on competitiveness, economic performance, ecological environment and society was analysed using data analysis for 37 Organization for Economic Co-operation and Development (OECD) countries in the period of 2000-2019 (data that available at the beginning of the 2021 year). This data provided was by the OECD (https://stats.oecd.org/).

Measures

Dependent variables

The real growth of gross domestic product the real growth (GDP_GR) is one of the main depend on indicators. Another indicator is Transport infrastructure investment (TII). This variable collected includes investment, maintenance spending and capital value of the road, rail, inland waterways, maritime ports and airports.

Control variables

The control indicators used in this analysis include the total population (POP), Share of employment of the transport sector (SETS) and Share of value added by the transport sector (SVATS).

Independent variables

1. Competitiveness

The first indicator, which is analysed, is Foreign Direct Investment (FDI). Another indicator used is the Regulatory Restrictiveness Index (RRI), which measures statutory restrictions on foreign direct investment and gauges the restrictiveness of a country.

2. Economic performance

An indicator referring to lean management used in this article was Environmental and resource productivity (ERP), which indicates whether economic growth is becoming greener with more efficient use of natural capital and to capture aspects of production. Also, the investigation included Total amounts of waste generated by sector (TAW), because this indicator show waste produced by the various sectors of economic activity.

3. Ecological environmental

This study included business with bioecological component (BBC) and business sub-ecological (BS). These indicators correspond to environmental technologies in various sectors of the economy.

4. Society

One of the indicators of customization is Consumer Support Estimate (CSE). Another indicator is Gross domestic expenditure on R&D by sector of performance and socio-economic objective (GDE_SEO).

Data analysis

A model of fixed effects was used to analyse the countries studied in the study and their indicators. The model used in the analysis is as follows:

$$LGDP\_GR_{it} = \alpha_i + \lambda_t + \beta_1 TII_{it} + \beta_2 POP_{it} + \beta_3 SETS_{it} + \beta_4 SVATS_{it} + \beta_5 LOGIST_{it} + \varepsilon_{it}, \qquad (1)$$

Where: $LGDP\_GR_{it}$ - an indicator of the impact of megatrends on logistics, $i = 1 \dots N$, i - country, $t = 1 \dots T$, t - time, α_i - country fixed effect, λ_t - time constant, β - estimate coefficient, TII - transport infrastructure investment, POP – population, SETS - share of employment of the transport sector, SVATS - share of value added by the transport sector, ε_{it} - error term. LOGIST shows the variables which are used as a proxy of megatrends in the context of logistics. Eight different models were formed in the study to analyse the relation between megatrends and logistics. As a proxy of the logistics sector used all independent variables (FDI, RRI, ERP, TAW, BBC, BS, CSE, GDE_SEO).

All the equations were estimated using the statistical analysis software STATA version 13.5.

RESULTS

Table 1 presents the results of descriptive statistics of the variables used in econometric modelling.

Table 2 presents the results of the correlation coefficients of the variables used in the study.

As it is shown in the Table 3, there is a positive and generally high correlation between GDP_GR levels and TII, POP, SETS, SVATS, RRI, ERP, BBC, BS, CSE, GDE_SEO. Also, there is a negative correlation between GDP_GR and FDI, TAW.

The analysis results belonging to the models are summarized in Table 3.

Table 1. Descriptive statistics for study variables

Variable	Mean	Standard deviation	Minimum	Maximum
GDP_GR	2.15	3.41	-14.84	25.18
TII	11996256079.80	49708243741.14	274052.45	655814699587.19
POP	34505697.66	55334234.92	281200.00	327167434.00
SETS	5.52	1.10	3.42	9.59
SVATS	27.84	7.67	7.14	48.41
FDI	25263.30	54415.38	-79075.29	483849.00
RRI	0.069	0.061	0.004	0.283
ERP	1.37	2.39	-13.06	14.25
TAW	85417.47	102764.29	501.43	405523.60
BBC	93.66	6.07	68.10	100.00
BS	73.08	12.15	41.45	96.28
CSE	-4139.12	12933.88	-61515.13	34198.73
GDE_SEO	2690143.80	10679335.32	29.87	89047077.12

Source: Calculated by the authors

Table 2. Correlation matrix for the variables

Variable	GDP_GR	TII	POP	SETS	SVATS	FDI	RRI	ERP	TAW	BBC	BS	CSE	GDE_SEO
GDP_GR	1.000												
TII	0.387	1.000											
POP	0.111	-0.267	1.000										
SETS	0.669	0.716	-0.169	1.000									
SVATS	0.102	-0.361	-0.120	-0.199	1.000								
FDI	-0.086	-0.273	0.621	-0.136	-0.422	1.000							
RRI	0.009	-0.207	0.010	-0.169	-0.499	0.589	1.000						
ERP	0.782	0.516	0.111	0.680	-0.386	0.007	-0.117	1.000					
TAW	-0.032	-0.089	-0.394	-0.198	0.347	-0.536	-0.349	-0.132	1.000				
BBC	0.521	0.403	-0.660	0.483	-0.177	-0.443	-0.067	0.489	0.222	1.000			
BS	0.370	0.465	-0.251	0.396	-0.399	-0.231	-0.113	0.641	0.217	0.712	1.000		
CSE	0.081	0.047	0.093	-0.145	-0.278	0.139	0.192	-0.009	-0.601	-0.021	-0.161	1.000	
GDE_SEO	0.137	-0.099	0.211	0.094	-0.572	0.658	0.584	-0.072	-0.322	-0.195	-0.088	0.070	1.000

Source: Calculated by the authors

Table 3. Regression results

LGDP	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
TII	−0.025***	−0.037***	−0.032***	−0.036***	−0.033***	−0.029***	−0.032***	−0.042***
	(0.093)	(0.081)	(0.098)	(0.086)	(0.097)	(0.084)	(0.081)	(0.085)
POP	0.021***	0.022***	0.025***	0.026***	0.028***	0.031***	0.023***	0.025***
	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)	(0.002)	(0.001)
SETS	0.003***	0.004***	0.005***	0.003***	0.004***	0.005***	0.003***	0.004***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0001)	(0.0002)	(0.0002)
SVATS	0.019***	0.015***	0.018***	0.015***	0.011***	0.016***	0.019***	0.022***
	(0.003)	(0.002)	(0.003)	(0.003)	(0.002)	(0.002)	(0.003)	(0.003)
FDI	0.022***	0.019***	0.017***	0.021***	0.015***	0.014***	0.019***	0.025***
	(0.005)	(0.004)	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)
RRI		0.026***						
		(0.002)						
ERP			0.016***					
			(0.004)					
TAW				-0.015***				
				(0.001)				
BBC					0.052***			
					(0.0002)			
BS						0.021***		
						(0.0003)		
CSE							0.011***	
							(0.0002)	
GDE_SEO								0.052***
								(0.0005)
Constant	11.732***	15.875***	10.594***	12.132***	16.283***	11.107***	14.735***	10.285***
	(1.498)	(1.648)	(1.438)	(1.512)	(1.653)	(1.473)	(1.533)	(1.466)
R2	0.85	0.88	0.84	0.86	0.89	0.85	0.87	0.84
F test	212.48	367.82	287.66	327.84	315.52	263.37	315.71	274.54
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Number of obs.	468	468	468	468	468	468	468	468

Source: Calculated by the authors

DISCUSSION

Regarding the variables in Table 4 referring to the reverse logistics and competitiveness, the Foreign Direct Investment (FDI) (Model 1: $\beta = 0.022$, $p < 0.05$) and the contemporary Regulatory Restrictiveness Index (RRI) (Model 2: $\beta = 0.026$, $p < 0.05$) have a positive impact. In this way, we support our *Hypothesis 1: Reverse logistics has a positive impact on the competitiveness of the enterprise.*

The results of another study also indicate a positive link between reverse logistics and competitiveness Reverse logistics brings strategic competitive advantage and helps to minimize the total costs generated by the launch of new products in the market and their reintegration into the value chain [Chaves et al., 2020]. Sabawi and Israa [2019] made a number of conclusions were reached that there is a significant role of reverse logistics in sustaining the competitive advantages. Reverse logistics is becoming more important to companies through achieving more competitive advantages [Moktadir et al., 2020]. Hence, reverse logistics management ensure that enterprises' competitive advantages are central to enterprise management [Yang et al., 2020].

Regarding the reverse logistics and competitiveness of the enterprise, Environmental and resource productivity (ERP) (Model 3: $\beta = 0.016$, $p < 0.05$) and Total amount of waste generated by sector (TAW) (Model 4: $\beta = 0.15$, $p < 0.05$) have a positive impact. In this way, we support *Hypothesis 2: Reverse logistics has a positive impact on the economic performance of the enterprise.*

This result is confirmed by other studies. The findings of the study Mutuku concluded that reverse logistics have a positive relationship with economic performance [Mutuku and Moronge, 2020]. In the study Bor [2020] was also established that reverse logistics had a significant and positive effect on the economic performance of enterprises. Another research showed that reverse logistics has a positive impact on financial performance [Prajapati et al., 2021].

Regarding the reverse logistics and ecological environmental impact of the enterprise, Business with bioecological component (BBC) (Model 5: $\beta = 0.052$, $p < 0.05$) and Business sub-ecological (BS) (Model 6: $\beta = 0.21$, $p < 0.05$) have a positive impact. In this way, we support *Hypothesis 3: Reverse logistics has a positive impact on the ecological environment of the enterprise.*

This result is in agreement with the other studies. Implementation of reverse logistics programs has been contemplated to mitigate the negative environmental effects of manufacturing [Job et al., 2020]. When the organizations competently manage their reverse logistics, it results in improving the environment [Phoosawad et al., 2019]. According to research by Fernando et al. [2018], reverse logistics contributes to the company's greater compliance with environmental standards.

Regarding reverse logistics and society, Consumer Support Estimate (CSE) (Model 7: $\beta = 0.011$, $p < 0.05$) and Gross domestic expenditure on R&D by sector of performance and socio-economic objective (Model 8: $\beta = 0.52$, $p < 0.05$) have a positive impact. In this way, we support *Hypothesis 4: Reverse logistics has a positive impact on society.*

The results of this study are consistent with the study by other authors. Findings of the research Milichovsky [2017] show the connection of reverse logistics and individual communication tools, which are well-accepted on the customer side. Majzoub et al. [2020] prove the significant impact of reverse logistics on customer satisfaction. Thus, reverse logistics acts as an element of differentiation among competitors, able to simultaneously intensify the growth of customer satisfaction and profitability of the company [Miranda et al., 2016].

CONCLUSIONS

The purpose of this study was to investigate the relationship between reverse logistics and competitiveness, economic performance, ecological environment and society. The main section of this study analysed data on 37 European countries for the period from 2000 to 2019. All the hypotheses that were proposed at the beginning of the study were eventually accepted. The study confirms the opinion that the introduction of reverse logistics has a positive impact on enterprises. Thus, this study provides confirmation of similar research findings and can serve as a benchmark for conducting similar studies.

The study has some limitations as the data are collected only from OESD countries. For more accurate results, similar research should be conducted in other countries. Perhaps if perform research within other countries, can find some additional dependencies.

Another limitation is that only the relationship between reverse logistics, competitiveness, economic performance, ecological environment, society is mentioned in the article. Therefore, subsequent research should investigate and identify patterns with other aspects. In addition, the impact of national legislation and culture on reverse logistics should be monitored.

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ORIGINAL PAPER

THE EFFECTS OF INFORMATION TECHNOLOGIES ON AUTOMOTIVE SUPPLY CHAIN AND FIRM PERFORMANCE. A PLS-SEM APPROACH

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ABSTRACT. Background: In today's context, information technology is increasingly taking a great interest for academics and practitioners. IT plays a critical role in supply chain readiness to meet market changes by lowering costs and enhancing quality. Hence, the objective of this article is to explore the effect of information technology integration (ITI) and supply chain information management (SCIM) on supply chain integration (SCI) and its association with supply chain performance (SCP) and firm performance in the automotive supply chain.

Methods: The research data were collected from 177 middle and top-level managers of automotive firms installed in Morocco. The structural equation modelling under the partial least squares approach was used in testing the hypotheses and proposed model.

Results: The study findings show that ITI and SCIM positively and significantly affect the level of SCI. In addition, SCI positively and significantly affects SCP and firm performance. Furthermore, SCP plays a direct and positive role in improving firm performance.

Conclusions: The study results provide direction on how automotive SC managers might enhance automotive SCP and firm performance.

Keywords: Supply chain, information technology, IT integration, information management, performance.

INTRODUCTION

The Moroccan automotive industry has succeeded in gradually becoming a leading sector of the national economic environment. The dedicated strategy to this sector has been time to establish the foundations of an efficient and competitive automotive industry, sufficiently integrated into global value chains.

First constriction hub in Africa, the Moroccan automotive industry is the leading sector of export, with over 250 national and international players, this sector contributes to the generation of more than 147,000 direct jobs creation between 2014 and 2019. With nearly 400,000 cars manufactured in 2019, the country is Africa's second-biggest automotive producer after South Africa and the first producer of passengers' cars.

Morocco currently operates with four large industrial hubs in Tangier, Kenitra, Rabat, and Casablanca, as also many training institutes specialized in the automotive industry. With these strengths, the automobile sector provides meaningful opportunities for multinational companies.

The automotive manufacturing business is demand-driven in a complex way, in which the supply chain has a pivotal function [Boysen et al. 2015].

In today's globalized economic environment, competition is not occurring through individual firms but rather across supply chains [Farahani et al. 2014]. Given its

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role in improving supply chain performance and business performance, the integrative supply chain has been a major concern for large automotive companies. In this regard, IT integration and supply chain information management seem to be essential to streamlining automotive supply chain practices.

From this perspective, the current study aims to explore the key factors influencing automotive supply chain performance and firm performance. Therefore, the research questions (RQ) are.

- RQ1: How does IT integration, and SC information management impact the SC integration?
- RQ2: What is the effect of SC integration on SC performance and firm performance?
- RQ3: How does SC performance affect firm performance?

To address these questions of the study, the article is organized through three sections. The first one provides a literature overview. The second presents the research methodology. Following a description of the findings in the third section, the results are discussed in the fourth section.

THEORETICAL FOUNDATIONS AND HYPOTHESES DEVELOPMENT

In general, supply chains are structured around both inter-functional integration and inter-organizational integration. Inter-functional integration involves integrating all upstream and downstream logistics processes [Tyndall et al. 1998]. While inter-organizational integration refers to sharing information, risks, and rewards between SC partners [Cooper and Ellram, 1993].

At this level, information systems generally, and supply chain information systems (SCIS) specifically, play a significant part in implementing supply chain best practices, by offering numerous benefits for organizations [Erceg and Damoska-Sekulowska, 2019; Bal and Pawlicka, 2021].

We consider the supply chain information system (SCIS) as an inter-organizational information system, which allows us to rationalize the internal and external functioning of the company, by allowing efficient flow management between supply chain partners (Fig. 1). SCIS encloses a number of technological solutions that take part at different levels, including the strategic level (advanced planning and scheduling systems -APS), the tactical level (enterprise resources planning systems -ERP), the operational and real-time level (supply chain execution systems -SCE).

In changing marketplace, supply chain information systems allow SC partners to meet clients' needs by providing the right product, at the right price, at the right place and time. In practice, APS solutions are designed for the long-term (strategic level), by helping companies to achieve various objectives at the right cost, time, and quality [Jamrus, Wang, & Chen, 2020]. Likewise, the ERP solutions provide business processes automation, which turns in enhancing efficiency and reducing logistics costs [Oghazi et al. 2018]. As well, electronic data interchange (EDI) solutions support coordination between partners along the supply chain, which in turn help to enhance performance across quality, cost and competitiveness [Hill and Scudder, 2009].

IT integration (ITI), SC information management (SCIM) and SC integration (SCI)

In today's context, information technology [IT] is increasingly taking a great interest for academics and practitioners. This interest in IT can be explained by their critical role in helping organizations collect, store, access, share and analyse data effectively and efficiently [Swafford, Ghosh and Murthy, 2008]. IT enhances the enterprises' ability to process information and sustains business transactions by building connections between organizations and their clients [de Barros et al. 2015].

IT integration can be defined as the degree of communication, coordination, and integration of relevant information between different internal functional departments and external supply chain members [Swafford et al.

2008]. It reflects the level to which information is communicated, coordinated and integrated in a meaningful way between different internal functional departments and external supply chain partners.

IT integration among supply chain partners covers communications, processes, sharing, coordination, and joint decision-making [Singh and Teng, 2016]. ITI covers three kinds of flow integration, namely physical flow integration, financial, and information flows [Rai, Patnayakuni and Seth, 2006].

Previous studies on SC management has been given to the impact of information IT/IS on supply chain integration. The IT is identified as a tool to ensure SC integration and collaboration, by synchronization of material flow, information and financial [Acar and Uzunlar, 2014], and facilitating the coordination and communication between the supply chain members [de Barros et al. 2015].

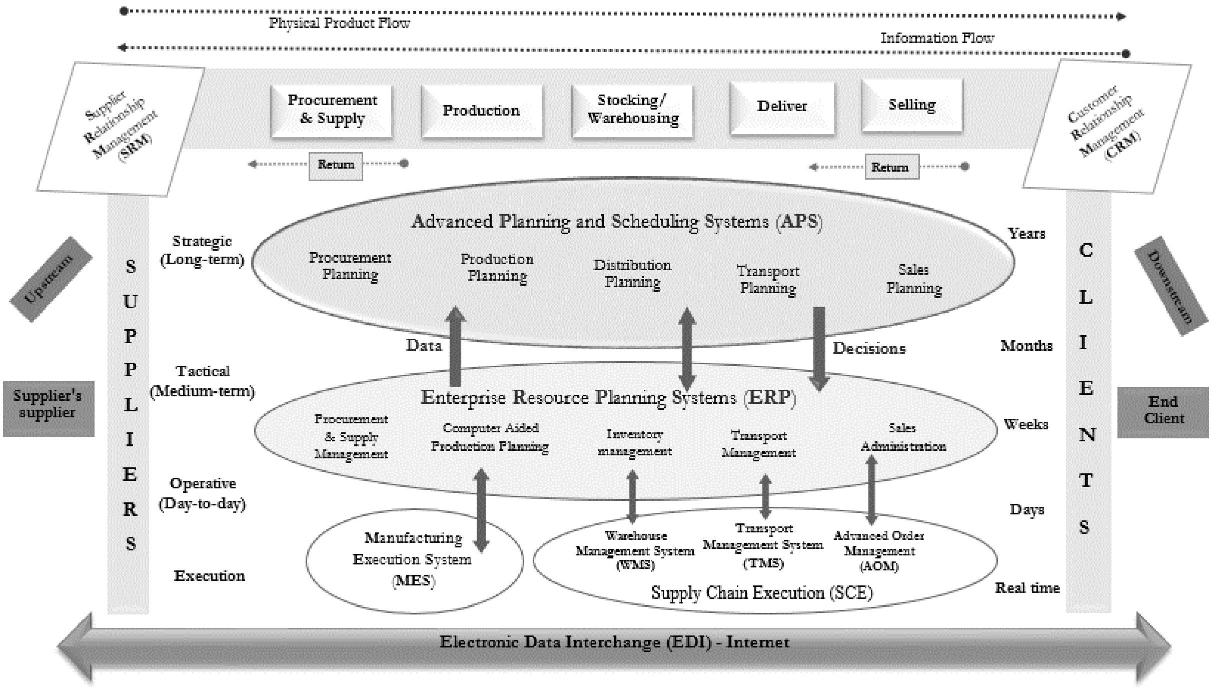

Fig. 1. Supply chain information systems tools used in the supply chain (own elaboration)

Scholars have also shown that IT integration represents a crucial element for the proper functioning of the supply chain, by facilitating the SC integration [Li et al. 2009]. Also, IT integration enhances effective interaction and cooperation for true integration of business processes across supply chain partners [Cooper and Tracey, 2005]. Kim [2017] empirically confirmed the positive influence of integrative IT on SC integration.

In addition, previous studies investigated the effect of SC information management on the SC integration. The purpose of SCIS is to diffuse information through the members of the supply chain [Sundram et al. 2018]. Based on an empirical study among 248 manufacturing businesses, Sundram et al. [2018] argued that SC information management affects positively the level of supply chain integration. Therefore, we can suppose that:

H1: ITI directly and positively affects SCI.

H2: SCIM directly and positively affects SCI.

SC integration (SCI), SC performance (SCP) and firm performance

Supply chain integration refers to the extent and strength of linkages of supply chain processes across firms [Leuschner, Rogers and Charvet, 2013]. It is enabled by informational, operational, and relational integration [Flynn, Koufteros and Lu 2016]. Existing studies suggest different perspectives to define SCI

[Özdemir, Simonetti and Jannelli, 2015]. This concept is analysed with two measures, namely downstream integration with customers and upstream integration with suppliers [Sun and Ni, 2012]. Another vision consists of both internal [Basnet, 2013], and external integration [Boon-itt 2009; Barratt and Barratt 2011; Wong, Wong and Boon-itt, 2013].

For other researchers the SCI can be approached according to three dimensions, namely internal, suppliers, and customer integration [Boon-itt 2009; Flynn, Huo and Zhao, 2010; Chang et al. 2016]. Even more, Ataseven et al. [2020] distinguish between three levels of integration such as supply integration, demand integration, and internal integration.

In sum, SCI refers to "*the degree to which an organization's internal functions and external supply chain partners strategically and operationally collaborate with each other to jointly manage intra- and inter-organizational quality-related relationships, communications, processes, etc., with the objective to achieve high levels of quality-related performance at low costs*." [Huo, Zhao and Lai, 2014:39].

In this study, we focus on both sides of integration, including internal and external integration among the supply chain members. This dual integration is essential to enable a seamless and synchronous flow of information in and through the entire manufacturing supply chain [Sundram et al. 2018].

Many studies have explored SCI well to identify its benefits [Leuschner et al. 2013]. At this level, a large number of existing studies generally agreed on the fact that SCI provides enhanced operational performance [Gimenez, van der Vaart and Pieter van Donk, 2012]. Flynn et al. [2010] argued that internal and customer and supplier integration contribute to the firm performance, by enhancing its level of operational and business performance. Even more, both Internal and customer integration contribute more closely to performance improvement than supplier integration [Flynn et al. 2010]. On their side, Özdemir et al. [2015] studied the effect of SCI and competition capabilities on business performance. They found a positive effect of SCI on competition capabilities and business performance.

In addition, it is recognized that external integration affects positively and directly product innovation [Wong et al. 2013]. Zhao et al. [2015] argued that that integration plays a central part in improving financial performance. As indicated by Chen et al. [2018] a higher degree of integration leads to enhanced firm performance. Based on a meta-analysis, Leuschner et al. [2013] found a positive and significant correlation between SCI [information, operational integration, and relational integration] and firm performance [business, relational and operational performance]. More recently, Chang et al. [2016] supported the positive effect of the internal, supplier, and customer integration on financial performance.

A number of studies support a positive relationship between SCI and SCP [Sezen 2008; Koçoğlu et al. 2011]. Li et al. [2009] claimed that integration in supply chain members [supplier integration, customer integration, and intra-organizational integration] enhance supply chain performance. More recently, Mofokeng and Chinomona [2019] verified empirically that supply chain integration plays a key determinant to supply chain performance improvement. Thus, we hypothesize that:

H3: SCI directly and positively affect SCP.

H4: SCI directly and positively affect firm performance.

Supply Chain Performance (SCP) and Firm Performance

Supply chain performance is defined as "the ability of a supply chain to cost-effectively carry out its activities while minimizing costs, for the main purpose of meeting the ultimate customer's needs" [Mofokeng and Chinomona, 2019:3]. There is a growing body of literature that recognizes the importance of supply chain performance in enhancing firm performance [Li et al. 2006; Qrunfleh and Tarafdar, 2014]. The supply chain's performance represents an essential condition for value-generating [Mofokeng and Chinomona, 2019]. Thus, we propose the following hypotheses.

H5: SCP directly and positively affects firm performance.

Our proposed research model includes two independent variables, namely IT integration and supply chain information management, and three dependent variables, supply chain integration, supply chain performance, and organization performance (Fig. 2).

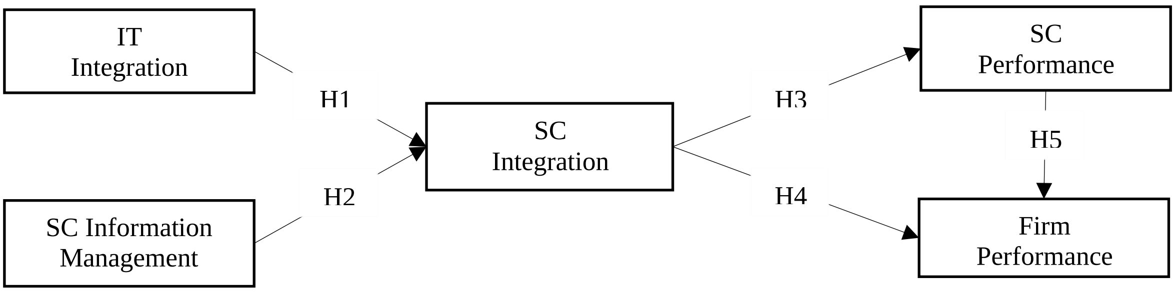

Fig. 2. Proposed research model.

MATERIAL AND METHODS

Research context

The Moroccan automotive industry has achieved sustained growth over the recent decade. This performance is especially noteworthy with regard to exportation and job generation, where the sector has registered a double-digit growth rate every year. Many stakeholders are interacting inside the automobile SC [Raj Kumar Reddy et al. 2021], including designers, third-tier suppliers (initial raw material suppliers: steel, rubber, plastic, silica); second-tier suppliers (component suppliers: piston, gears, alloy wheels, rubber tyre, leather, seat frames, electronics, processors, adhesives, glass sheets), first-tier suppliers (component suppliers: tyre, seats, electronics, glass suppliers); original equipment manufacturer (OEM), transporters, and distributors (Fig. 3).

In this context, the integration of the various players in the supply chain constitutes a major challenge for major automotive firms. Thus, this study focuses on identifying factors that foster supply chain integration and consequently enhance the supply chain and automotive firm performance.

Sample and data collection method

The convenience sampling method is used for data collection among respondents through on-line questionnaire. At that stage, the Google Forms tool was used to administer the research questionnaire, by disseminating the survey link to the target population via social and professional networks, such as Telegram, Viadeo, and LinkedIn. The research questionnaire was conducted in two steps. In the first step, a pre-testing phase of the questionnaire items was conducted to ensure the validity of the questionnaire content. In a second step, the questionnaire was administered via an online survey that applied to the middle and top-level managers of automotive supply chain partners installed in Morocco for five months from November 2020 and March 2021.

Our research questionnaire is arranged in two parts. The first part concerns the socio-demographic and company characteristics, including respondent gender, age range, job title, education level, work experience, company's role in the automotive supply chain, and company geographical location. While the second part of the questionnaire measures the various latent variables, i.e., IT integration (ITI), SC information management (SCIM), SC integration (SCI), SC Performance (SCP), and firm performance (FP).

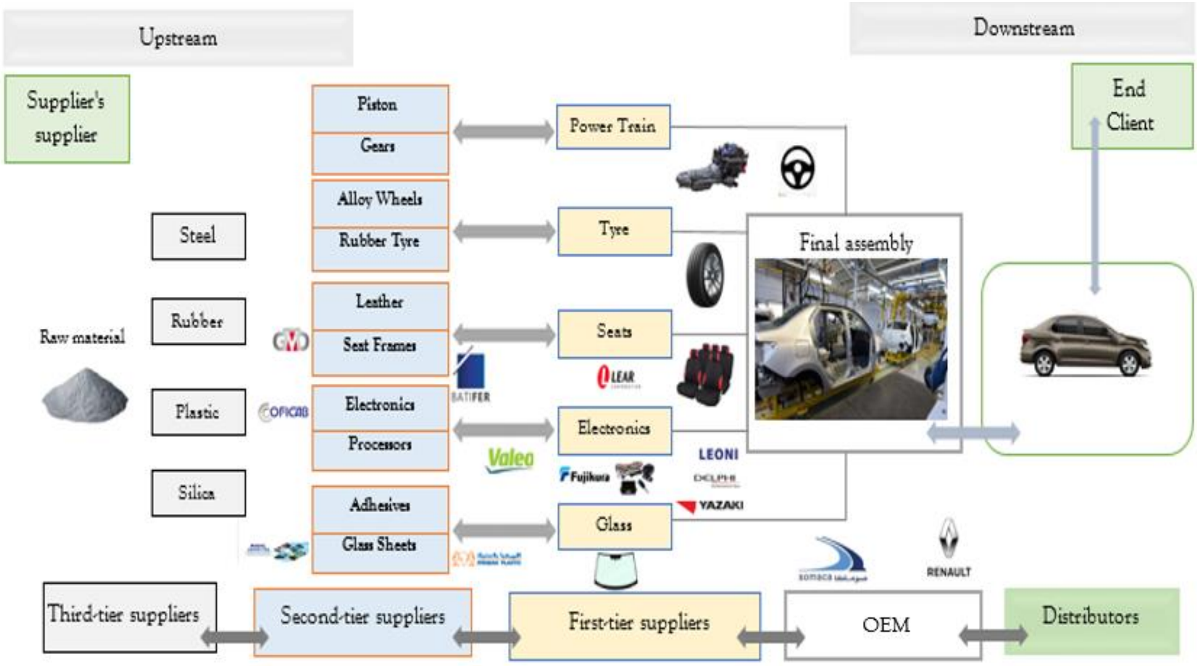

Fig. 3. Automotive supply chain in Morocco.

During the data collection period, we received 177 correct responses (Table 1), including 147 responses from males (83.1%) and 30 from females (16.9%). Regarding the age of respondents, 69 of them are aged between 20 and 26 years old (39%), followed by 67 between 36 and 44 years old, and 22 are aged between 27 and 35 years old. A small number of respondents (19) are over 50 years old (10.7%). The highest percentage of survey participants (84.7%) has a master degree (BAC+5). Regarding the occupation of the respondents, we note that more than 24% of the respondents are production planners, followed by 12.4% of customer service specialists, and more than 30% of respondents are logistics coordinators (10.7%), supply planning managers (10.7%), and procurement managers (10.2%). 38.4% of respondents are between 3 and 5 years old as work experience. Statistics descriptive revealed that 49.2% of respondents were from first-tier suppliers, 37.3% from second-tier suppliers, and finally, 13.6% from original equipment manufacturers. A large part of these companies is located in Tangier (42.4%) and Casablanca (26%).

Measurement instruments

The questionnaire design has been based on measurement scales selected from earlier studies. Hence, information technology integration (ITI) was measured using the Chen [2019] scale with five items. For both variables supply chain information management (SCIM) and supply chain integration (SCI), we mobilized the Sundaram et al. [2018] scale with five items. Referring to Chowdhury et al. [2019], supply chain performance (SCP) was measured with five items. Finally, the measurement of firm performance (FP) was based on the non-financial performance measured by five items selected from the study of Wu and Chiu [2018]. We adopted the seven Likert-type scale to measure each variable. The agreement options are from one as a total disagreement to seven as total agreement (Appendix 1).

Table 1. Descriptive statistics (n = 177)

Categorical		Frequency (%)
Gender	Male	147 (83.1%)
	Female	30 (16.9%)
Age range	20-26 years old	69 (39.0%)
	27-35 years old	22 (12.4%)
	36-44 years old	67 (37.9%)
	Above 50 years old	19 (10.7%)
Education	Bachelor (BAC+3)	15 (8.5%)
	Master degree (BAC+5)	150 (84.7%)
	Master of business administration (MBA)	10 (5.6%)
	PhD (BAC+8)	2 (1.1%)
Job title	Production planner	43 (24.3%)
	Customer service specialist - logistics	22 (12.4%)
	Logistics supervisor	21 (11.9%)
	Logistics coordinator	19 (10.7%)
	Supply planning manager	19 (10.7%)
	Procurement manager	18 (10.2%)
	Transport planner	10 (5.6%)
	Transport manager	9 (5.1%)
	Logistic manager	7 (4.0%)
	Logistics project manager	6 (3.4%)
	Supply chain manager	3 (1.7%)
Work experience (years)	1-3	10 (5.6%)
	3-5 years	68 (38.4%)
	5-7 years	26 (14.7%)
	Above 7 years	73 (41.2%)
Company place in automotive SC	First-tier suppliers	87 (49.2%)
	Second-tier suppliers	66 (37.3%)
	OEM	24 (13.6%)
City	Tangier	75 (42.4%)
	Casablanca	46 (26.0%)
	Kenitra	42 (23.7%)
	Meknes	11 (6.2%)
	Taza	3 (1.7%)

Data analysis method

In order to test the hypotheses and research model, the partial least squares structural equation modelling method was used [Hair et al. 2019; Boubker and Douayri 2020]. For generating descriptive statistics, IBM SPSS Statistics 21 were used. In addition, Smart PLS 3.3.3 software was used to assess the outer model and inner model. The first step of the PLS approach consists in checking the measurement models' validity, through convergent and discriminant validity. Convergent validity requires the assessment of various criteria, namely, reliability of individual items (≥ 0.7), composite reliability (CR ≥ 0.7), factor loadings, and average variance extracted (AVE ≥ 0.5). Discriminant validity involves the examination of the following three criteria: variable correlation, cross landings and heterotrait-monotrait (HTMT) ratio [Henseler, Ringle and Sarstedt 2015]. The second phase of the PLS method involves structural model assessment under several criteria including coefficient of determination (R^2), effect size (f^2), predictive relevance (Q^2), goodness-of-fit (GoF), and hypotheses testing under β-value, t-value, and p-value [Boubker, Douayri and Ouajdouni, 2021].

RESULTS

Results of outer models assessment

Table 2 outlines the results of measurement model's assessment. The outer loading of all indicators is above 0.7 (Fig. 4). In addition, the values of AVE are all above 0.5, indicating that all concepts explain at a minimum of 50%of the variance in its items [Hair et al. 2019]. In addition, the values of Cronbach's α, and CR are more than 70%. Therefore, these findings proved to have robust convergent validity. In addition, the discriminant validity assessment is verified by the criterion of Fornell-Larcker. As recommended by Henseler et al. [2015], the highest value of HTMT ratio is 0.74 (Table 3).

Table 2. Results of reliability, convergent and discriminant validity

Construct	Alpha	CR	rho_A	AVE	FP	ITI	SCIM	SCI	SCP
FP	0.97	0.97	0.97	0.88	0.94				
ITI	0.97	0.97	0.98	0.90	0.66	0.95			
SCIM	0.94	0.96	0.95	0.80	0.23	0.20	0.89		
SCI	0.91	0.93	0.93	0.74	0.60	0.62	0.27	0.86	
SCP	0.96	0.97	0.97	0.87	0.71	0.64	0.14	0.57	0.93

Table 3. Discriminant validity using the HTMT ratio

Construct	FP	ITI	SCIM	SCI	SCP
FP					
ITI	0.68				
SCIM	0.23	0.20			
SCI	0.63	0.65	0.31		
SCP	0.74	0.66	0.13	0.59	

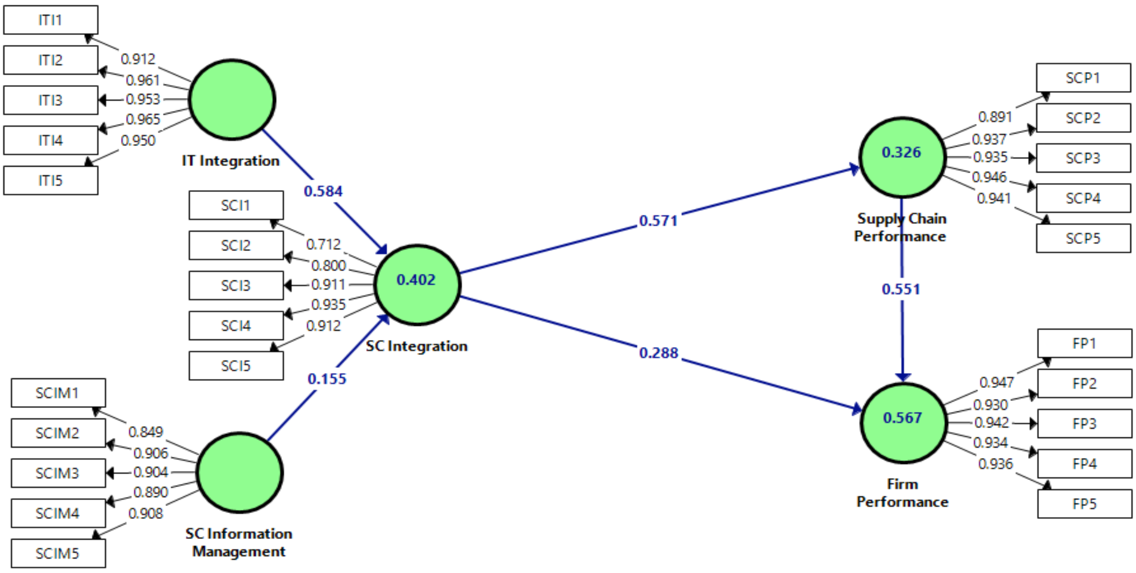

Fig. 4. Measurement model assessment results.

As shown in Table 4, the discriminant validity is also ensured with the cross-loading criteria, showing that the loadings of the indicators are higher than all its cross-loadings.

Results of assessing structural model

For the inner model assessment the R-square values for the three endogenous latent variables, SCI, SCP and FP are 0.40; 0.33; 0.57 and 0.802, respectively. This indicates an acceptable level of determination [Hair et al. 2011]. Cohen [1988] suggested that f^2 values higher than 0.35, 0.15, and 0.02 can be categorized as strong, moderate, and weak, respectively. In this study, the f^2 of ITI and SCIM on SCI are 0.55, and 0.04, which means that their effect sizes are strong and weak, respectively. In addition, the f^2 of SCI on SCP and FP are strong (0.48) and weak (0.13), respectively. The f^2 value of SCP on TP is 0.47, which reflect à strong effect size.

The results listed in Fig. 5 confirm that all values of the Q^2 index are greater than zero, indicating that the constructs have a predictive relevance for the considered endogenous construct [Hair et al. 2011]. Finally, the value of the goodness-of-fit is 0.596647, which reflect a large GoF [Henseler, Ringle and Sinkovics, 2009].

The findings provide evidence to support all research hypotheses. The first hypothesis was accepted (H1. β= 0.584, t = 12. 284; p = 0.000), showing a significant and positive relationship between IT integration and SC integration. The second hypothesis, which states that SC information management has a positive effect on SC integration, is statistically significant (H2. β= 0.155; t = 2.332; p = 0.020). The SEM-PLS results also confirm the third and fourth hypotheses, by showing a positive relationship between SC integration and SC performance (H3. ***β* = 0.571; *t* = 12.**531; *p* = 0.000), and firm performance (H4. *β* = 0.288; *t* = 4.291; *p* = 0.000). The fifth hypothesis was also supported by showing a positive, significant and direct effect of SC performance on firm performance (H5. *β* = 0.551; *t* = 7.621; *p* = 0.000).

Table 4. Discriminant validity based on the cross-loading criteria.

	FP	**ITI**	**SCIM**	**SCI**	**SCP**
FP1	0.95	0.62	0.19	0.56	0.70
FP2	0.93	0.60	0.24	0.57	0.62
FP3	0.94	0.62	0.23	0.52	0.63
FP4	0.93	0.63	0.18	0.54	0.70
FP5	0.94	0.63	0.24	0.63	0.69
ITI1	0.65	0.91	0.15	0.54	0.61
ITI2	0.65	0.96	0.18	0.60	0.65
ITI3	0.61	0.95	0.22	0.60	0.62
ITI4	0.60	0.96	0.17	0.60	0.60
ITI5	0.63	0.95	0.23	0.57	0.58
SCIM1	0.15	0.13	0.85	0.18	0.07
SCIM2	0.15	0.17	0.91	0.21	0.06
SCIM3	0.19	0.20	0.90	0.23	0.13
SCIM4	0.23	0.17	0.89	0.24	0.10
SCIM5	0.27	0.20	0.91	0.31	0.21
SCI1	0.38	0.42	0.49	0.71	0.34
SCI2	0.42	0.44	0.29	0.80	0.33
SCI3	0.53	0.52	0.14	0.91	0.51
SCI4	0.63	0.64	0.17	0.94	0.63
SCI5	0.57	0.57	0.16	0.91	0.56
SCP1	0.59	0.49	0.12	0.46	0.89
SCP2	0.75	0.66	0.19	0.52	0.94
SCP3	0.72	0.69	0.14	0.59	0.94
SCP4	0.63	0.58	0.08	0.57	0.95
SCP5	0.62	0.55	0.11	0.50	0.94

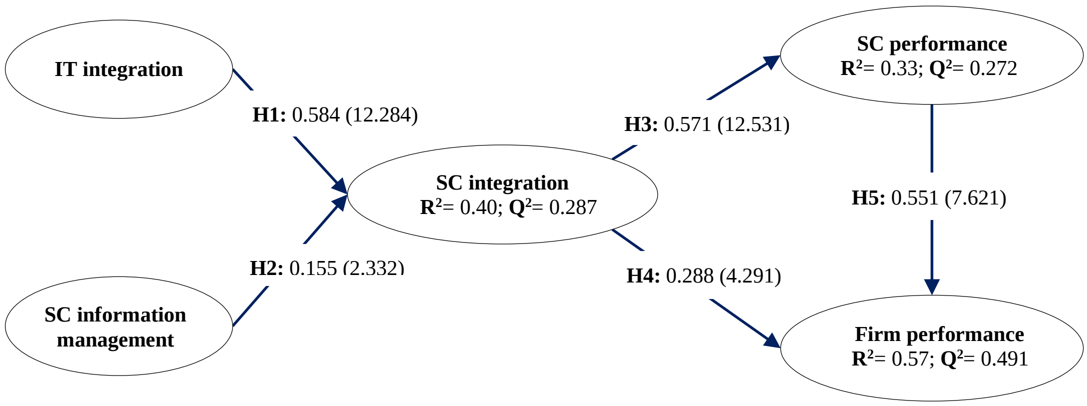

Fig. 5. Hypotheses testing results.

DISCUSSION AND CONCLUSION

The objective of this study was to investigate the link between ITI, SCIM, SCP and firm performance in the case of the Moroccan automotive supply chain. The results reveal that the ITI and SCIM plays a central role in enhancing the level of automotive SCI. These results are consistent with the previous studies, which suggest that ITI contributes to building SCI [Li et al. 2009; Acar and Uzunlar, 2014]. The empirical study of Sundram et al. [2018] confirmed the positive link between SCIM and SCI. In addition, it turns out that automotive SCI enhances SCP and firm performance. As suggested by earlier research, the integrative supply chain plays a central role in firm performance improvement [Flynn et al. 2010; Chen et al. 2018]. As indicated by Chen et al. [2018] a higher level of SC integration leads to enhanced firm performance. Also, SCI is presented as a solution to enhance the level of SCP [Mofokeng and Chinomona, 2019].

Further, the findings of this research confirmed the positive, direct and significant link between SC performance and firm performance. The validation of this hypothesis is in line with past literature [Li et al. 2006]. Qrunfleh and Tarafdar [2014] concluded that improving the level of SCP positively affect the level of firm performance.

Previous studies suggest that national culture characteristics dictate the type of inter-organizational trust, which in turn affects the nature of SC integration [Balambo, 2013]. Accordingly, our conclusions may be extended for other countries, which are characterized by a similar national culture to Morocco, such as Tunisia.

In both Morocco and Tunisia, the implementation of automotive value chains is the outcome of industrial policy that seeks to enhance comparative advantages by stimulating innovation and technological learning. These two countries have achieved a level of manufacturing capabilities in the automotive industry allowing to increase the North African region's involvement in global value chains. At this level, IT integration and SC information management may turn into unavailable conditions for improving the level of integration of the automotive supply chain in the North African context, which may contribute to achieving a high-level SC performance and firm performance.

Our findings highlight the importance of ITI and SCIM on the enhancement of automotive. SCI also contribute to the explanation of the level of SCP and firm performance. Likewise, SC performance is identified as a determinant of firm performance. This research has enriched the supply chain management literature. Consequently, the major theoretical contribution concerns proposing a model adapted to the context of the automotive supply chain, allowing a better understanding of the contribution of integrative SC and SC information management to the automotive SC performance.

This study also provides some implications for automotive supply chain managers and practitioners. The study has demonstrated that ITI integration and SC information management play a central role in fostering SC integration. In the same, the SC integration contributes to fostering the level of SCP and to enhancing automotive firm performance. At this level, we suggest that the use of inter-organizational IS and the integration of IT in the automotive SC partners should be reinforced in order to ensure SC integration, by responding to demand changes with optimal stock.

In order to enhance automotive SC performance and firm performance, SC partners are invited to reinforce the integrative SC, by establishing more frequent contact with other SC members, creating a compatible communication and information system, participating in the sourcing decisions of their suppliers, and assisting in their customers' marketing efforts.

Despite these implications, the present study has a number of limitations. The conceptual model includes just three variables to predict SC performance and firm performance. It may be interesting to also include other variables such as SC collaboration, information quality, supply chain information system infrastructure, inter-organizational trust, and risk management culture. Moreover, this study is based on previous research to elaborate the research questionnaire. In order to develop a measurement scale adapted in the context of the automotive industry, a qualitative study will be appropriate.

Appendix 1. Questionnaire

Gender	:	□ Female		□ Male	
Age range (years)	:				
Education	:	□ Bachelor	□ Master degree	□ MBA	□ PhD
Job title	:				
Work experience (years)	:	□ 1-3	□ 3-5	□ 5-7	□ ≥ 7
Company place in automotive SC	:				
City	:				

IT integration (SCI)	
ITI 1.	Use of IT to coordinate/integrate activities in design and development
ITI 2.	Use of IT to coordinate/integrate activities in procurement
ITI 3.	Use of IT to coordinate/integrate activities in manufacturing
ITI 4.	Use of IT to coordinate/integrate activities in logistics and distribution
ITI 5.	Use of enterprise resource planning or SC planning software for managing/ coordinating global SC
Supply chain information management (SCIM)	
SCIM 1.	Timely disseminate the information along with the SC
SCIM 2.	Joint production planning and scheduling among suppliers, manufacturing, marketing and distributors
SCIM 3.	Link information systems so that each member of a SC knows others' requirement and status
SCIM 4.	Practice quick information flows along the supply chain
SCIM 5.	Accurate information is usually available for decision-making in our organization.
Supply chain integration (SCI)	
SCI 1.	Firms in SC establish more frequent contact with each other
SCI 2.	Firms in SC create a compatible communication and information system
SCI 3.	Firm extends its SC beyond its customers/suppliers
SCI 4.	Firm participates in the marketing efforts of its customers
SCI 5.	Firm participates in the sourcing decisions of its suppliers
Supply chain performance (SCP)	
SCP 1.	Lead time
SCP 2.	Quality
SCP 3.	Sales growth
SCP 4.	Profit
SCP 5.	Cost
Firm Performance	
FP 1.	The SC can help the firm improve its return on investment.
FP 2.	The SC can help the firm improve its return on assets.
FP 3.	The SC can help the firm improve sales growth.
FP 4.	The SC can help the firm improve production and inventory cost

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ORIGINAL PAPER

FUZZY FAILURE MODE AND EFFECT ANALYSIS MODEL FOR OPERATIONAL SUPPLY CHAIN RISKS ASSESSMENT: AN APPLICATION IN CANNED TUNA MANUFACTURER IN THAILAND

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ABSTRACT. Background: This study proposes a multi-criterion decision-making (MCDM) framework for operational supply chain risks assessment based on fuzzy failure mode effect analysis model. The proposed framework attempts to overcome some weaknesses and disadvantages of the traditional FMEA in many aspects such as (i) considering "degree of difficulty to eliminate risks" in the assessment process, (ii) using MCDM ranking methodology instead of a risk priority number, (iii) taking both subjective and objective weights of risk criteria into account. Application of the proposed framework used canned tuna production in Thailand as a case study.

Methods: In this study, the operational supply chain risks assessment is treated as fuzzy MCDM problem. Subjective weights of risk criteria are determined by experts' judgements. Objective weights are derived by Shannon entropy method. VIKOR approach is employed to prioritize the failure modes. A sensitivity analysis is performed to examine the robustness of the proposed framework.

Results and conclusions: The findings from this study indicates that the most three critical FMs are "risk of product deterioration" followed by "risk of volatility raw materials supplied" and "risk of variabilities in production processes", respectively. It recommends that the practitioners in canned tuna industry should give the priority to mitigate these risks. Although the present study focuses on canned tuna industry, the other similar industries can apply this proposed framework to assess their operational supply chain risks in the same way.

Keywords: Operational supply chain risks; FMEA; MCDM; Shannon entropy; VIKOR

INTRODUCTION

The rapidly changing business environment causes manufacturers to encounter various risks and uncertainties in managing their supply chain activities, such as variations in the lead time of incoming raw materials, demand volatility, unexpected machines and equipment breakdown, labour shortage and IT disruption [Wu et al. 2019]. These risks adversely affect not only the efficiency of supply chain operations but also the desired performance outcomes of manufactures. Organizations that seek only high performance and neglect risk management are doomed to failure in today's turbulent business environment [Fan et al. 2016]. Risks may arise from natural disasters or man-made problems and it should have a negative impact on industries in the form of financial and operational difficulties that could lead to business disruption [da Silva et al. 2020].

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Principally, the sources of supply chain risks can arise from both inside and outside of organizations [Moktadir et al. 2018]. However, most manufacturers have internal risk management and often overlook significant risks throughout their supply chains. Although some risks are inevitable, organizations should seek proactive mechanisms to monitor, control and manage them to alleviate their affection [Mohamed and Youssef 2017]. Hence, supply chain risk management (referred as SCRM) becomes an essential part of operations management [Shan et al. 2020]. SCRM can be described as the identification, assessment of risks and development of an effective risk mitigation plan [Butdee and Phuangsalee 2019]. Proper risk management has a positive effect on supply chain efficiency and it can help manufactures be more resilient in the face of major disruptions. Supply chain risks can be classified by the source of risk as (i) disruption risk and (ii) operational risk. Disruption risks come from human-made and natural disasters such as terrorist attacks, economic crises, earthquakes, pandemics, storms, and floods [Nakandala et al.2017]. While, operation risks arise from the execution of business processes or activities in supply chain [Heckmann et al. 2015]. Major sources of operational risks are demand uncertainties, supply chain volatility, market price fluctuation, and machine and equipment breakdown [Shen et al. 2020]. These risks pose a disturbance in the supply chain and require an appropriate assessment to develop risk mitigation strategies [Junaid et al. 2020]. In order to prevent the deterioration in profitability, supply chains management is able to accurately assess risks and fast respond to the risk events. Hence, risk assessment is one of the important processes in risk management [Fan et al. 2016]. There are many risk assessment approaches reported in the literature. Failure Mode and Effect Analysis (FMEA) is one of the most wildly used tools in risk management [Panchal et al. 2018]. The aim of the FMEA method is to proactively manage risks against potential future risk events. The basic concept of FMEA is to determine risk priority number (RPN). There are three quantified risks criteria as severity (S), probability of occurrence (O), and probability of detection (D), then multiply them as a risk priority number (RPN) [Yazdi 2019]. Eliminating or mitigating potential risks will be planned and implemented based on RPN prioritization manner [Liu et al., 2018]. The FMEA calculation procedure can be divided into three main components: (i) determining the critical risk threshold, (ii) calculating the RPN, and (iii) capturing data uncertainty [Scheu et al. 2019]. As can be seen from various studies in literature, the risk assessment and failure modes prioritization procedures for FMEA can be considered as multi-criteria decision making (MCDM) problem [Fattahi and Khalilzadeh 2018]. In addition, fuzzy set theory (FST) is commonly used to deal with imprecise information in decision-making processes [Shaker et al. 2019]. A recent example of the application of MCDM-based FST approaches in FMEA are summarized in Table 1.

Although FMEA technique is applied in many real-world decision-making problems, there has been little research on supply chain risk assessment, especially in seafood supply chain such as tuna industry. The tuna industry has a complex supply chain and is highly volatile in both demand and supply. This could increase the operational risk of the supply chain. Comprehensive operational supply chain risk assessment in tuna industry has not been fully explored from existing literature. To the best of the author’s knowledge, no studies so far have assessed the operational risk of the supply chain in tuna industry. To bridge the gap, this study proposes a new multi-criteria decision-making framework based on FMEA model to assess operational supply chain risk under uncertain environment. To validate the proposed framework, canned tuna industry in Thailand is therefore used as a case study.

Table 1. Recent examples of the application of MCDM-based FST approaches in FMEA

No.	Authors and year of publication	FMEA problems	MCDM Methodology used
1	Karatop et al. (2021)	Renewable energy investment	Fuzzy AHP-EDAS
2	Rathore et al. (2021)	Evaluation of risks in foodgrains supply chain	Fuzzy VIKOR
3	Yener and Can (2021)	Risk assessment of air insulated metal shielded cells production	Fuzzy AHP- MABAC
4	Nabizadeh and Khalilzadeh (2021)	Health, safety and environment risks assessment	Fuzzy goal Programming-VIKOR
5	Pourmadadkar et al. (2020)	Healthcare services risk assessment and quality enhancement	Fuzzy TOPSIS
6	Sagnak et al. (2020)	Evaluation of manufacturing equipment failure in hot-dip galvanizing production process	Fuzzy AHP-TODIM
7	Yazdi et al. (2020)	Risk analysis on a supercritical water gasification	Fuzzy best-worst method-Data Envelopment Analysis
8	Yan et al. (2019)	Risk assessment for construction of urban rail transit projects	Fuzzy matter-element model
9	Wang et al. (2019)	Evaluating and prioritizing risk the potential failure modes of steam valve system	Fuzzy Choquet integral-TODIM
10	Mete (2019)	Assessing occupational risks in pipeline construction	Fuzzy AHP- MOORA

RESEARCH HIGHLIGHTS AND CONTRIBUTIONS

This study attempts to overcome some weaknesses and drawbacks of the traditional FMEA method by proposing a new approach to operational supply chain risk assessment. The highlights of this paper and the contributions to the literature on supply chain risk assessment and FMEA model can be summarized as follows:

- The conventional FMEA is restricted to using only three risk criteria as S, O and D for the FMs rating, lacking consideration of the difficulties in eliminating any risk exposure. In this study, a new risk factor namely "degree of difficulty to eliminate risks" (E) is included to analyze FMEA.
- RPN values are normally used to measure FMs risks level in traditional FMEA. However, the mathematical foundation for computing RPN (S*O*D) is controversial because it is not rational and highly sensitive to variations in results. Because the different combination values of S, O, and D may produce the same RPN values, but the different FMs can have different risk levels. In this study, a compromise programming (CP) approach as VIsekriterijumska optimizacija i KOmpromisno Resenje (VIKOR) approach is used instead of RPN values to assess the operational supply chain risk. The main reasons for using VIKOR in this study are that (i) it is able to assess and identify gaps of FMs performance leading to further improvements (ii) it is straightforward and uncomplicated in computation.
- The classical FMEA assumes risk criteria have equal important weights in risk criteria rating which may not be realistic in various problems in the real-world problems. The advantage of using VIKOR method is that the important weight of risk criteria can be altered in the assessment process.
- Most of the previous research used either subjective weights (purely based on the opinion of decision-makers) or objective weights (based on information gathered from criteria but ignoring opinions from decision-makers) to determine the important weights of risk criteria. In this study, the subjective and objective weights are combined to make the important weights of risk criteria more reliable.
- The proposed framework of this paper will help the practitioners and managers in canned tuna industry to effectively assess the operational risks and prioritize the failure modes in supply chain. Although this study focuses on the canned

tuna industry, the proposed framework can be applied to other industries in a similar procedure.

The present study is organized as follows: a brief of mathematical preliminaries is included in the second part. The proposed framework for operational supply chain risks assessment is presented in the third part of the study. The fourth part illustrates the application of the proposed framework of this study. Finally, the conclusions and future research are drawn in the fifth part.

MATHEMATICAL PRELIMINARIES FUZZY SET THEORY

Fuzzy set theory (FST) was proposed by Zadeh [1965] to logically map linguistic variables to crisp variables in the decision-making processes of human judgement. FST is wildly used to deal with uncertain and imprecise information in fuzzy multi-criteria decision-making (FMCDM) problems. The main concept of FST is defined as linguistic variables based on a specific type of fuzzy set. A fuzzy set is generally represented by a membership function that assigns a degree of membership within the range [0,1] known as fuzzy number to each linguistic variable belonging to the fuzzy set. A fuzzy set can be mathematically defined in terms of fuzzy numbers as: N = $\{(x), \mu_N(x), x \in R\}$; where $\mu_N(x)$ is a degree of membership within the range [0,1].

TRAPEZOIDAL FUZZY NUMBERS (TrFN)

There are different types of fuzzy numbers such as Triangular Fuzzy Number (TFN), Trapezoidal Fuzzy Number (TrFN), and Gaussian Fuzzy Number (GFN). In this study, TrFN is used to address uncertain and imprecise information because it is a comprehensive computation and broadly used in various problems. A pictorial TrFN is shown in figure 1 and the mathematical membership function can be denoted as follows [Wang et al. 2019]:

$$\mu_N(x) = \begin{cases} (x-l)/(m_1-l), & x \in [l, m_1] \\ 1 & x \in [m_1, m_2] \\ (r-x)/(r-m_2), & x \in [m_2, r] \\ 0 & ; otherwise \end{cases} \quad (1)$$

*where $\{(l, m_1, m_2, r) | l, m_1, m_2, r \in R;\ l \le m_1 \le m_2 \le r\}$.

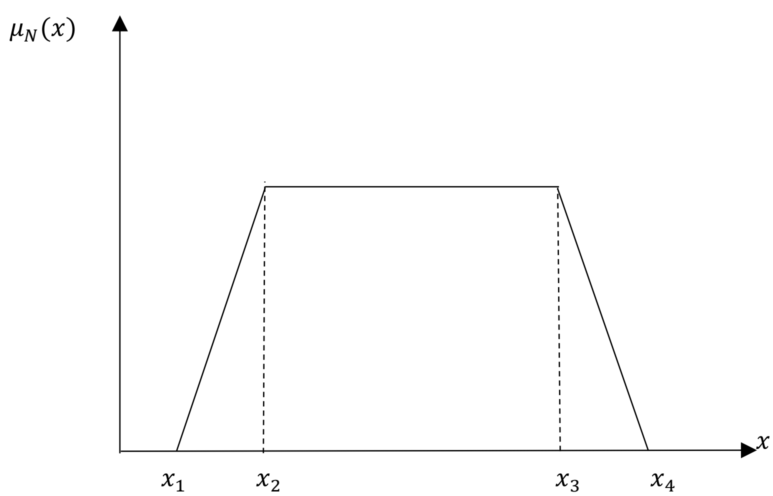

Fig. 1 Trapezoidal fuzzy number

COMPUTING THE SUBJECTIVE WEIGHTS OF RISK

The fuzzy rating for subjective weight of j^{th} criterion is given by the expert k^{th} be $\widetilde{w}_{jk}^{s} = \{(w_{jk1}^{s}, w_{jk2}^{s}, w_{jk3}^{s}, w_{jk4}^{s}) | j = 1,2,..,n\}$. Hence, the fuzzy rating for subjective weights (w_j^s) from all experts are aggregated into group as [Shemshadi et al. 2011]:

$$w_j^s = \begin{cases} w_{j1}^s = \min_k\{w_{jk1}^s\} \\ w_{j2}^s = \frac{1}{k}\sum_{k=1}^{k} w_{jk2}^s \\ w_{j3}^s = \frac{1}{k}\sum_{k=1}^{k} w_{jk3}^s \\ w_{j4}^s = \max_k\{w_{jk4}^s\} \end{cases} \quad (2)$$

*where $w_j^s = [w_{j1}^s, w_{j2}^s, w_{j3}^s, w_{j4}^s]$ is the subjective weight of j^{th} risk criterion.

CONSTRUCT AGGREGATED FUZZY RATING MATRIX

The fuzzy rating score collected from expert k^{th} for i^{th} alternative regarding j^{th} criterion is denoted as $\tilde{x}_{ijk} = (x_{ijk1}, x_{ijk2}, x_{ijk3}, x_{ijk4})$. Then, the fuzzy rating scores from all experts are aggregated into a group as [Shemshadi et al. 2011]:

$$\tilde{X}_{ij} = \begin{cases} x_{ij1} = \min_k\{x_{ijk1}\} \\ x_{ij2} = \frac{1}{K}\sum_{k=1}^{K} x_{ijk2} \\ x_{ij3} = \frac{1}{K}\sum_{k=1}^{K} x_{ijk3} \\ x_{ij4} = \max_k\{x_{ijk4}\} \end{cases}$$

(3)

Thus, the aggregated fuzzy rating matrix $(\tilde{R})$ is constructed as:

$$\widetilde{D} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (4)$$

*where $x_{ij} = (x_{ij1}, x_{ij2}, x_{ij3}, x_{ij4})$

DEFUZZIFY THE AGGREGATED FUZZY RATING MATRIX

Each element in the aggregated fuzzy rating matrix $(\tilde{R})$ is defuzzified into crisp values as [Shemshadi et al. 2011]:

$$\text{Defuzz}(x_{ij}) = \frac{\int \mu(x).xdx}{\int \mu(x)dx} \quad (5)$$

$$= \frac{\int_{x_{ij1}}^{x_{ij2}}\left(\frac{x-x_{ij1}}{x_{ij2}-x_{ij1}}\right)\cdot xdx + \int_{x_{ij2}}^{x_{ij3}} xdx + \int_{x_{ij3}}^{x_{ij4}}\left(\frac{x_{ij4}-x}{x_{ij4}-x_{ij3}}\right)\cdot xdx}{\int_{x_{ij1}}^{x_{ij2}}\left(\frac{x-x_{ij1}}{x_{ij2}-x_{ij1}}\right)dx + \int_{x_{ij2}}^{x_{ij3}} dx + \int_{x_{ij3}}^{x_{ij4}}\left(\frac{x_{ij4}-x}{x_{ij4}-x_{ij3}}\right)dx}$$

$$= \frac{-x_{ij1}x_{ij2} + x_{ij3}x_{ij4} + \frac{1}{3}(x_{ij4} - x_{ij3})^2 - \frac{1}{3}(x_{ij2} - x_{ij1})^2}{-x_{ij1} - x_{ij2} + x_{ij3} + x_{ij4}}$$

SHANNON ENTROPY APPROACH

Shannon [2001] introduced the entropy approach to measure the uncertainty inherited in information and explain it with probability theory. In this study, entropy is employed to determine the objective weights of risk criteria. The entropy procedure is presented as follows [Lee and Chang, 2018]:

Step 1: Normalize the evaluation of the decision matrix

Based on the defuzzify aggregated fuzzy rating matrix, all elements are normalized to render the evaluation criteria become dimensionless as:

$$P_{ij} = \frac{P_{ij}}{\sum_j P_{ij}} \quad (6)$$

Step 2: Calculate entropy measuring values of criteria

The entropy measuring values (e_j) of the evaluation criteria are calculated as:

$$e_j = -k\sum_{j=1}^{n} P_{ij}\ln(P_{ij}) \quad (7)$$

*where k = $(\ln(m))^{-1}$ and m is the number of alternatives.

Step 3: Determine the divergence values

The divergence values (d_j) of evaluation criteria are determined as:

$$d_j = 1 - e_j \quad (8)$$

Step 4: Compute the normalized weights of criteria

The normalized weights of evaluation criteria are computed as:

$$w_j = \frac{div_j}{\sum_j div_j} \quad (9)$$

FUZZY VIKOR

VIKOR is one of MCDM techniques that help decision-makers prioritize the alternatives with respect to assessment criteria. The basic concept of this technique is that the location of the best alternative is close to the ideal solution. In other words, the best one has the shortest distance from the ideal solution. In this study, fuzzy VIKOR is employed to prioritize the failure modes. The computation procedure of fuzzy VIKOR is illustrated as follows [Shemshadi et al. 2011]:

Step 1: Normalize the aggregated fuzzy rating matrix

Based on the aggregated fuzzy rating matrix $(\tilde{R})$, all elements are normalized to make them can be comparable. Then, the normalized the aggregated fuzzy rating matrix $\left(U = [u_{ij}]_{m\times n}\right)$ is constructed as:

$$u_{ij} = \left\{\left(\frac{x_{ij1}}{x_{ij1}^{-}}, \frac{x_{ij2}}{x_{ij1}^{-}}, \frac{x_{ij3}}{x_{ij1}^{-}}, \frac{x_{ij4}}{x_{ij1}^{-}}\right)\right\} \text{ for cost criterion } (10)$$

$$u_{ij} = \left\{\left(\frac{x_{ij1}}{x_{ij4}^{+}}, \frac{x_{ij2}}{x_{ij4}^{+}}, \frac{x_{ij3}}{x_{ij4}^{+}}, \frac{x_{ij4}}{x_{ij4}^{+}}\right)\right\} \text{ for benefit criterion } (11)$$

*where $x_{ij4}^{+} = \max_i\{x_{ij4}\}$ for benefit criterion, while $x_{ij1}^{-} = \min_i\{x_{ij1}\}$ for cost criterion.

Step 2: Calculate the overall performance rating

The overall performance ratings values of alternatives (f_{ij}) are calculated as [Shemshadi et al. 2011]:

$$F = [f_{ij}]_{m\times n}$$

$$f_{ij} = defuzz(u_{ij} \otimes w_j^s) \quad (12)$$

$$f_{ij} = \frac{\int \mu(x).xdx}{\int \mu(x)dx}$$

$$f_{ij} = \frac{\int_{u_{ij1}w_{j1}^s}^{u_{ij2}w_{j2}^s}\left(\frac{x-w_{j1}^s}{u_{ij2}w_{j2}^s-u_{ij1}w_{j1}^s}\right)\cdot xdx + \int_{u_{ij2}w_{j2}^s}^{u_{ij3}w_{j3}^s} xdx + \int_{u_{ij3}w_{j3}^s}^{u_{ij4}w_{j4}^s}\left(\frac{u_{ij4}w_{j4}^s-x}{u_{ij4}w_{j4}^s-u_{ij3}w_{j3}^s}\right)\cdot xdx}{\int_{u_{ij1}w_{j1}^s}^{u_{ij2}w_{j2}^s}\left(\frac{x-u_{ij1}w_{j1}^s}{u_{ij2}w_{j2}^s-u_{ij1}w_{j1}^s}\right)dx + \int_{u_{ij2}w_{j2}^s}^{u_{ij3}w_{j3}^s} dx + \int_{u_{ij3}w_{j3}^s}^{u_{ij4}w_{j4}^s}\left(\frac{u_{ij4}w_{j4}^s-x}{u_{ij4}w_{j4}^s-u_{ij3}w_{j3}^s}\right)dx}$$

$$f_{ij} = \frac{-(u_{ij1}u_{ij2})\left(w_{j1}^s w_{j2}^s\right)+(u_{ij3}u_{ij4})\left(w_{j3}^s w_{j4}^s\right)+\frac{1}{3}\left(u_{ij4}w_{j4}^s-u_{ij3}w_{j3}^s\right)^2-\frac{1}{3}(u_{ij2}w_{j2}^s-u_{ij1}w_{j1}^s)^2}{-u_{ij1}w_{j1}^s-u_{ij2}w_{j2}^s+u_{ij3}w_{j3}^s+u_{ij4}w_{j4}^s}$$

where $w^s = \left[w_{j1}^s, w_{j2}^s, w_{j3}^s, w_{j4}^s\right]$ is the subjective weights of risk criterion.

Step 3: Determine the best ideal and the worst ideal values

The best ideal value $\left(f_j^*\right)$ and the worst ideal values $\left(f_j^-\right)$ of the overall performance rating values of alternatives (f_{ij}) can be defined as:

$$f_i^* = \max_i\{f_{ij}\} \quad (13)$$

$$f_i^- = \min_i\{f_{ij}\} \quad (14)$$

Step 4: Calculate the values of utility measure S_i and regret measure R_i for each alternative

The value of S_i and R_i for each alternative can be calculated by using LP-matric $\left(L_{P,i}\right)$ as an aggregating function to determine the compromise raking of the alternative. According to LP-matric, $L_{1,i}$ and $L_{\infty,i}$ are used to compute S_i and R_i as follows:

$$L_{P,i} = \left\{\sum_{j=1}^{n}\left[w_j\left(r_j^* - r_{ij}\right)/\left(r_j^* - r_j^-\right)\right]^p\right\}^{1/p} \quad (15)$$

$$S_i = \sum_{j=1}^{n}\frac{w_j^o(f_i^*-f_{ij})}{(f_i^*-f_i^-)} \quad (16)$$

$$R_i = \max_i\left(\frac{w_j^o(f_i^*-f_{ij})}{(f_i^*-f_i^-)}\right) \quad (17)$$

*where w_j^o the objective weight of risk criterion obtained from Shannon entropy.

Step 5: Compute the values of Q_i for failure modes

The value of Q_i for each failure mode can be computed as:

$$Q_i = \frac{\upsilon(S_i-S^*)}{S^--S^*} + \frac{(1-\upsilon)(R_i-R^*)}{R^--R^*} \quad (18)$$

*where

$$S^- = \max_i\{S_i\} \quad (19)$$

$$S^* = \min_i\{S_i\} \quad (20)$$

$$R^- = \max_i\{R_i\} \quad (21)$$

$$R^* = \min_i\{R_i\} \quad (22)$$

υ stands for weight for the strategy of maximum group utility, while $1-\upsilon$ stands for the weight of the individual regret. In this study, the υ value is 0.5.

Step 6: Prioritize the failure modes

The failure modes are prioritized based on S_i, R_i, and Q_i in ascending order.

Step 7: Examine the condition of the compromise solution

In this step, the condition of the compromise solution is examined. Considering the minimum value of Q_i, the failure mode $FM^{(1)}$ is the first ranked if the following two conditions are fulfilled.

Condition #1: Acceptable advantage: $Q\left(FM^{(2)} - FM^{(1)}\right) \geq DQ$ where $FM^{(2)}$ is the second-ranked list by Q_i and $DQ = {}^{1}/_{J-1}$.

Condition #2: Acceptable stability in the decision making. The failure mode $FM^{(1)}$ must be the first priority ranked by S_i or/and R_i . It indicates that the compromise solution is stable in decision-making process (when $\upsilon > 0.5$ is required, or "by experts' consensus" $\upsilon \approx 0.5$, or "by veto" $\upsilon < 0.5$).

If one of the conditions cannot be met, then a set of compromise solutions is assigned as follows:

- Failure mode $FM^{(1)}$ and $FM^{(m)}$ if only if "Condition# 2" is not met, or
- Failure mode $FM^{(1)\cdot}$, $FM^{(2)\cdot}$,... , $FM^{(m)\cdot}$ If only if "Condition# 1" is not met; $FM^{(m)}$ is defined by the relation $Q\left(FM^{(\mathrm{m})} - FM^{(1)}\right) \geq DQ$ for maximum M.

PROPOSED FRAMEWORK FOR OPERATIONAL SUPPLY CHAIN RISKS ASSESSMENT

This study proposed eight phases framework for operational supply chain risks assessment based on fuzzy FMEA as: Phase I-Identify potential operational supply chain risks based on FMEA, Phase II-Define risk criteria and measuring scale, Phase III-Compute the subjective weights of risk criteria, Phase IV: Construct aggregated fuzzy rating matrix of FMs, Phase V- Defuzzify the aggregated fuzzy rating matrix of FMs, Phase VI-Compute the objective weights of risk criteria, Phase VII-Prioritize the FMs, and Phase VIII-Perform a sensitivity analysis. The schematic diagram of the proposed framework is illustrated in figure 2.

APPLICATION OF THE PROPOSED FRAMEWORK

CASE STUDY

The proposed framework is validated by using one of the leading canned tuna manufacturers in Thailand. This manufacturer is regarded as the largest producer of ready-to-eat canned tuna products in Southeast Asia with annual sales exceeding US$ 3.2 billion in the year 2020. The company operates as an original brand manufacturer (OBM). In the past few years, this company encounters various risks causing an interruption in the supply chain. Company executive staffs need to proactively develop an effective plan to mitigate those risks. To do this, a panel of experts consists of six experts with more than ten years of experience including plant manager, logistics manager, quality assurance manager, risk management manager, procurement manager and academician. Therefore, the proposed framework in this study is used as a tool to assist a panel of experts to identify, assess and prioritize the risks inherited in supply chain operations.

RESULTS

Phase I: Identify potential operational supply chain risks based on FMEA

The experts are invited to investigate the potential failure modes (FMs) of operation supply chain risks for case manufacturing. After several rounds of discussions, eleven FMs are identified as presented in Table 2.

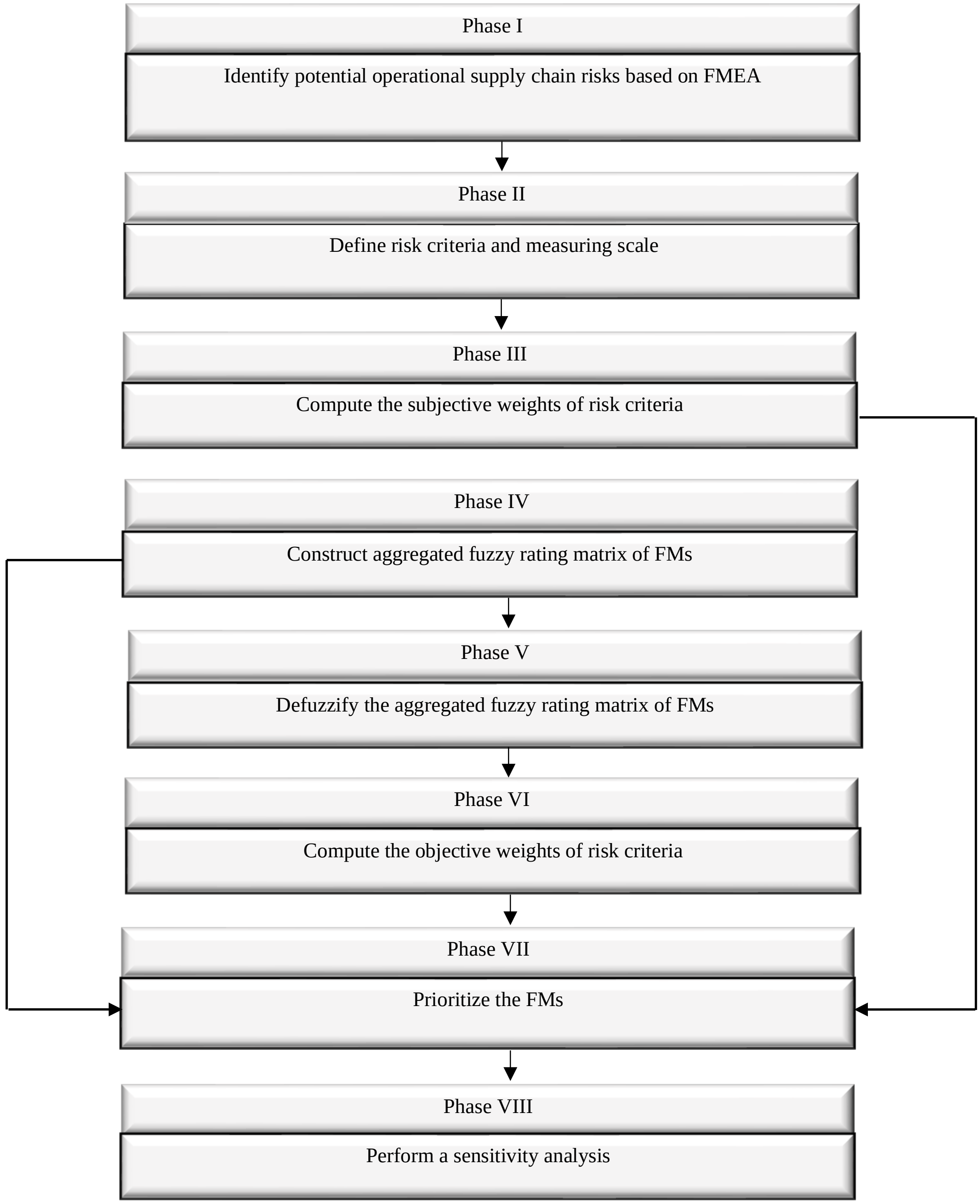

Fig. 2. The proposed framework

Table 2. The identification of potential FMs for case manufacturing

Code	***Failure Mode of operational supply chain risks***	***Effect***
FM1	Risk of volatility raw materials supplied	Manufacturers face a shortage of raw materials and/or raw materials that do not meet the requirements. This results in excess lead times and unacceptable quality levels of the raw materials supplied.
FM2	Risk of relying on a few major suppliers	Manufacturers have low bargaining power with suppliers as their dependence on a few major suppliers results in high raw material costs.
FM3	Risk of product deterioration	Manufacturers face deterioration and spoilage of tuna products caused by the use of improper temperatures. Disease and contamination in transport activities This results in higher cost of quality and loss of business reputation.
FM4	Risk of variabilities in production processes.	Manufacturers face variability in the production process, resulting in higher production costs, loss of productivity and non-conforming finished products.
FM5	Risk of improper inventory management	Manufacturers face higher inventory costs, inventory shortage and obsolete inventory due to keeping too low or too high inventory.
FM6	Risk of failing to comply with industrial standard	Manufactures face revocation of required industry standard certificates such as Good Manufacturing Practice: GMP, Hazard Analysis and Critical Control Point: HACCP resulting in production halts and damage to business reputation.
FM7	Risk of inefficient traceability system across supply chain processes.	Manufacturers do not meet the security requirements for record storage and counterfeit detection. This results in ongoing problems that are difficult for manufactures to deal with in the event of a nonconforming product recall.
FM8	Risk of a shortage of skilled workers	Manufacturers face a shortage of skilled workers. This can lead to a competitive disadvantage in the seafood market.
FM9	Risk of products damage and contamination during transportation.	Manufacturers face damage and product contamination during transportation. This results in higher reverse logistics costs for nonconforming products and customer complaints.
FM10	Risk of technological innovation change.	Manufacturers cannot keep up with the rapid changes of technological innovations. This could lead to a competitive disadvantage in the seafood market.
FM11	Risk of failure in information technology (IT) system	Manufacturers face disruptions in their businesses including sales, production and cash flow in the supply chain due to IT system failure.

Phase II: Define risk criteria and measuring scale.

Through brainstorming session, the experts define the four risks of FMs as “severity” (S), “probability of occurrence” (O), “probability of detection” (D) and “degree of difficulty to eliminate risks” (E). Also, the measurement scales in linguistic terms for subjective important weights of risk criteria, and for assessment of FMs are provided in Table 3 and Table 4, respectively.

Phase III: Compute the subjective weights of risk criteria

The experts evaluate the subjective weights of risk criteria (S, O, D, E) by using linguistics terms in Table 3 and the results are shown in Table 5. The linguistic terms are converted to their corresponding fuzzy numbers as shown in Table 6. The subjective weights of risk criteria (w_j^s) are computed by aggregating the fuzzy numbers by equation (2) and the results are shown in Table 7.

Table 3. The measurement scales for subjective important weights of risk criteria

Linguistic terms	*Abbreviation*	*Fuzzy number*
Very low	VL	(0.0,0.0,0.1,0.2)
Low	L	(0.1,0.2,0.2,0.3)
Medium low	ML	(0.2,0.3,0.4,0.5)
Medium	M	(0.4,0.5,0.5,0.6)
Medium high	MH	(0.5,0.6,0.7,0.8)
High	H	(0.7,0.8,0.8,0.9)
Very high	VH	(0.8,0.9,1.0,1.0)

Table 4. The measurement scales for assessment FMs

Severity (S)	*Occurrence* (O)	*Detection* (D)	*Degree of difficulty to eliminate risks* (E)	*Trapezoidal fuzzy numbers (TFN)*
No (N)	Almost Never (AN)	Almost Certain (AC)	Almost no difficulty (N)	(0,0,1,2)
Very Slight (VS)	Remote (RS)	Very High (VH)	Remote (R)	(0,1,2,3)
Slight (S)	Very Slight (VS)	High (H)	Low (L)	(1,2,3,4)
Minor (M)	Slight (S)	Moderately High (MH)	Relative Low (RL)	(2,3,4,5)
Moderate (MO)	Low (L)	Medium (M)	Moderate (M)	(3,4,5,6)
Significant (SI)	Medium (M)	Low (L)	Moderate High (MH)	(4,5,6,7)
Major (M)	Moderate High (MH)	Slight (S)	High (H)	(5,6,7,8)
Extreme (E)	High (H)	Very Slight (VS)	Very High (VH)	(6,7,8,9)
Serious (SE)	Very High (VH)	Remote (R)	Extremely High (EH)	(7,8,9,10)
Hazardous (H)	Almost Certain (AC)	Almost Impossible (AI)	Almost Impossible (AI)	(8,9,10,10)

Table 5: The evaluation of subjective weights in linguistic terms

Experts	S	O	D	E
E_1	VH	MH	M	H
E_2	VH	H	ML	MH
E_3	H	MH	M	H
E_4	VH	MH	M	H
E_5	VH	MH	ML	MH
E_6	H	MH	M	H

Table 6. The evaluation of subjective weights in fuzzy numbers

Experts	*Risk criteria*															
	S				*O*				*D*				*E*			
E_1	0.8	0.9	1.0	1.0	0.5	0.6	0.7	0.8	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9
E_2	0.8	0.9	1.0	1.0	0.7	0.8	0.8	0.9	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.8
E_3	0.7	0.8	0.8	0.9	0.5	0.6	0.7	0.8	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9
E_4	0.8	0.9	1.0	1.0	0.5	0.6	0.7	0.8	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9
E_5	0.8	0.9	1.0	1.0	0.5	0.6	0.7	0.8	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.8
E_6	0.7	0.8	0.8	0.9	0.5	0.6	0.7	0.8	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9

Table 7. The subjective weights of risk criteria (w_j^s)

Subjective weights	S				O				D				E			
w_j^s	0.700	0.867	0.933	1.000	0.500	0.633	0.717	0.900	0.200	0.433	0.467	0.600	0.500	0.733	0.767	0.900

Phase IV: Construct aggregated fuzzy rating matrix of FMs

The experts employ the linguistic terms in Table 4 to evaluate eleven FMs with respect to risk criteria and the results are shown in Table 8. The elements in Table 8 are then converted into corresponding fuzzy numbers. Using equations (3)-(4), the aggregated fuzzy rating matrix of FMs is constructed as shown in Table 9.

Phase V: Defuzzify the aggregated fuzzy rating matrix of FMs into crisp numbers

According to the aggregated fuzzy rating matrix Table 9, all elements are defuzzified into crisp numbers by using equation (5). The subjective weights can be obtained from Phase III. Table 10 shows the crisp numbers of FMs rating matrix.

Table 8. The evaluation of eleven FMs in linguistic terms

No.	S	O	D	E
FM1	SE,SE,SE,SE,SE,E	H,VH,H,VH,H,VH	M,MH,MH,MH,M,MH	H,MH,MH,M,M,MH
FM2	E,MA,MA,SI,SI,MA	M,M,MH,H,H,MH	H,H,H,VH,VH,H	MH,MH,H,H,MH,VH
FM3	SE,SE,SE,SE,SE,E	H,VH,H,VH,H,VH	H,H,H,MH,H,MH	VH,EH,EH,VH,VH,EH
FM4	SI,MA,MA,SI,MA,MA	H,VH,H,VH,H,VH	H,MH,H,MH,MH,H	H,MH,MH,M,MH,H
FM5	SI,MA,MA,MA,MA,SI	M,M,L,L,M,MH	H,H,MH,H,MH,MH	H,H,MH,MH,M,M
FM6	SE,SE,SE,SE,SE,E	M,L,L,L,M,L	H,H,H,VH,H,VH	H,H,MH,H,VH,VH
FM7	SI,SI,MA,MA,SI,MA	MH,MH,M,H,MH,M	H,M,MH,MH,M,MH	MH,MH,H,H,MH,M
FM8	E,E,SE,MA,MA,E	H,H,VH,MH,H,MH	H,VH,H,VH,H,VH	H,H,H,VH,MH,MH,H
FM9	E,SE,SE,E,E,SE	M,L,L,L,L,M	L,L,S,VS,S,M	H,VH,VH,MH,H,MH
FM10	MA,MA,E,MA,MA,MA	M,H,MH,MH,MH,MH	H,H,H,VH,M,VH	H,MH,MH,H,MH,MH
FM11	E,E,MA,MA,E,MA	L,L,S,M,M,M	H,H,VH,MH,V,M	MH,MH,M,M,MH,H

Table 9. The aggregated evaluation decision matrix of FMs

	S				O				D				E			
	x_1	x_2	x_3	x_4	x_1	x_2	x_3	x_4	x_1	x_2	x_3	x_4	x_1	x_2	x_3	x_4
FM1	6.000	7.833	8.833	10.000	6.000	7.500	8.500	10.000	6.000	7.500	8.500	10.000	5.000	6.167	7.167	9.000
FM2	4.000	5.833	6.833	9.000	4.000	6.000	7.000	9.000	4.000	6.000	7.000	9.000	4.000	5.667	6.667	9.000
FM3	6.000	7.833	8.833	10.000	6.000	7.500	8.500	10.000	6.000	7.500	8.500	10.000	5.000	6.167	7.167	9.000
FM4	4.000	5.667	6.667	8.000	6.000	7.500	8.500	10.000	6.000	7.500	8.500	10.000	5.000	6.167	7.167	9.000
FM5	4.000	5.667	6.667	8.000	3.000	4.833	5.833	8.000	3.000	4.833	5.833	8.000	3.000	5.000	6.000	8.000
FM6	6.000	7.833	8.833	10.000	3.000	4.333	5.333	7.000	3.000	4.333	5.333	7.000	4.000	6.167	7.167	9.000
FM7	4.000	5.500	6.500	8.000	4.000	5.500	6.500	8.000	4.000	5.500	6.500	8.000	3.000	5.167	6.167	8.000
FM8	5.000	6.833	7.833	10.000	5.000	7.167	8.167	10.000	6.000	7.500	8.500	10.000	5.000	6.167	7.167	9.000
FM9	6.000	7.500	8.500	10.000	3.000	4.333	5.333	7.000	4.000	6.000	7.000	9.000	4.000	5.667	6.667	9.000
FM10	5.000	6.167	7.167	9.000	4.000	6.000	7.000	9.000	6.000	7.500	8.500	10.000	5.000	6.167	7.167	9.000
FM11	6.000	7.833	8.833	10.000	6.000	7.500	8.500	10.000	6.000	7.500	8.500	10.000	5.000	6.167	7.167	9.000

Table 10. The crisp numbers of FMs rating matrix

Failure mode	S	O	D	E
FM1	8.133	8.000	5.438	6.867
FM2	6.435	6.500	2.067	6.370
FM3	8.133	8.000	5.933	6.867
FM4	6.067	8.000	5.933	6.867
FM5	6.067	5.435	3.000	5.500
FM6	8.133	4.933	2.067	6.565
FM7	6.000	6.000	3.565	5.565
FM8	7.435	7.565	2.000	6.500
FM9	8.000	4.933	6.000	6.500
FM10	6.867	6.500	2.810	5.933
FM11	7.000	4.630	2.937	5.435

Phase VI: Compute the objective weights of risk criteria

In this study, Shannon entropy method is employed to compute the objective weights of risk criteria. Based on Table 10, the elements in FMs rating matrix are normalized using equation (6). The entropy measuring values (e_j) the divergence values (d_j) of risk criteria are computed using equation (7) and equation (8), respectively. The objective weights (w_j) of risk criteria can be obtained by using equation (9). Table 11 shows the results of objective weights computation. It can be seen that the objective weights of risk criteria be *S* (0.253) = *E* (0.253)> *O* (0.251)>*D* (0.242).

Phase VII: Prioritize the FMs

In this study, fuzzy VIKOR is applied to prioritize the FMs. Based on aggregated fuzzy rating matrix in Table 9, the elements are normalized using equation (10) for cost criterion (S, O, E) and equation (11) for benefit criterion (D). Table 12 shows the normalized aggregated fuzzy rating matrix. Then, the overall performance rating (f_{ij}) of each FM with respect to risk criteria is calculated using equation (12), as shown in Table 13. Based on Table 13, the best ideal value (f_j^*) and the worst ideal value (f_j^-) of FMs are determined by using equation (13) and equation (14), respectively. The values of utility measure S_i, and regret measure R_i for each FM are obtained using equations (15)-(17), respectively. Based on the objective weights obtained from Phase VI, the Q_i value for each FM is computed by using equations (18)-(22). In this study, the υ value is defined as 0.5. Table 1 shows the values of S_i, R_i and Q_i. Two conditions of compromise solution are examined and the results of both conditions are satisfied as shown in Table 14. Based on the results from Table 13 and Table 14, FMs are ranking, according to their Q_i values in ascending order (the smaller value is the higher the ranking). The results show that $FM3 > FM1 > FM4 > FM9 > FM8 > FM10 > FM6 > FM2 > FM7 > FM11 > FM5$. Therefore, *FM3* is the most critical failure mode and the tuna industry should give the first priority to proactively manage risks.

Table 11. The object weights of risk criteria

	S	O	D	E
e_j	5.733	5.703	5.538	5.741
d_j	-4.733	-4.703	-4.538	-4.741
w_j	0.253	0.251	0.242	0.253

Table 12. The normalized aggregated fuzzy rating matrix

	S				*O*				*D*				*E*			
	x_1	x_2	x_3	x_4	x_1	x_2	x_3	x_4	x_1	x_2	x_3	x_4	x_1	x_2	x_3	x_4
FM1	1.500	1.958	2.208	2.500	3.000	3.750	4.250	5.000	0.222	0.537	0.648	1.000	1.667	2.056	2.389	3.000
FM2	1.000	1.458	1.708	2.250	2.000	3.000	3.500	4.500	0.000	0.185	0.296	0.444	1.333	1.889	2.222	3.000
FM3	1.500	1.958	2.208	2.500	3.000	3.750	4.250	5.000	0.444	0.593	0.704	0.889	1.667	2.056	2.389	3.000
FM4	1.000	1.417	1.667	2.000	3.000	3.750	4.250	5.000	0.444	0.593	0.704	0.889	1.667	2.056	2.389	3.000
FM5	1.000	1.417	1.667	2.000	1.500	2.417	2.917	4.000	0.111	0.278	0.389	0.556	1.000	1.667	2.000	2.667
FM6	1.500	1.958	2.208	2.500	1.500	2.167	2.667	3.500	0.000	0.185	0.296	0.444	1.333	2.056	2.389	3.000
FM7	1.000	1.375	1.625	2.000	2.000	2.750	3.250	4.000	0.111	0.352	0.463	0.667	1.000	1.722	2.056	2.667
FM8	1.250	1.708	1.958	2.500	2.500	3.583	4.083	5.000	0.000	0.167	0.278	0.444	1.333	2.000	2.333	3.000
FM9	1.500	1.875	2.125	2.500	1.500	2.167	2.667	3.500	0.333	0.611	0.722	1.000	1.333	2.000	2.333	3.000
FM10	1.250	1.542	1.792	2.250	2.000	3.000	3.500	4.500	0.000	0.222	0.333	0.667	1.333	1.778	2.111	2.667
FM11	1.250	1.625	1.875	2.250	1.000	2.167	2.667	3.500	0.000	0.259	0.370	0.667	1.000	1.611	1.944	2.667

Table 13. The overall performance rating (f_{ij}) of each FM

Failure mode	S	O	D	E	S_i	R_i	Q_i	***Prioritization***		
								S_i	R_i	Q_i
FM1	1.817	2.812	0.338	1.729	0.060	0.060	0.153	2	2	2
FM2	1.457	2.316	0.124	1.631	0.626	0.240	0.829	7	4	8
FM3	1.817	2.812	0.410	1.729	0.000	0.000	0.000	1	1	1
FM4	1.367	2.812	0.410	1.729	0.245	0.245	0.622	3	6	3
FM5	1.367	1.916	0.184	1.423	0.880	0.245	0.983	11	6	11
FM6	1.817	1.721	0.124	1.678	0.530	0.250	0.794	6	7	7
FM7	1.352	2.115	0.217	1.438	0.802	0.253	0.955	9	8	9
FM8	1.674	2.718	0.121	1.662	0.394	0.242	0.703	5	5	5
FM9	1.787	1.721	0.385	1.662	0.340	0.250	0.686	4	7	4
FM10	1.539	2.316	0.172	1.506	0.639	0.199	0.757	8	3	6
FM11	1.569	1.713	0.178	1.407	0.833	0.253	0.973	10	8	10

Table 14. The condition of compromise solution

	Condition	*Check*	*Result*
Condition I	Acceptable advantage	$Q\ (FM1) - Q(FM3) \geq\ 1/(m-1)$ $0.153 - 0.000\ \geq 1/10$ $0.153\ \geq 0.1$	Satisfied
Condition II	Acceptable stability in decision making	*FM3* is the best ranking indicated by Q_i, S_i and R_i	Satisfied

Phase VIII: Perform a sensitivity analysis

To evaluate the robustness of the proposed FMEA model, the sensitivity analysis of the decision is conducted by altering the different values of weights for the strategy of maximum group utility (ν). The objective is to examine whether the FMs changes (according Q_i values) when the ν value changes. In this study, a total of different eleven scenarios are analyzed by varying ν values to 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and 1.0. The results of sensitivity analysis are shown in Table 15 and figure 3. It can be seen that *FM3* is the most critical failure mode followed by *FM2* in all scenarios. Moreover, the overall ranking of FMs is remained unchanged when ν = 0.4, 0.5 and 0.6, but it is sensitive at other ν values. It implies that the selection of ν values is necessary to balance between utility measure (S_i)

and regret measure (R_i) plays an important role for implementing the proposed model. Thus, the implementation of the proposed framework should apply $\nu = 0.5$, which means the failure modes are evaluated in a consensus way.

Table 15. The results of sensitivity analysis

Q_i											
Scenario	1	2	3	4	5	6	7	8	9	10	11
υ	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
FM1	0.238	0.221	0.204	0.187	0.170	0.153	0.136	0.119	0.102	0.086	0.069
FM2	0.946	0.923	0.899	0.876	0.852	0.829	0.806	0.782	0.759	0.735	0.712
FM3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FM4	0.966	0.897	0.828	0.760	0.691	0.622	0.553	0.484	0.416	0.347	0.278
FM5	0.966	0.969	0.973	0.976	0.980	0.983	0.986	0.990	0.993	0.997	1.000
FM6	0.985	0.947	0.909	0.870	0.832	0.794	0.755	0.717	0.679	0.640	0.602
FM7	0.998	0.990	0.981	0.972	0.964	0.955	0.946	0.937	0.929	0.920	0.911
FM8	0.957	0.906	0.855	0.804	0.753	0.703	0.652	0.601	0.550	0.499	0.448
FM9	0.985	0.925	0.865	0.806	0.746	0.686	0.626	0.566	0.506	0.446	0.386
FM10	0.787	0.781	0.775	0.769	0.763	0.757	0.751	0.745	0.739	0.733	0.726
FM11	1.000	0.995	0.989	0.984	0.979	0.973	0.968	0.963	0.957	0.952	0.947

Table 16. The priority of FMs in each scenario

Priority of FMs											
Scenario	1	2	3	4	5	6	7	8	9	10	11
υ	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
FM1	2	2	2	2	2	2	2	2	2	2	2
FM2	4	6	7	8	8	8	8	8	8	8	7
FM3	1	1	1	1	1	1	1	1	1	1	1
FM4	6	4	4	3	3	3	3	3	3	3	3
FM5	6	9	9	10	11	11	11	11	11	11	11
FM6	8	8	8	7	7	7	7	6	6	6	6
FM7	10	10	10	9	9	9	9	9	9	9	9
FM8	5	5	5	5	5	5	5	5	5	5	5
FM9	8	7	6	6	4	4	4	4	4	4	4
FM10	3	3	3	4	6	6	6	7	7	7	8
FM11	11	11	11	11	10	10	10	10	10	10	10

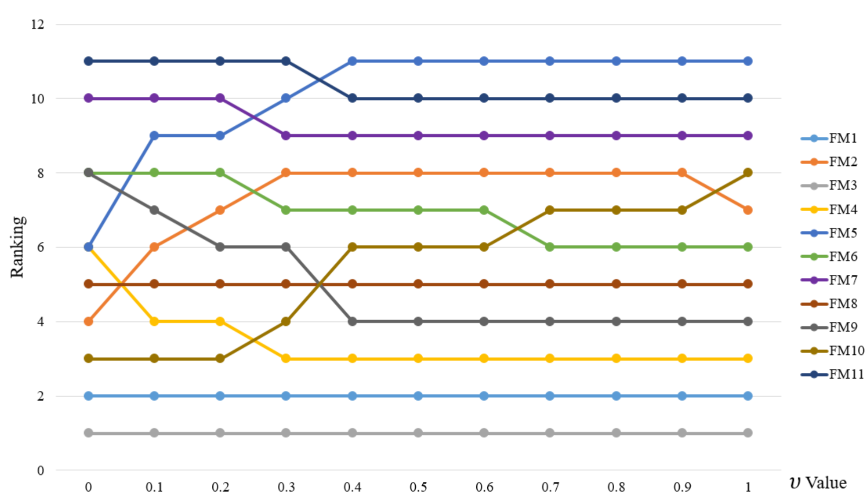

Fig. 3. Sensitivity analysis of eleven scenarios

CONCLUSIONS AND FUTURE RESEARCH

In this study, a new FMEA based on MCDM approach is proposed to assess operational supply chain risks. The proposed framework can mitigate the disadvantages of conventional FMEAs in a number of ways. This study distinguishes from previous researches in many aspects. First, the fuzzy set theory under trapezoidal fuzzy number is used to deal with the uncertain and imprecise information in decision-making processes. Second, the eleven failure modes of operational supply chain risks are identified by a panel of experts. Third, the new risk criteria namely "degree of difficulty to eliminate risks" includes risk assessment. Forth, the important weights of risk criteria are determined by combining subjective weights and objective weights. The subjective weights are obtained by opinion of experts, while the objective weights are derived obtained by Shannon entropy method. Next, fuzzy VIKOR is employed to prioritize failure modes instead of a risk priority number (RPN). Finally, a sensitive is performed and the results indicate that the proposed framework provides the stability and robustness for failure modes ranking. A validation of the framework presented here uses the canned tuna industry in Thailand as a case study. The findings from this study indicates that the most three critical FMs are "risk of product deterioration" (*FM3*) followed by "risk of volatility raw materials supplied" (*FM1*) and "risk of variabilities in production processes" (*FM4*), respectively. The outcomes of this study enable tuna industry practitioners to proactively assess the operational supply chain risks. Moreover, the proposed framework can be applied to other seafood industries in the same procedure. Further research may extend from this framework by investigating the interaction between risk criteria using DEMATEL approach. Apart from that, the other MCDM methods such as CRITIC can be utilized to determine the objective weights. Also future research should include the sustainability dimensions of the supply chain in identifying failure modes.

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ORIGINAL PAPER

FLIGHT DELAY PREDICTION BASED WITH MACHINE LEARNING

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ABSTRACT. Background: The delay of a planned flight causes many undesirable situations such as cost, customer satisfaction, environmental pollution. There is only one way to prevent these problems before they occur, and that is to know which flights will be delayed. The aim of this study is to predict delayed flights. For this, the use of machine learning techniques, which have become widespread with the development of computer capacities and data storage systems, is preferred.

Methods: Estimations are made with three up-to-date techniques XGBoost, LightGBM, and CatBoost techniques based on Gradient Boosting from machine learning techniques. The bayesian technique is used for hyper-parameter settings. In addition, the Synthetic Minority Over-Sampling Technique (SMOTE) technique is also used, as the majority of flights are on time and delayed flights, which constitute a minority class, may adversely affect the results. The results are analyzed and shared with and without SMOTE.

Results: As a consequence of the application, which was run on a data set containing all of an international airline's flights [18148 flights] for a year, it was discovered that flights may be predicted with high accuracy.

Conclusions: The application of machine learning techniques to anticipate flight delays is new, but it has a lot of potential. Companies will be able to avert problems before they develop if delays are correctly estimated, which can generate plenty of issues. As a result, concrete advantages such as lower costs and higher customer satisfaction will emerge. Improvements will be made at the most vulnerable place in the aviation business.

Keywords: GBDT, XGBoost, LightGBM, Catboost, delay prediction

INTRODUCTION

Except for the extraordinary pandemic situation in 2020, the number of global air traffic passengers has increased since 2006 [IATA, 2019]. While there was no case of an emergency in the first three months of 2020, a similar rise in demand was seen [Mazareanu, 2020]. According to NEXTOR [2010], the cost of delayed flights to airlines is $ 8.3 billion, and the cost of passengers due to delayed, canceled, or missed connecting flights is calculated as $ 9.4 billion in total.

Flight delays cause economic losses in the US of approximately 600 million $ per year, which has been estimated from passenger time and fuel consumption [Nakornsri, Apivatanagul, & Pisitkasem, 2020]. Environmental damage caused by delays is another negative impact that cannot be assessed as clearly as the cost. However, the additional fuel used during the delay and the resulting gas emissions have a negative impact on the environment [Simić & Babić, 2015; Dray, Antony, Vera-Morales, Reynolds, & Schafer, 2008]. Moreover, airline schedule success on time is a crucial factor in sustaining existing customer loyalty and attracting new customers [Abdelghany, Shah, Raina, & Abdelghany, 2004; Efthymiou, Njoya, Lo, Papatheodorou, & Randall, 2019].

Detailed information on flight timings is kept, as punctuality is of great importance in many different aspects of the entire airline industry. The aim of this study is to determine

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the flights that will be delayed by examining the big data analysis methods by using various machine learning approaches in order to prevent the aforementioned problems. The big data used belongs to a private airline company and consists of all flights throughout the year. In addition to the flight data, the weather data of the time period closest to the flight was also added to the data set. After the initial tests, to prevent the imbalanced distribution of the dataset, the obtained data set was balanced with SMOTE and then the status of the flights was estimated using LightGBM, XGBoost, and Catboost methods.

The study is motivated by the need for information for commercial airline companies to overcome mentioned negative effects of delayed flights. In addition to this need, studies on flight delay topic are mostly built on the Bureau of Transportation Statistics. This study also showed that the data of individual airline companies is also used well. Another contribution is to find the most suitable solution using the three different gradient-based machine learning methods introduced by the creators as the most high-performance models.

Literature Review on Machine Learning and Flight Delays

Machine learning and flights delay topic are started to be studied not long ago. One of the reasons for this is the development of machine learning methods and the fact that big data operations can be done easily with machine learning. Since the topic has vital importance in air traffic control, airline decision-making processes and ground operations have been studied from various perspectives. The very first study is done by Choi et al. [2016]. Flight delays that are caused due to weather are forecasted with the domestic flight data and the weather data is used from 2005 to 2015. Kim et al. [2016] also worked on a two-step machine learning model with Recurrent Neural Networks and Long Short Term Memory. The model predicts whether the aircraft will be delayed, and then gives results on how long they will be late within 15 minutes of categorical time periods. Data of ten major airports in the U.S. have been collected and the model's accuracy is between 85% and 92%. Another 2-step model is built by Thiagarajan et al. [2017]. Their model predicts whether the delay will happen or not at the first step and then the delay's time duration is determined. For the first step Random Forests, Gradient Boosting, AdaBoost, Extra-Trees, LOYCVKi, and K-Fold CV are tried and Gradient Boosting is preferred and for the next step Gradient Boosting, MLP, Random Forests, Extra-Trees are tried and Extra-trees are preferred. The US Domestic Airline On-Time Performance data and weather data [World Weather Online API] from the year 2012 to 2016 are used. Manna et al. [2017] build a model to determine the delay time of aircraft. They used Gradient Boosted Decision Tree and find out that the method gives outstanding accuracy results with Coefficient of Determination of 92.31% for arrival delays and 94.85% for departure delays. The busiest 70 airports in the USA within April-November 2013 time period of the US domestic airline data used. Similarly, a comparison of methods is done by Kuhn and Jamadagi [2017]. Decision tree, logistic regression, and artificial neural network models are developed. The results of the models are compared and it is shown that they are almost the same. The data set is collected from Kaggle. Another study which is again based on the Kaggle dataset is done by Venkatesh et al. [2017]. Artificial neural network and deep belief network are used for forecasting whether the aircraft is on time or late. The model gives 92% accuracy. Modammed et al. [2018] are also compare models, but their study focuses on decision tree classifiers which are REPTree, Forecast, Stump, and J48. The data used is gathered from Egypt Airlines and the best results are found with REPTree model. Yu et al. [2019] focused on average delays between Beijing Capital Airport and Hangzhou Xiaoshan International Airport. They used Novel Deep Belief Network model to find a mean of delays. McCarthy et al. are focused on flight delays with a different perspective. They analyze the two European low-cost airlines. Delays that are less than 15 minutes are predicted with Long Short-Term Memory (LSTM). Chen and Li [2019] are focused on delays for connected flights. Bureau of Transportation Statistics is used with Multi-Label Random Forest and approximated delay propagation model.

METHODOLOGY

In this section, proposed approaches are introduced. Firstly, the schematic flowchart is provided in Fig. 1 which presents the whole process flow of the study. As this figure depicts, the dataset consists of flight and weather datasets that are preprocessed, cleaned, and merged. Since the data set was unbalanced, the observations allocated for training are also passed through a preliminary stage using SMOTE, and then three different methods are implemented.

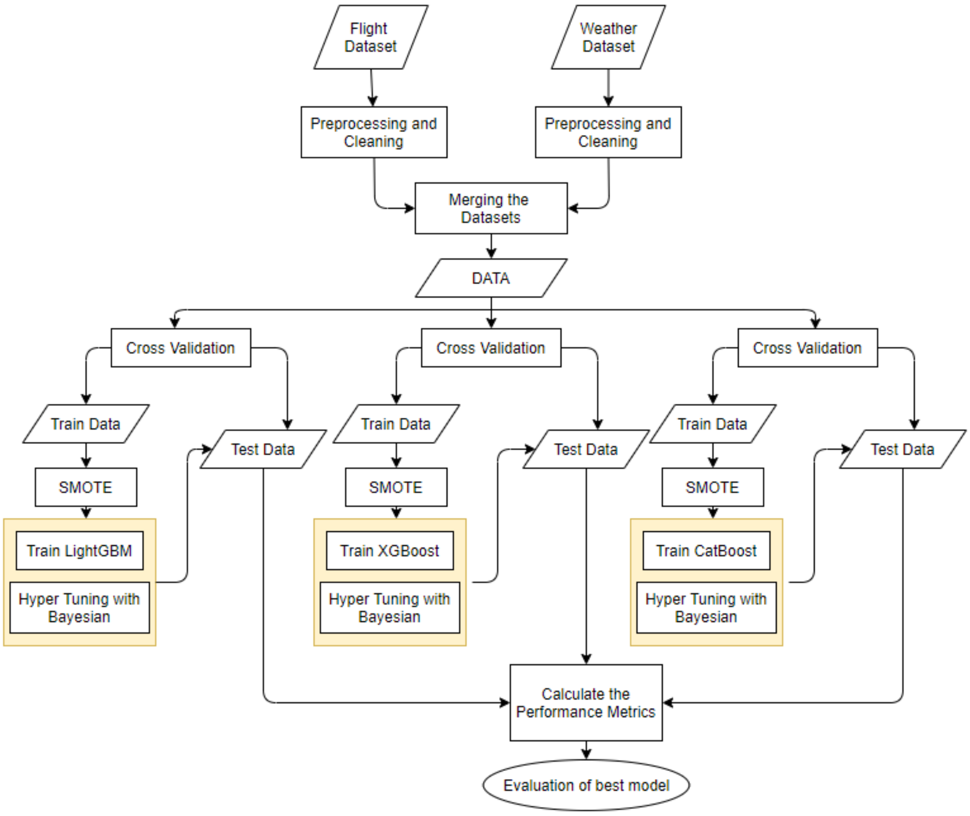

Fig. 1 Flowcharts of the proposed approaches

Imbalanced data handling

Even though machine learning techniques are well-built models to be applied to classification or regression problems, it is still very difficult to classify imbalanced data sets [Haixiang, Yijing, Shang, Mingyun, & Yuanyue, 2017], because imbalanced data sets could result in lower performance of the learners [He & Garcia, 2009]. Imbalanced distribution of the classes not only lowers the performance of the given model but also the model could focus on majority class to accurately predict or categorize, while the minority class is overlooked [López, Fernández, García, Palade, & Herrera, 2013]. Since minority class is ignored, performance metrics could result in misleading results [Loyola-González, Martínez-Trinidad, Carrasco-Ochoa, & García-Borroto, 2016]. The flight data set is also imbalanced since the delayed flights are 0.46 times lower than the on-time flights. In order to overcome this problem different suggestions are given in the literature. Two main categories of them are cost-sensitive learning approach and data preprocessing techniques [Hsixiang, Yijing, Shang, Mingyun, & Yuanye, 2017]. Cost-sensitive models are aimed to solve this problem by giving higher penalties for the misclassifications of minority observations. The preprocessing techniques are often applied before the learning process and with the help of this better learning is aimed. Since the resampling methods are more useful and popular for this study Synthetic Minority Over-Sampling Technique [SMOTE] is preferred. The method is a useful way to generate synthetic minority and also SMOTE method is practiced in various problems with good results [Chawla, Bowyer, Hall, & Kegelmeyer, 2002].

Gradient boosting decision tree

Gradient boosting decision tree (GBDT) is a machine learning method that is applied frequently [Friedman, 2001] for different problems and performs well. The method basically works with the idea of building a strong classifier from a combination series of weak ones.

Given a training set $\{(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)\}$, x represents the data samples and y represents the class labels. $F[x]$ is used to represent the estimated function. GBDT aims to minimize loss function which is $\hat{F}[y, F(x)]$:

$$\hat{F} = arg\min_{F} E_{x,y}[L(y, F(x))] \quad [2]$$

Model is updated with [3]:

$$F_m(x) = F_{m-1}(x) + \gamma_m h_m(x) \quad [3]$$

Where $\gamma_m = \arg\min_{\gamma} \sum_{i=1}^{n} L[y_i, F_{m-1}(x_i) + \gamma h_m[x_i]]$, m is the iteration number, $h_m[x]$ represents the base decision tree.

Extreme Gradient Boosting (XGBoost)

The method is developed by Chen and Guestrin [2016] and it is implied that the algorithm is able to run ten times faster than the known ones. XGBoost works a set of classification and regression trees which are called CART. Differently, CART evaluates each leaf with a decision value and this enables the model to make better assumptions rather than doing just simple classification. Mathematically, it can be shown as where K is the number of trees, f is a function in the functional space of F where F represents all possible CARTs. For a data set with n observations and m features $D = \{(x_i, y_i), x_i \in R^m, y_i, \in R\}$ $[|D| = n]$ a tree ensemble model uses K to get better predictions with additive training strategy.

$$\hat{y}_i = \sum_{k=1}^{K} f_k(x_i), \qquad f_k \in F \quad [4]$$

$F = \{f(x) = w_{q[x]}, q : R^m \to T, w \in R^T\}$ represents the set of all possible CARTs, w is vector of scores on leaves, q is function of each data assignment to corresponding leaf, and T is the number of leaves. Objective function can be given as

$$obj^{[t]} = \sum_{i=1}^{n} \left[l(y_i, \hat{y}_i^{t-1}) + g_i f_t(x_i) + \frac{1}{2} h_i f_t^2[x_i] \right] + \Omega[f_t] \quad [5]$$

where

$$g_i = \partial_{\hat{y}_{i(t-1)}} l\left(y_i, \hat{y}_i^{(t-1)}\right), h_i = \partial^2_{\hat{y}(t-1)} l\left(y_i, \hat{y}_i^{(t-1)}\right) \quad [6]$$

Regularization, pruning, ability the work with missing values are the main differences of the method against GBDT.

However, GBDT results could not be satisfactory according to their efficiency and accuracy when the data is big. In other words, if the data set contains a large number of samples or features a trade-off between efficiency and accuracy would emerge. A traditional GBDT requires scanning all data samples for every feature. In this way, it only gains the information to estimate all the best split points. In short, these computational complexities could require more time when big data is handled.

In this study, binary classification is used to make predictions if the airplane will be departure on time or not according to the input features. Three different methods based on GBDT are used. First, their definitions are given as follows and then their results are compared.

LightGBM

As mentioned before handling big data with GBDT could result in problems. In order to solve these, Gradient-based One-Side Sampling (GOSS) and Exclusive Feature Bundling (EFB) are proposed by Ke et al. [2017] and this new method is named LightGBM. The GBDT uses the information to split each node whereas LightGBM uses GOSS in order to determine the split point via calculating variance gain. At first, GOSS sorts the data samples according to the absolute value and the top a x 100% data samples of gradient values are selected and called A. Afterwards, subset B which size b x 100% is obtained from the remaining data, whose size is b x $|A^c|$. In the end, the samples are split via the estimated variance $\widetilde{V}_j[d]$ on $A \cup B$.

$$\widetilde{V}_j(d) = \frac{1}{n}\left(\frac{\left(\sum_{x_i \epsilon A_l} g_i + \frac{1-a}{b}\sum_{x_i \epsilon B_l} g_i\right)^2}{n_l^j[d]} + \frac{\left(\sum_{x_i \epsilon A_i} g_i + \frac{1-a}{b}\sum_{x_i \epsilon B_r} g_i\right)^2}{n_r^j[d]}\right) \quad [7]$$

Where, $A_l = \{x_i \epsilon A : x_{ij} \leq d\}$, $B_r = \{x_i \epsilon B : x_{ij} > d\}$, g_i stands for the negative gradient of the loss function, $\frac{1-a}{b}$ is employed in order to normalize the sum of gradients as a constant.

Without changing the original data distribution by much, GOSS boosts the sample data with small gradients. EFB algorithm leads to the speedup of GDBT with the help of the ability to bundle many sparse features to the fewer dense features. The method is also based on decision tree, but the difference is the fitting operation of negative gradients of loss function one by one. The LightGBM equation $F_M[x]$ can be get through a weighted combination scheme.

$$F_M = \sum_{m-1}^{M} \gamma_m h_m[x] \quad [8]$$

Categorical Boost

Categorical Boost (CatBoost) is another version of GDBT algorithm. It is developed by Yandex in April 2017 [Yandex, 2017]. Differently, the CatBoost allows the usage of the whole data set while the model is training. Firstly, a random permutation of the dataset is performed and then the average label value is calculated for each example with the same category value placed in the permutation before the given one. If a permutation is $\sigma = [\sigma_1, \ldots, \sigma_n]$, then $x_{\sigma_p,k}$ is substituted with,

$$\frac{\sum_{j=1}^{p-1}\left[x_{\sigma_j,k} = x_{\sigma_p,k}\right] Y_{\sigma_j} + a \,.\, P}{\sum_{j=1}^{p-1}[x_{\sigma_j,k} = x_{\sigma_p,k}] + a} \quad [9]$$

Where P is a prior value and a is the weight of the prior [Dorogush, Ershov, & Gulin, 2018]. Another different feature of the method is feature combinations. When a new split is going to build any combination is not considered for the first split in the tree, but for the following splits, all combinations are presented with all categorical features in the data set. All selected splits in the tree are perceived as a two-value classification and combined [Huang et al., 2019]. Moreover, unlike GBDT, Cat Boosting uses target statistics and thus deviation of the solution would not occur [Yandex, 2017].

Bayesian hyperparameter optimization

The supervised machine learning process is based on the input and output data and the learning process of the model, apart from this, hyper-tuning is what makes learning perfect. This process is not learned directly from the inputs. Selecting hyper-parameters manually is time-consuming, repetitive and requires ad-hoc decisions by the practitioner [Feurer, Springenberg, & Hutter, 2015]. For some, it is a "black art" since tuning requires expert knowledge and some luck [Snoek, Larochelle, & Adams, 2012]. Common methods are grid search, random search, and automatic hyper-parameter tuning. The Bayesian hyper-parameter tuning differs itself from them by using a different method, which is downscaling the search space according to past evaluations. Sequential Model-Based Global Optimization (SMBO) is a formalization of Bayesian optimization, it predicts hyper-parameters and sequentially updates the probability model to get better results [Hutter, Hoos, & Leyton-Brown, 2011]. In order to find local optima Expected Improvement function is used. The function is popularized by Jones et al., [1998] which is defined as follows:

$$EI_{y^*}(x) = \int_{-\infty}^{y^*} (y^* - y) p[y|x] dy \quad [10]$$

In the Eq. [10] y^* represents the objective function's threshold value, x is the suggested set of hyper-parameters, the actual value of an objective function, which is calculated with hyper-parameters x, is represented by y, and $p[y|x]$ is surrogate probability model.

APPLICATION

Data description

In this study, flight data of a Turkish airline company is used. The data set consists of the daily flights of the company from 2018. This data is merged with weather condition information that is matched with the flights, which includes instant weather information that occurs in the closest time zone to the flight departure time.

The aim of the study is to predict whether a planned flight will be delayed or not. According to the international rules, if the time difference between actual departure and scheduled departure is greater than 15 minutes the flight is labeled as delayed. There are 18148 observations in which 5717 are delayed and 12431 are on-time flights. Based on the literature survey and expert decisions Table I shows selected variables.

Table 1. Attributes integrated into the dataset

Variable name	Definition	Data type
Day	Day of the month	Categorical
Month	Month of the year	Categorical
Weekday	Day of the week	Categorical
Scheduled departure	Scheduled departure time of the flight	Continuous
Taxi out	The time duration elapsed between departure from the airport gate and wheels off	Continuous
Wheels off	The time point that the aircraft's wheels leave the ground	Continuous
Time on runway	Time spent on the runway	Continuous
Scheduled arrival	Scheduled arrival time of the flight	Continuous
Wheels on	The time point that the aircraft's wheels touch the ground	Continuous
Taxi in	The time duration elapsed between wheels-on and gate arrival at the destination airport	Continuous
Air time	Flight duration	Continuous
Temperature	Air temperature of the airport at or near the flight time	Continuous
Po	Atmospheric pressure measured at the weather station of the airport at or near the flight time	Continuous
U	Relative humidity of the airport at or near the flight time	Continuous
DD	Mean wind direction measured of the airport at or near the flight time	Categorical
FF	Mean wind speed measurement of the airport at or near the flight time	Continuous
VV	Horizontal visibility measured at the airport [km]	Continuous
Td	Dew point temperature of the airport at or near the flight time	Continuous
C	Total cloud cover of the airport	Categorical

Except for the date, wind direction and cloud cover feature all the variables are collected as continuous numbers. The categorical variables are combined to numerical values using the "one-hot-encoding" transformation technique, in which each unique observation of the variables is transformed to binary variables. There are 19 unique values in wind direction, and 547 in cloud cover. Also 7 for the day of the week, 12 for the month, and 31 for the day of the month variables. Therefore, after the transformation, the data set has 630 variables. Also, 70% of the data is used for the training phase and the remaining part for the test data. All the codes are written in Python.

RESULTS AND DISCUSSION

Model selection

From different machine learning approaches, based on both popularity and their good performance, CatBoost algorithm, XGBoost and LightGBM are selected in this study. The model's performance can be evaluated by various performance criteria. The main objective is the prediction of delayed flights thus developed models were evaluated by various performance measures such as accuracy, recall, receiver operating characteristic (ROC) score, and Cohen's Kappa score. All performance indicators are based on the confusion matrix.

In binary classification problems, such as this problem, observations can be classified as positive or negative. According to this information, the results of the classification problem can be classified as true positive (TP), true negative (TN), false positive (FP), and false negative (FN). TP and TN represent correct classification. FP is a false alarm also called Type I error and FN represents miss-classified ones also called Type II error. The accuracy rate is obtained by dividing the correctly classified observations into all observations. Usage of this ratio is suitable when the classified classes are equal, otherwise, results will yield misleading outcomes. A recall is the proportion of real positive cases that are correctly predicted as positive. This ratio is suitable when minimum false negative classification is more important. ROC graph is formed with TP (Y axis) and FP rates (X axis). The score is calculated by measuring the area under the ROC curve, and a higher score indicates a better model since it indicates that model's capability of distinguishing the classes. Cohen's kappa score measures the inter-rater reliability [Cohen, 1960]. For classification problems, it takes into account random success as a norm, such as reality, and the observations are evaluated as their degree of agreement. There is no definite way to interpret the result but, Landis et al. [1977] provided a scale which is -1 to 0 indicates no agreement, 0-0.20 slight agreement, 0.21-0.40 as fair agreement, 0.41-0.60 as moderate agreement, 0.61-0.80 as substantial agreement, and 0.81-1 as almost perfect agreement. Finally, when the class labels are predicted and false negatives are more costly, F2 score is advised to consider [Fernández et al., 2018]. It is actually Fbeta-measure with a *beta* value of 2, so the recall score becomes more important. Again it is based on confusion matrix and calculated as follows [11]:

$$F2 - measure = \frac{\left(5 * \frac{TP}{TP + FP} * \frac{TP}{TP + FN}\right)}{\left(4 * \frac{TP}{TP + FP} + \frac{TP}{TP + FN}\right)} \qquad [11]$$

Cross-validation is conducted in order to evaluate the model. In other words, the dataset is randomly divided into 10 sets, where each set has approximately the same imbalance ratio. Furthermore, these sets are trained with proposed algorithms separately.

For the Bayesian optimization, hyper-parameters for each machine learning algorithm, range of the values, and the best-found values are given in the following Table II with and without using SMOTE. After the hyper-parameter tuning, the selected algorithms are applied. Table III shows the results of all three algorithms without SMOTE usage and Table 4 shows results with SMOTE. These results are given in order to clarify the contribution of SMOTE algorithm. Normally, it is expected to get better results with SMOTE, however for this dataset without SMOTE results are preferable. To overcome this situation Table III should be evaluated mostly with the F2 measure, as it is appropriate when the data is unbalanced and the minimization of false negatives is more important to this particular model. LightGBM is more suitable for our case, according to both accuracy, recall, Cohen's Kappa, and F2 score. XGBoost can be considered to have performed slightly worse. Although Catboost has the lowest results, it is worth noting that these results, which are considered to be bad, are around 0.90. When Table IV is examined by focusing on the recall score only, it can be said that LightGBM yielded better results again, but when we look at all the results, it will not be overlooked that it has yielded very close results with XGBoost. CatBoost shows little underperformance here, too. As a result, the recommended model was LightGBM, although all of them were actually available. It is possible to attribute good results without using SMOTE to the fact that the grouping is good at the cross-validation stage and the models are advanced.

Table 2. Hyper-parameters

Algorithm	Hyper-parameter	Range	Best value found	Best value found with SMOTE
XGBoost	Learning rate	[0.01, 1]	0.160	0.076
	Number of estimators	[100, 1000]	740	380
	Max depth	[3, 10]	9	9
	Subsample	[0, 1]	1	0.641
	Gamma	[0, 5]	0.32	0.779
	Minimum child weight	[0, 20]	0	1
LightGBM	Number of leaves	[25, 45]	25	42
	Max depth	[5, 35]	7	33
	Lambda L1	[0, 0.05]	0.011	0.047
	Lambda L2	[0, 0.05]	0.013	0.034
	Minimum child samples	[5, 100]	10	21
	Minimum data in leaf	[5, 100]	7	35
	Feature fraction	[0.1, 0.9]	0.839	0.64
	Bagging fraction	[0.8, 1]	0.852	0.821
CatBoost	Bagging temperature	[3, 10]	6	4.67
	L2 leaf regularization	[2, 5]	5	2
	Max depth	[5, 15]	14	12

Table 3. Algorithm results without SMOTE

Model	Accuracy		Recall		ROC Score		Cohen's Kappa		F2 Measure	
	Train	Test	Train	Test	Train	Test	Train	Test	Train	Test
XGBoost	0.999	0.969	1	0.925	0.999	0.958	0.999	0.926	1	0.9662
LightGBM	0.999	0.967	1	0.929	0.999	0.957	0.999	0.924	1	0.9707
CatBoost	1	0.947	1	0.858	1	0.923	1	0.873	1	0.9379

Table 4. Algorithm results with SMOTE

Model	Accuracy		Recall		ROC Score		Cohen's Kappa		F2 Measure	
	Train	Test	Train	Test	Train	Test	Train	Test	Train	Test
XGBoost	0.998	0.962	0.999	0.903	0.999	0.946	0.998	0.910	0.999	0.951
LightGBM	1	0.959	1	0.904	1	0.945	1	0.905	1	0.957
CatBoost	0.999	0.937	0.999	0.825	0.999	0.906	0.999	0.847	1	0.931

CONCLUDING REMARKS

Flight delays have become a regular phenomenon in the aviation industry with the ever-growing travel demand, restricted airport capacity, and increasing amount of aviation traffic. Therefore, the prediction of late flights is important for all parties affected by this situation.

This paper has developed a new approach for airline companies to detect delayed flights. In order to achieve this different approaches, which are XGBoost, LightGBM, and CatBoost, were used. In addition, the SMOTE method was used in order not to be affected by the instability of the data set, but according to the results, the proposed algorithms performed well with the available data without the need for synthetic data processing. The reason for this could be the implementation of cross-validation or the use of advanced models.

This study, which is carried out by examining the data of a particular airline, can be evaluated as an event study. However, the results obtained are extremely promising. This degree of accurate estimation of delayed flights by algorithms also paves the way for future studies. In the following studies, it will be possible to predict delays in connecting flights or to replace cargo flights that require urgent transportation with alternatives. According to all these estimates, it is thought that opportunities such as applying different pricing policies or making flight insurance by taking into account the estimates in insurance costs can be offered.

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ORIGINAL PAPER

EXPLORING REAL-TIME VISIBILITY TRANSPORTATION PLATFORM DEPLOYMENT

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ABSTRACT. Background: Scholars have studied the determinants of visibility in the supply chain for years and, together with practitioners, agree that real-time visibility is beneficial to supply chain performance. However, expectations of supply chain professionals on supply chain visibility benefits do not meet reality. The purpose of this study is to explore determinants affecting real-time visibility in the transportation network where subcontracting predominates and understand the governance of digital of a platform for real-time visibility and its implications.

Material and Methods: This study utilizes action research as a methodology for pragmatism to understand supply chain professionals' standpoint regarding the operationalization of real-time visibility. A complex network of fast-moving consumer good companies was chosen for research because there is a greater need for visibility, and visibility improvement is also more challenging.

Results: The resources of freight forwarders and subcontractors, platform complementors are crucial for achieving real-time visibility. Willingness to information sharing is impacted by the asymmetry of benefits and privacy concerns. Low saturation of company-owned smartphones and technological interfaces, IT systems amongst researched enterprises a platform deployment slowdowns. The governance mechanism does not address the asymmetry of costs and benefits amongst platform partners.

Conclusions: This study is bridging the research-practice gaps in supply chain visibility. Future studies should analyze the role of tensions amongst the platform's partners from the paradox perspective. The in-depth analysis should focus on freight forwarders' strategies for building a competitive advantage to provide real-time visibility.

Keywords: supply chain visibility, transportation visibility platform, supply chain, freight forwarders, digitization

INTRODUCTION

Although scholars have discussed the determinants of visibility in the supply chain, including transportation networks, for years [Jakobs et al., 2001] it is still a call for a better understanding of how visibility within a supply chain emerges, develops, and must be implemented to succeed [Somapa et al., 2018]. There is no well-defined common understanding of visibility in a supply chain and sound approach available to effectively operationalize visibility in supply chains [Leung et al., 2017]. Following Somapa [2011], [2018] implementing real-time supply chain visibility is a challenge. The cause-effect relationship between supply chain visibility and business performance can be ambiguous [Somapa et al., 2018]. On the other hand, scholars and practitioners generally agree that real-time information about products, customers, and order fulfillment is beneficial to supply chain performance.

However, [Caridi et al., 2014] claimed research on the benefits of visibility was theoretical, and only a few benefits have been measured quantitatively for the dyadic relationships between retailers and manufacturers. Holcomb's [2011] study regards the relationship among 16 factors, and four perceived firm performance measures gave mixed results.

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Table 1. Supply chain visibility benefits literature review

Benefits	
Mitigating the effects of disruptions and enhancing resilience in the supply chain	[Brandon-Jones et al., 2014], [Dubey et al., 2018];[Mubarik et al., 2021; [Mandal et al., 2016]; Al-Talib et al., 2020], [Messina et al., 2020]; [Muñuzuri et al., 2016]; [McKinney et al., 2015]
Improving responsiveness, agility, flexibility, and customer service	[Dubey et al., 2018; Brusset, 2016], [Prajogo and Olhager, 2012]
Increasing operating efficiencies and effectiveness	[Holcomb et al., 2011], [Shamsuzzoha and Helo, 2011]
Reducing distribution and inventory costs	[Shamsuzzoha and Helo, 2011]
Enabling sustainable logistics and supply chain processes	[Sunmola and Apeji, 2020], [Luthra et al., 2020], [Junge, 2019], [de Vass et al., 2020], [Brun et al., 2020; [Kim and Shin, 2019]

[Caridi et al., 2014] prepared a value assessment model of the benefits of supply chain visibility and described the first attempt to construct a theory in the field of supply chain visibility [Caridi et al., 2014]. Lee and Rim [2016] proposed a quantitative approach regarding SCV. However, they did not conduct an empirical study of the relationship between visibility and financial performance. [Leung et al., 2017] showed the operational and tactical benefits from visibility but only from a six-month pilot.

Scholars used RBV logic, following which resources are combined to create capabilities, to conceptualize supply chain visibility as capability [Barratt and Oke, 2007]. Both supply chain connectivity and information sharing can be positioned as resources that may lead to a visibility capability through bundling these resources [Brandon-Jones et al., 2014], [Dubey et al., 2018]. Connectivity relates to the technological infrastructure through which information is conveyed to supply chain partners, and information sharing links to the quality of the information being shared [Brandon-Jones et al., 2014], [Nguyen et al., 2019]. The focus of visibility development should be on sharing information that can be used to improve performance. [Dubey et al., 2018] suggested other resources such as human skills (i.e. managerial skills and technical skills) and learning culture may also have significant effects on supply chain visibility as a desired capability of the organization. [Nguyen et al., 2019] provided empirical evidence that IT integration capability and interpersonal communication capability complement each other to attain internal information visibility. Although Somapa [2011] identified determinants of real-time visibility and categorized them into individual, organizational, technological, and environmental categories did not proceed with research to understand how identified factors affected visibility.

Studies on benefits and factors affecting visibility do not address types of SC relations in the transportation network where subcontracting predominates, though this business model gained importance. For example, Unilever, Procter & Gamble, Carlsberg, to name a few companies, transformed their transportation model to centralize in the Control Towers. Centralized Procurement contracted low-cost carriers, including, to a large extent, freight forwarders. Centralized operations managed by the Control Towers paved the way toward deploying digital platforms, a new model to combine resources to achieve real-time visibility. The leveraging of an internet-based platform to facilitate the exchange of information between supply chain partners has shown itself to be a powerful approach to avoid the complexities of integrating IT systems across the partner organizations [Schreieck et al., 2017]. Digital industrial platforms are platforms as [1] collect and integrate data from a heterogeneous set of industrial assets and devices, [2] provide this data and additional technical support to an ecosystem of third-party organizations who develop and enable complementary solutions that [3] affect the operation of industrial assets and devices, and [4] provide a marketplace to facilitate interactions between platform owner, third-parties and business customers [Pauli et al., 2021]**.** Technology architecture and mechanisms for governing the ecosystem of complementors make up the organizational form that is the platform [Gawer, 2014]. Platform governance concerns decisions about a platform [Tiwana et al., 2010]. Depending on the ownership status of platforms, the platform owners establish governance mechanisms that define the ground rules for orchestrating interactions in the ecosystems [Hein et al., 2020]. Platform governance requires addressing tensions, including the need to balance platform openness and control, exerting influence over the quality and range of complements, managing simultaneous collaboration and competition with complementors, and creating ecosystem value while also capturing some of that value [Rietveld and Schilling, 2020]. The first avenue for digital platform ecosystem research is attracting complementors and ensuring they continuously engage with the platform [Hein et al., 2020]. The success of digital industrial platforms largely depends on their ability to attract an active ecosystem of actors. If complementors join a platform, they can change their role to competitors [Gawer, 2014], [Hein et al., 2020].

Theoretical contributions regard real-time visibility in a supply chain, and platform architecture can be found in the Internet of Things [de Vass et al., 2020, Fahim et al., 2021, Lee and Rim, 2016, Lee and Lee, 2015], technologies for supply chain tracking and tracing (visibility) [Shamsuzzoha and Helo, 2011, Shamsuzzoha et al., 2013, Wang and Potter, 2007, Kandel et al., 2011; Hajdul and Kawa, 2015, Papatheocharous and Gouvas, 2011], synchronized logistics [Giusti et al., 2019]. These contributions do not address the governance mechanism and factors affecting real-time visibility with the platform. Based on Wang and Potter [2007] there is an asymmetry of benefits and risks affecting the willingness of subcontractors to share information. Most research focused on platforms' technological and business aspects, taking the platform owner's viewpoint. Scholars conducted little research to understand and analyze heterogeneous complementors and customers in the platform ecosystem [Deilen and Wiesche, 2021]. Factors affecting visibility need more insightful analysis to understand the root causes of gaps between expectations and reality regarding visibility in the transportation network where subcontracting predominates.

The research question of this study for the transportation network where subcontracting is in the majority are: *What factors affect real-time visibility? What is the governance of a platform for real-time visibility?*

MATERIAL AND METHODS

Bridging knowing–doing and expectations- reality gaps regarding the deployment of a real-time visibility platform requires a research approach that contributes to understanding the complexity of socio-technical systems and change processes. Action research is the research methodology for pragmatism and change implementation [Kotzab and Westhaus, 2005]. In this sense, action research is designated to fill the gaps between practice and research [Naim, 2010]. Action research can solve the problem of balancing practical and theory-relevant research and theoretical advances and managerial usefulness for the supply chain [Elg et al., 2020], a young field of research [Kotzab and Westhaus, 2005]. Following Näslund [2002] logistics research would benefit from more case-study articles based on action research. Action research projects seem appropriate when new solutions are tested and developed with partners in the supply chain [Kotzab and Westhaus, 2005]. It is a case for real-time visibility transportation platforms deployment. Therefore, the author used the action research-oriented case study approach as a research method.

The cycle of action research begins with a pre-step that involves context and purpose. The next step is diagnosing, encompassing naming the issues, however provisionally, as a working theme. Planning is the next step of the action research cycle and follows from the analysis of the context and purpose of the project, the framing of the issue and the diagnosis, and is consistent with them. Taking action as the following step encompasses implementation plans and interventions to be made. Finally, the outcomes of the action, both intended and unintended, are examined. The second is a reflection cycle which is an action research cycle about the action research cycle. In the action research cycle, learning encompasses: experiencing, reflecting, interpreting, taking action. Attending to experience is the first step to learning. The second step is to stand back from these experiences, inquire into them, and reflect on experiences of diagnosing, planning action, taking action, and evaluating action in the project. In interpreting is to find answers to the questions posed in the reflection. Taking action encompasses what is done as a result of reflecting and interpreting. What actions are taken is a consequence of reflection on diagnosing, planning action, taking action, and evaluating action. Reflection is the process of stepping back from experience to process what the experience means, with a view to planning further action [Coghlan, D. and Brannick, T., 2005], [Coughlan and Coghlan, 2002].

The role of the author was as an internal consultant involved in the platform deployment. The author's involvement encompassed the actions to onboard transport service providers, monitor compliance. Whenever required, the author should intervene and make changes to ensure platforms deployment. As the Logistics Research and Development center team member in the European Control Tower of the fast-moving consumer goods company, the researcher should support the projects that automate and digitize the transportation network of a complex supply chain. Logistics Control Tower acts as a focal company and coordinator from the point of view of material and information flows. Logistics Control Tower provides transport operations and service between suppliers and factories and between factories and primary warehouses. Logistics Control Tower focused on transport services provided to the focal company business partners (e.g., factories, co-packers, suppliers, and marketing and sales organizations), including transports from suppliers to factories and deliveries from factories to distribution centers. The role of the Logistics Research and Development Centre was to consult projects that should improve efficiency and reduce the negative environmental impact of transport in the European Union. One of the projects regarded the real-time visibility platform deployment. This project's scope encompassed the transportation network of 45 own factories and 260 co-packers, 60 warehouses from which Logistics Service Providers managed the vast majority. From the perspective of a platform logic, a focal company is a customer, whereas transport service providers, GPS providers, IT providers are complementors.

In the first phase, a brainstorming session with onboarding team members and the procurement team helped create the reason codes. The idea of reason codes was to simplify data collection by giving interviewees a limited choice of responses. More importantly, reason codes facilitated internal communication and reporting to ensure repeatability and reproducibility. The bot automatically sent emails containing reason codes to about 110 transport service providers weekly over 40 weeks (between months 13 and 23 as per figure number 1). In the second stage, transport service providers should attribute a reason code to each untracked shipment. The author inductively analyzed responses from Transport Service Providers. An effective response rate accounted for nearly 35%. In the third stage, during weekly compliance calls where Procurement, transport planning, internal customers service, and external stakeholders discussed the progress of the deployment, the author utilized the abductive thought process to understand the governance mechanism and its implications. The onboarding team of which the research was a member checked if the appropriate persons executed the actions and their impact on compliance the following week. The onboarding team carried it over to the following week if the responsible person did not execute the action. The researcher with the onboarding team checked the effect of agreed-upon actions on compliance in the next weeks. If no improvement in terms of compliance, the onboarding team escalated the case to senior management.

In the fourth step, during workshops, the researcher discussed actions to correct governance and manage tensions to improve compliance. A focal company workshop discussed methods to accelerate deployment was the forum to share views and perspectives from different levels of the organization and the platform owner.

Actions to understand the factors affecting real-time visibility and the governance of a real-time visibility transportation platform were parts of the action research cycle. Diagnosing used the reason code form, and planning and intervention applied weekly calls. The author coded information in a weekly tracker. Compliance, calculated as the number of tracked loads (both in the pick-up and delivery locations) divided by the total number of loads, was the indicator to measure performance. Regarding the second cycle, the author coded information on the learning in the other weekly tracker, including reflection on the content, process, premise, as well as the learning loops: single (question - how?), double (why?), triple loop (how do we decide what is right?). Within this research approach, the author used, for the most part, abduction to develop propositions by putting the empirical material in dialogue with theory.

Table 2 Information collection

Phase	Meetings	Researcher role	Informants
Factors affecting real-time visibility identification	Face-to-face sessions	Facilitator, Observer	Onboarding team members, Procurement Specialists, Procurement Junior Manager
Factors affecting real-time visibility identification	Virtual connections	Observer Providing and presenting analysis	Transport Service Providers
The governance of a platform for real-time visibility	Weekly calls	Facilitator Observer	Platform customer (Procurement Specialists), Platform owner (Implementation Specialists)
The governance of a platform for real-time visibility	Workshops	Facilitator Observer	Platform owner (Vice President, Key Account Manager, Implementation Specialists), Platform customer (Procurement Specialists)

RESULTS

The project on deploying a real-time visibility transportation platform should enable the digitization and automation of processes and unlock numerous opportunities. The senior stakeholders called it the most critical project in the European transportation network. The project was a crucial part of a global transformation program sponsored by the European supply chain leadership team and governed by the global logistics leadership team. The assumption was to deploy a real-time visibility platform over six months using two solutions: 1) integrating information systems of focal company, transport service provider, and Global Positioning System provider, 2) smartphone application for drivers. The deployment should encompass two steps: 1) carriers onboarding, 2) achieving compliance of 60% of tracked shipments that, in senior management's view, should be sufficient to make the platform usable in practice. The steering committee set an ambitious goal to reach 60% of full truckloads tracked in real-time mode in three months and, respectively, 90% in nine months.

Steering Committee encompassed representatives of logistics and IT. Direct responsibility for the implementation should have European Business Support Manager and Technical Support Manager from the global team. The transportation operations and logistics procurement teams should support implementation. The external service company provided IT services and reported to Enterprise Technical Support Manager. The IT capabilities of the project worked from in India, whereas business support, operations, and Procurement in the Control Tower in Poland (Table 3).

Table 3. The team members

Title	Roles and responsibilities in the project, company, geography	Title	Roles and responsibilities in the project, company, geography
European Supply Chain Vice President	Steering Committee, a focal company, the Netherlands	Project Lead	Implementation team, focal company, Poland
Logistics Director Primary & Inbound Europe and Control Tower Director	Steering Committee, Key Decision maker, focal company, Poland	Senior Logistics Development Specialist	Implementation team, focal company, Poland
Procurement Director Manufacturing Partners, Logistics and Capex	Steering Committee, focal company, Switzerland,	Subject Expert	Implementation team, focal company, Poland
Global Logistics Process Excellence Director	Steering Committee, Key Decision maker, focal company, UK	Operations Specialists	Implementation, focal company, Poland
IT Director Make & Deliver	Steering Committee, focal company, India	Technical Support Manager	Implementation, focal company, Bangalore
European Business Support Manager	Leadership/Implementation, focal company, Poland	Procurement Junior Manager	Implementation, focal company, Poland
Operations Manager (Transport)	Leadership/Implementation, focal company, Poland	Finance Junior Manager	Support, focal company, Poland
Global Transport Platform Owner	Leadership/Implementation, focal company, Bangalore	Strategic Account Executive	Leadership, platform owner, US
ETS Log. Process Excellence Junior Manager	Leadership/Implementation. the focal company, Poland	Implementation Specialists	Support, platform owner, US
Procurement Manager	Leadership/Implementation, focal company, Poland	Manager Consulting Services Manager	Support for a focal company, external company

A Strategic Account Executive from the owner of the transportation visibility platform was involved in the governance structure. Implementation Specialists from the owner of the transportation visibility platform should work on the onboarding of transport service providers. Implementation teams from a focal company and the owner of the transportation visibility platform should lead onboarding. The transport service provider's obligation was to contact data suppliers and accelerate their work if necessary. Once issues occur, the procurement business team of a focal company should be involved in contact with carriers. The business transport team of a focal company with project champions should support the onboarding team to resolve potential operational issues.

The average time for onboarding a transport service provider on a transportation visibility platform was about 90 days. The median was hardly above 80 days and recorded the longest time of 250 days, whereas the shortest was about ten days. For the onboarding of transport service provider, it was required 30 emails on average, out of which almost 20% was on account of the need for further clarification and fix misunderstandings in elementary vocabulary like transport management system, GPS, fleet management system. Due to business and contractual relationships issues, transport service providers stopped sending data, which explained the decrease in the percentage of onboarded transport service providers.

Before a transportation visibility platform deployment, the steering committee ignored that freight forwarders provide 65% of all shipments, resulting in low compliance. The next complexity contributor was a fragmented group of transport service providers. The most significant transport service provider accounted only for a 5% share in the total number of shipments. The application for a smartphone was developed as a solution to track subcontracted loads.

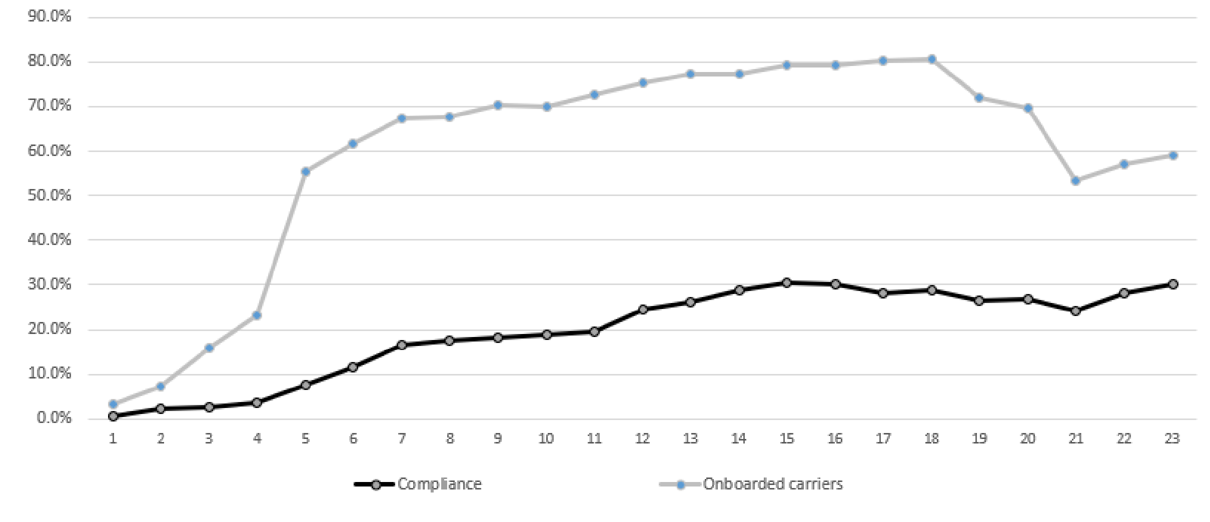

Fig. 1. The percentage of the onboarded carrier and compliance.

The respondents gave a lack of smartphones as the most common reason behind not-tracked shipments. Drivers used either personal smartphones or old-fashioned phones on which installation of applications was not doable. Because of the small number of shipments, drivers showed little willingness to use the smartphone application. Low digital skills of drivers and willingness made downloading and operating the smartphone application very time and effort-consuming. Error-prone manual data entry affected data quality and even made it impossible for real-time tracking. Low saturation of company-owned smartphones combined with disabled roaming reflected a low technological maturity level amongst transport service providers in a scope.

Table 4. Results of reason codes analysis.

Reason Code	Percentage
Drivers did not have a smartphone to use the application	35
Drivers not being able to use the application for smartphones correctly	23
Technical problems within the integration of IT systems	19
Drivers' phones had roaming disabled	12
Data privacy concerns to be resolved	8
Others	3

Freight forwarders also pointed to disabled roaming as a blocker to the usage of applications on international routes. Connectivity issues among systems of the focal company, real-time transportation visibility platform, freight forwarders, Global Positioning System service providers, was the following reason behind untracked shipments.

Because of the lack of a system for storing track and trailer plate numbers, about 15% of carriers entered the truck and trailer plate numbers manually on the real-time transportation visibility platform web page. The vast majority of carriers used file transfer protocol for sending excel files to real-time transportation visibility platforms. 15% of transport service providers used application interface programming. The focal company frequent updates of planned pick-up time resulted in not updating accordingly trucks and trailers plate numbers in the transport service providers and focal company system.

Because of subcontracting, data needful for tracking had to be fetched either directly from the subcontractor's system for storing track and trailer plate numbers or freight forwarder that brought data from a subcontractor system. Freight forwarders realized they could build subnetworks to control over data they share with a real-time visibility transportation platform. As freight forwarders integrated subcontractors within their subnetwork, they became indirect competitors to the transportation visibility platform. Simultaneously, they collaborated by sharing data on the real-time position of loads of a focal company what resulted in coopetition tensions. Freight forwarders can be real-time transportation visibility platform owners and gain a role of a network integrator. Willingness to earn this role triggered tensions between autonomy and control. Both needs for autonomy within the network of a real-time visibility transportation platform and aspiration to be a network integrator are reasons behind competition between freight forwarders and the real-time transportation visibility platform.

Transport service providers reported privacy concerns as the following reason behind the not tracked shipment. Transport service providers claimed that application usage is against drivers' privacy and can break General Data Protection Regulation if an application follows drivers in private time. Regarding "others," issues with data quality, including incomplete, incorrect timestamps, delayed updates of pick-up time and delivery times, inefficient shipment planning processes, have been highlighted by transport service providers.

Because of low compliance, the average accuracy of the expected arrival time amounted to 40% in month number 23. The expected time of arrival of high accuracy has not been achieved in a repeated manner. The reason for that was gaps in tracking between pick and delivery locations and frequent change of drivers on subcontracted shipments with different driving patterns, making it difficult to calculate the exact time of arrival in a repeatable manner.

As per researcher interventions, the first was to propose the process to understand the low percentage of tracked shipments. The compliance process itself comprised the cycle of diagnosis, planning, taking action, and evaluation. It was the first-order change and occurred as change is identified and implemented within an existing way of thinking. Key decision-makers aimed to improve based on the same capabilities and repeated the same thought process when escalation and pressure should help fix issues.

Because of the lack of expected improvement, key decision-makers in the focal company agreed to have pilots with other transportation visibility providers. It was the subsequent intervention representing second-order change altering the core assumptions that underlie the situation. A focal company had pilots on selected lanes with four visibility providers. The global IT team supported the initial visibility provider, a default worldwide solution, and slowed down integrating chosen for pilot’s visibility providers with the global platform of a focal company. The other issue was for transport service providers. While two visibility providers delivered a performance of about 5% of tracked shipments, the one had performance better by a few percentage points from the initial visibility provider. The solution of the other visibility provider was too cost-intensive and complex though it delivered high compliance. Because of the intervention, two visibility providers (the best from competitors) and the initial one provided services simultaneously. The final decision was to choose the challenger because of the disappointing improvement of the initially chosen supplier.

The other intervention was the bonus-malus scheme to ease tensions among the platform members. Following the scheme, transport service providers could be awarded or punished depending on whether they track real-time shipments. The scheme should balance the asymmetries of benefits from being part of a real-time visibility transportation platform. Key decision-makers put a plan on hold because of prioritizing the other goals, including costs and service. Instead of the scheme, Procurement added a clause to contracts with transport service providers to obligatory track shipments.

Although some carriers ignored fulfilling this clause, a focal company applied no fines.

The following intervention was a change of coordination and information flow in the project. It was to increase the speed of decisions making and integrate project governance. The implementation team from the Control Tower of a focal company had direct relationships with carriers. Capabilities and carriers' willingness to cooperate were prerequisites for a project's success. Since the intervention, the implementation team from a focal company's Control Tower governed a project.

As per the outcomes of reflections, the first one was a highly complex governance structure subject to intervention. The suboptimal behaviors were because of different KPIs of the involved stakeholders. Because of that, stakeholders prioritized achieving goals in terms of costs and customer service. Although senior managers classified the project as IT, it was highly dependent on the external business partners of a focal company. The changes were IT-driven, while transport service providers should build necessary capabilities. A gap between IT requirements and the focal company's ability to enforce transport service providers to build essential capabilities made it impossible to operationalize the project. The change in assumption was also about the achievability of goals with the current visibility provider. The chosen real-time transportation visibility platform should provide the global service while they only started to build the footprint in Europe. The subsequent change in assumption was also whether the goals were achievable at all. The transportation model with the freight-forwarders in the majority did not enable achieving ambitious goals regardless of a visibility provider.

CONCLUSIONS

In managerial terms, this paper makes significant contributions. Insights can help firms assess opportunities and challenges associated with enhancing real-time visibility via platform adoption. Managers can investigate their current needs and status of supply chain visibility and invest in the parts they need to improve.

Regarding the internal governance of a focal company for strategic stakeholders of a focal company, the deployment project should not be IT-driven. A gap between IT requirements and the focal company's ability to enforce transport service providers to build essential capabilities makes it impossible to operationalize the project. Intra-company alignment is a prerequisite for inter-company integration. Thanks to action research intervention, key competencies have been attributed to the business part of a project. Getting the proper knowledge to the right people at the right time was an outcome of an intervention. Establishing new ways of working improved the compliance process. The organization experienced a steep learning curve. It resulted in a period of experimenting with new visibility providers. The focal company acquired detailed knowledge of carriers' capabilities and knew what should be done to operationalize real-time visibility.

Previous research ignored the role of complementors as a factor affecting real-time visibility. Based on the understanding of the resources of freight forwarders and subcontractors, which are platform complementors are crucial for achieving real-time visibility. The author proposes: freight forwarder develops connectivity and information sharing capabilities focused on the specific situation at hand. Freight forwarders develop their platforms to maintain autonomy and control their subcontractors. Asymmetry of benefits and risks affects the willingness of subcontractors to share information. Over time, freight forwarders gained coopetition capabilities to avoid unproductive conflict and the escalation of the tensions.

Based on the analysis, the author proposes that trade-off between transport service providers with their fleet and freight forwarders of multi-level subcontracting impacts predominantly the deployment of a platform. The deployment scope narrowed to transportation lanes where short lead time, high gross margins, and on the other hand, repeatedly occurred operational issues justify deploying a transportation visibility platform

Given the increasing role digital platforms play in the supply chain, scholars' focus should be on clarifying platform business models, identifying their success factors, and dynamic models of platform firms' behavior. Further research should analyze relationships within the network of subcontractors, which impacts behaviors towards information sharing. The in-depth analysis should focus on freight forwarders' strategies for building a competitive advantage to provide real-time visibility. There should also be investigated the strategy of other complementors as partners of a real-time visibility transportation platform. The research agenda on platforms is at an inflection point [Gawer, 2020].

Recommendations for theory building, the relationships, and causal loops among partners of a real-time transportation visibility platform need to be investigated from a dual theoretical perspective of system approach and network theory. Therefore, future studies should analyze the context specifics of tensions and the manifestation of tensions as a paradox of digital platforms.

The issue of generalizability is because of the focal company's supply chain model, where subcontractors are in the majority. The scientific community is also skeptical about action research, questioning its rigor [Näslund, 2002], and the identification of theory is never an easy task in action research. However, the study encompassed three years of action research, a repeated weekly process, and reason codes form sent for 23 months to transport service providers to confirm the work's validity.

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A BIBLIOMETRIC ANALYSIS OF THE APPLICATION OF SOCIAL NETWORK ANALYSIS IN SUPPLY CHAIN MANAGEMENT

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ABSTRACT. Background: This paper presents a bibliometric overview of research published application of social network analysis in supply chain management in recent decades. It may be useful for showing the most important problems in this area. With this aim, Citespace is used to analyse the literature on the application of social network analysis in supply chain management to clarify the development and research trend. Bibliometric analysis is the quantitative study of bibliographic material. It provides a general picture of a research field that can be classified by papers, authors, and journals. The main objective of this study is to investigate the knowledge domain about application social network analysis in the supply chain field and reveal the thematic patterns and topics of high interest to researchers to predict emerging trends in the literature.
Methods: To investigate the growth of studies about the applicable social network in supply chain management, 647 articles were reviewed by CiteSpace software. These papers were collected from the Core Collection of Thomson Reuters and published in 16 journals in operations research and management science from 2004 to 2021. Document co-citation analysis, clustering analysis, and citation burst detection were conducted to investigate and examine the thematic patterns, emerging trends, and critical articles of the knowledge domain.
Results: Social network approaches are increasingly popular in the supply chain. Four major clusters are discussed in detail, namely multi-objective optimization, sustainable supply chain, supply network, and circular economy. Three research trends of supply chain network design, structural characteristics, and supplier selection and evaluation were identified based on citation bursts analysis.
Conclusions: The present study offers a new approach to visualizing relevant data to synthesize scientific research findings of the application of social network analysis in supply chain management. Additionally, directions for future research in this area are presented.

Keywords: social network analysis, supply chain management, bibliometric analysis, CiteSpace

INTRODUCTION

Social network analysis is a quantitative analysis method developed by sociologists based on mathematical methods and graph theory [Bing 2011]. SNA has been used widely in the social and behavioural sciences, as well as in economics, marketing, and industrial engineering at present. Some scholars have used SNA methods for assessment [Li et al. 2018, Leydesdorff et al. 2018, Fursov and Kadyrova 2017, Liu et al 2019]. With the development of economic globalization, the supply chain becomes more and more complex. Social network analysis plays a very important role in the analysis of supply chain structure [Borgatti and Li 2009, Kim et al. 2011]. Many scholars have used the social network method to analyse the structure of the supply chain. Son et al. [2021] analysed the impact of catastrophic supply chain disruptions on enterprise supply chain structure based on social network structure indicators in the context of the 2011 Japan earthquake. Seiler et al. [2020] combined the social network and

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measurement method, established a social network of 448 nodes through the supply chain relationship of 15 small and medium-sized enterprises, and studied the direct impact of social network indicators on enterprise performance. Bellamy et al. [2014] used the social network analysis method to evaluate the structural characteristics of the supply chain network and explored the relationship between structural characteristics and enterprise performance through a regression model. Some scholars also summarized the application of social network analysis in the field of the supply chain. Descriptive analysis and content analysis are the main research methods. For instance, Han et al. [2020] systematically reviewed 63 works of literature published between 2000 and 2019 on social network analysis in supply chain management. Alinaghian et al. [2020] analysed the current development of social network analysis in sustainable supply chains. Galaskiewicz [2011] argued that social network analysis is crucial to understanding the relationships in supply chain networks. However, there is a limited number of papers analysing the application of social network analysis in the supply chain field through bibliometric software. Therefore, it is greatly important and necessary to fill this gap.

This study uses CiteSpace to analyse the knowledge map of existing literature. The knowledge graph can evaluate and predict the current situation and development trend of a certain research field by using mathematics, statistics, and other methods according to various quantitative characteristics of literature [Chen 2006]. It can also express the interrelationship between information through a spatial form and show the development process and structural relationship of knowledge [Chen 2017]. Comparing the traditional literature reviews that are generated typically based on the prior knowledge and personal judgment of a domain expert, this kind of computational approach guides our review from a more diverse and much broader range of relevant topics to offer relatively objective results and insights over conventional approaches. In addition, the process can be replicated as needed.

The objective of this study is therefore to evaluate the application of social network methods to supply chain management. Using bibliometric techniques, the study does so by examining the literature published in leading journals. With the help of these techniques, and by analysing the articles and citations used by researchers in their studies, we aim to investigate the knowledge domain about application social network analysis in the supply chain field and reveal the thematic patterns and topics of high interest to researchers to predict emerging trends in the literature.

METHOD

Data collection

The bibliometric articles were collected from Advanced Search in the Web of Science Core Collection of Thomson Reuters, incorporating Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), Arts and Humanities Citation Index (A&HCI), Emerging Sources Citation Index (ESCI), Current Chemical Reactions (CCR-EXPANDED) as well as Index Chemicus (IC). Following the suggestion of Han et al. [2020], two primary keywords “Supply chain management” and “Social network analysis” were combined through a Boolean logic to search the databases. Specifically, the data set was collected through the following strategies:

Topic= (supply chain OR SCM OR supply network) AND (social network OR degree centrality OR network centralization OR network complexity OR network density), which means that articles with those words in title or abstract, or keywords will be retrieved.

Language=English.

Document Type=Article &Review.

5791 papers in total were obtained from more than 100 journals. According to the recommendations of Han et al. [2020], this study chose 16 journals in Operations research and management science from the Association of Business Schools (ABS) journal ranking, 2018 (see Table 1 for the journals selected). After manual removal deduplication and cleaning, 647 papers were finally obtained, including 576 papers and 71 reviews.

Table 1. Selection of journals and the number of published papers

Number	The name of journals	The number of published papers	ABS ranking
1	Journal of Supply Chain Management	21	3
2	Journal of Operations Management	34	4
3	International Journal of Production Research	90	3
4	Supply Chain Management: An International Journal	59	3
5	International Journal of Operations and Production Management	42	4
6	Journal of Purchasing and Supply Management	16	2
7	International Journal of Production Economics	87	3
8	Production Planning and Control	33	3
9	Journal of Business Logistics	11	2
10	International Journal of Logistics Management	24	1
11	International Journal of Physical Distribution and Logistics Management	29	2
12	Management Science	0	4
13	Operations Research	0	4
14	Manufacturing and Service Operations Management	0	3
15	Decision Sciences	10	3
16	Journal of Cleaner Production	191	2

Instrument

CiteSpace was developed by Chen [2004], which can analyse and visualize the hot topic and research trends of the collected papers. It can be used to analyse co-occurrence networks, cooperative networks, and co-citation networks. Co-occurrence network involving term, keyword, source, and category. A cooperative network involving author, institution, and country. Co-citation networks involving authors, references, countries, etc. These are useful for identifying knowledge transfer processes and finding critical points in the development of a research field.

To more scientifically and effectively identify and show the application trend of social network analysis in supply chain management, this study identified the research patterns and detected the research hotspots through co-citation documents and reference burst citation.

RESULTS

Publication years and journals

The annual number of papers published was shown in Figure 1. In 2003, no articles applying social network analysis to supply chain management were published. In 2004, 2005, and

2006, there were four papers published respectively. However, from 2018 to 2020 more than 80 papers appeared every year. Meanwhile, the number of papers published annually was fitted by an exponential function, and it was found a continued growth of publications on the application of social network analysis to supply chain management.

The number of publishing per journal includes their ABS ranking is presented in Table 1. The most published in the Journal of Cleaner Production (191), followed by the International Journal of Production Research (90) and the International Journal of Production Economics (87). In contrast, no papers have been published in Management Science, Operations Research and Manufacturing, and Service Operations Management.

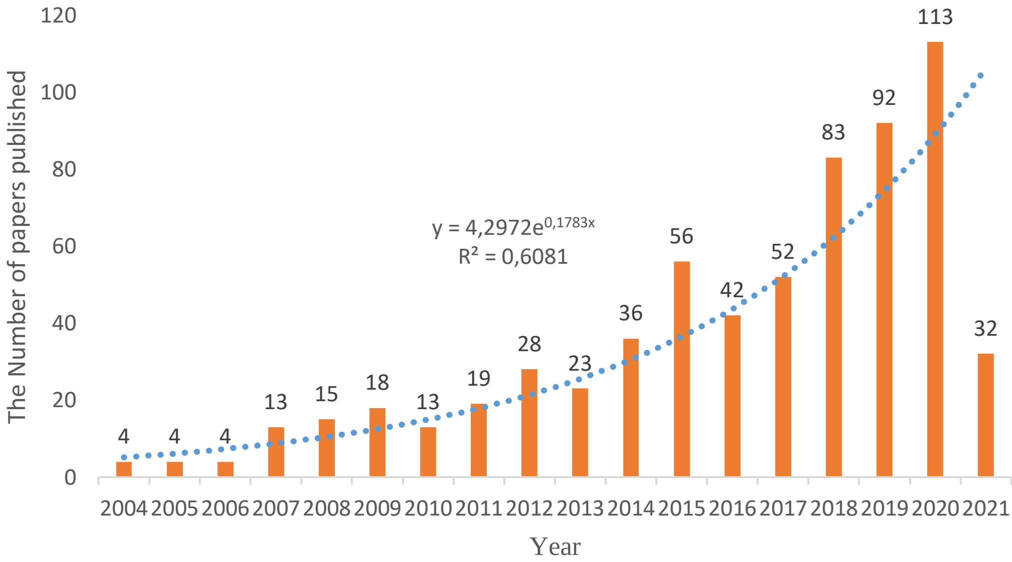

Fig. 1. Annual number of papers published in WoS.

Document co-citation analysis

Based on 647 bibliographic recordings from 2004 to 2021, the map of document co-citation analysis is displayed in Figure 2. There were 748 individual nodes and 1848 links, representing cited articles and co-citation relationships among the whole data set, respectively. Table 2 illustrates the top five most cited articles about social network analysis in supply chain management. The most cited paper is a review published by Eskandarpour et al. [2015]. In this paper, Eskandarpour et al. comprehensively investigated the literature published from 1990 to 2004 on the supply chain network design. They think there are no reviews that study the theme of methods for sustainable supply chain network design. They summarized the characteristics of this supply chain network from four aspects, namely, environmental supply chain network design, social supply chain network design, modelling approaches, solution methods, and applications. Borgatti and Li [2009] is the second most cited paper, which provided supply chain researchers with an overview of social network analysis. They illustrated key concepts in social network analysis, such as similarities, social relations proper, interactions, and so on. Some criteria also were recommended, for instance, structural holes, node centrality, cohesive subgroups, and so on. The third most cited paper is Kim et al. [2011]. They constructed a theoretical framework to evaluate supply network constructs based on critical social network analysis metrics. According to materials flow and contractual relationships, this research conducted three automotive supply networks. At the same time, key node-level metrics (degree centrality, closeness centrality, betweenness centrality) and key network-level metrics (supply network centralization, supply network complexity) were used to assess the characteristics of the supply network. They argued that it is very useful to apply social network analysis to understand the complexity of supply chain networks. Carter et al. [2015] is the fourth most cited article. It proposed six foundational premises to lay down the underpinnings of the theory of supply chain. Carter et al. believed that the supply chain is a network, which has the characteristics of complexity and relativity. They also hope to test and investigate the theory with more evidence in the future. The fifth most cited article is Brandenburg et al. [2014]. It summarized 134 articles about sustainable supply chain management from 1994 to 2012. They found that the number of publications in sustainable supply chain management was growing, and research areas included variations in focus by function, research perspective, methodology, and the type of sustainability focus of the supply chains.

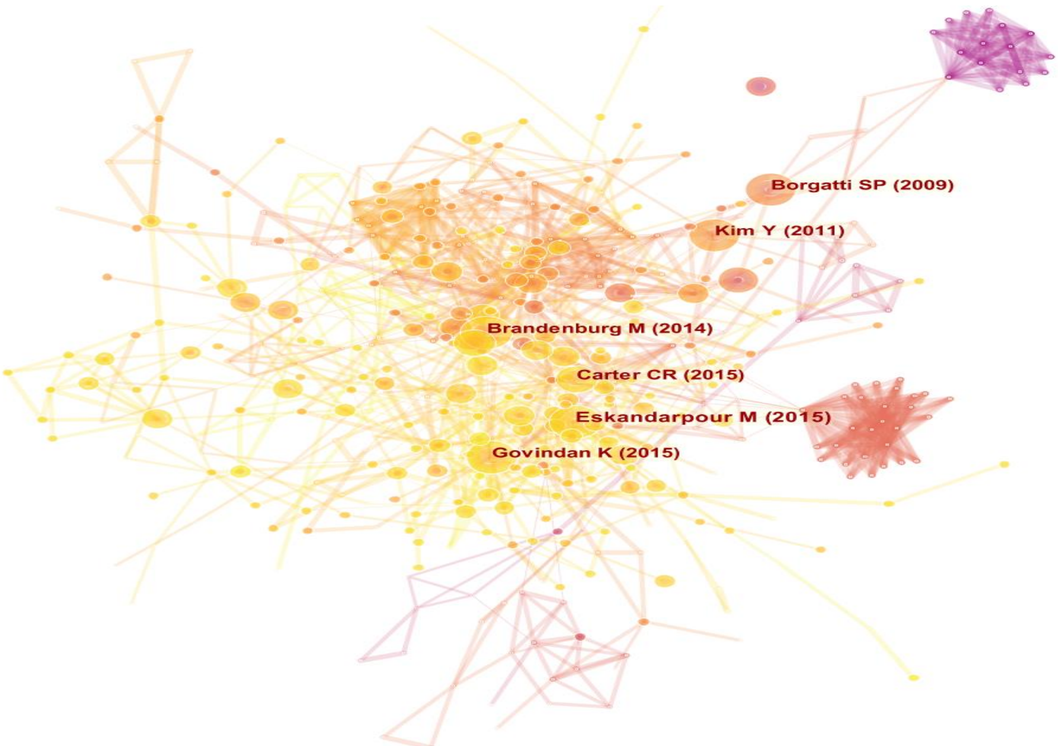

Fig. 2.. Map of document co-citation analysis

Table 2. The top five most cited articles

Citation counts	Author[year]	Title	Journal
24	Eskandarpour et al. [2015]	Sustainable supply chain network design: An optimization-oriented review	The International Journal of Management Science
22	Borgatti and Li [2009]	On social network analysis in a supply chain Context	Journal of Supply Chain Management
22	Kim et al. [2011]	Structural investigation of supply networks: A social network analysis approach	Journal of Operations Management
22	Carter et al. [2015]	Toward the theory of the supply chain	Journal of Supply Chain Management

22	Brandenburg et al. [2014]	Quantitative models for sustainable supply chain management: Developments and directions	European Journal of Operational Research

Clustering analysis

The 647 papers generated 11 clusters through CiteSpace. The modularity Q is 0.85 and the mean silhouette is 0.92, which indicates the clustering is significant and reliable. According to the narrative summary of CiteSpace, cluster #0, cluster #1, cluster #2, and cluster #3 have the highest citation bursts, indicating that these four clusters are the critical and active study efforts in the duration of 2004-2021. Figure 3 presents the results of cluster analysis.

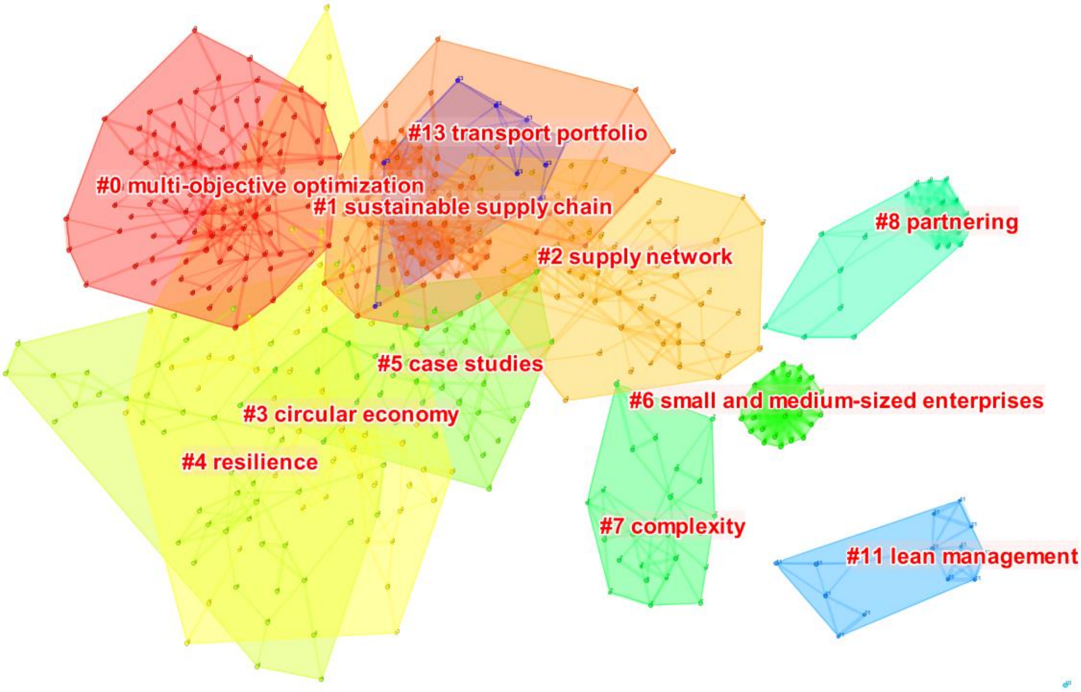

Fig. 3. Results of cluster analysis

Cluster #0 is defined as multi-objective optimization, with more focus on supply chain design and network optimization. 94 papers are included in this cluster whose mean silhouette is 0.91 and the mean year is 2015. The five most cited articles include Eskandarpour et al. [2015], Govindan et al. [2015], Mota et al. [2014], Fahimnia et al. [2015], and Devika et al. [2014]. Eskandarpour et al. [2015] is a review that analysed

87 papers in the field of supply chain network design. Govindan et al. [2015] reviewed 382 papers in the reverse logistic and closed-loop supply chain in scientific journals published between January 2007 and March 2013. They found that the integration of different levels of decision-making and defining new decision variables are future opportunities for the decision variables category.

Meanwhile, paying attention to multi-objective problems, utilizing new approaches, and applying more green, sustainable, and environmental objectives can be the future directions in single and multiple objective problems. Mota et al. [2014] provided a generic multi-objective mathematical programming model for the design and planning of supply chains, integrating the three dimensions of sustainability. In addition, they created a social indicator and incorporated it into the model, which allows studying the impact of facility location decisions. Then, this model has applied a real case study of a Portuguese battery producer and distributor, and the result indicated it allows improvements in all three dimensions of sustainability. Fahimnia et al. [2015] presented a thorough bibliometric and network analysis based on over 1,000 published articles in green supply chain management. Using rigorous bibliometric tools, established and emergent research clusters are identified for topological analysis, identification of key research topics, interrelations, and collaboration patterns. The results showed that many of the more influential papers seemed to have occurred in the middle of the last decade, and prescriptive, normative, quantitative modelling has started to take on greater importance. Devika et al. [2014] proposed a multi-objective optimization model for a general closed-loop supply chain network with six echelons. The performance and reliability of the proposed algorithms were evaluated in comparison with available benchmark algorithms. The results obtained that the NIV algorithm was better than other approaches. Finally, they verified the availability of the algorithms by a real case study for the glass industry. Other papers in this cluster also explored the design and optimization of supply chain network structure under different scenarios.

Cluster #1 is defined as a sustainable supply chain, which indicated that scholars pay more attention to the sustainable development of the supply chain. There are 79 papers in this cluster whose mean silhouette is 0.92 and the mean year is 2011. The five most cited articles include Brandenburg et al. [2014], Seuring [2013], Hassini et al. [2012], Chaabane et al. [2012], and Govindan et al. [2013]. Brandenburg et al. [2014] carefully analysed 134 articles on quantitative models of sustainable supply chain management. Seuring [2013] summarized the status of research on sustainable supply chain management applying (mathematical) modelling techniques. They found that life-cycle assessment which is based on approaches and impact criteria dominates on the environmental side. Furthermore, on the modelling side, there are three dominant approaches: equilibrium models, multicriteria decision making, and analytical hierarchy process. Hassini et al. [2012] investigated 707 articles on sustainable supply chain management published from 2000 to 2010. On the one hand, they established an evaluation framework for sustainable supply chain management based on literature survey results. On the other hand, a case study was used to confirm supply chain sustainability metrics. Chaabane et al. [2012] developed mixed-integer linear programming based on the framework for sustainable supply chain design that considers life cycle assessment (LCA) principles in addition to the traditional material balance constraints at each node in the supply chain. The framework was used to evaluate the trade-offs between economic and environmental objectives under various cost and operating strategies in the aluminium industry. The results suggested that current legislation and Emission Trading Schemes (ETS) must be strengthened and harmonized at the global level to drive a meaningful environmental strategy. Moreover, the model demonstrated that efficient carbon management strategies will help decision-makers to achieve sustainability objectives cost-effectively. Govindan et al. [2013] explored sustainable supply chain initiatives and proposed an assessment model combining fuzzy criteria and fuzzy TOPSIS. A case study, then, showed the effectiveness of the model. To sum up, the articles in this cluster focus more on the index composition and evaluation model construction of a sustainable supply chain.

Cluster #2 is defined as a supply network, and the main structural characteristics of the supply chain network were investigated. 68 articles are included in this cluster whose mean silhouette is 0.89 and the mean year is 2010. The top four most-cited articles include Borgatti and Li [2009], Kim et al. [2011], Choi and Wu [2009], and Galaskiewicz [2011]. Borgatti and Li [2009] introduced the critical concepts and structural features in the context of the supply chain. Kim et al. [2011] proposed a supply chain evaluation framework based on social network analysis metrics and analysed the structural characteristics of three automated supply networks. Choi and Wu [2009] built buyer-supplier–supplier triads relationship, according to the buyer-supplier relationship and supplier–supplier relationship literature. They applied balance theory and the structural-hole concept to present a theoretical framework. Nine triadic archetypes of buyer-supplier–supplier relationships were identified. Galaskiewicz [2011] thought supply chain architects should consider small-world properties of supply chains and networks should be studied over time and not as stagnant structures. They proposed a new methodology Social Network Image Animator for supply chain forecasting and innovation. To conclude, the attention of Cluster #2 is attributed to using the social network analysis index to explore the characteristics of the supply chain network.

Cluster #3 is defined as the circular economy. There are 50 papers in this cluster whose mean silhouette is 0.94 and the mean year is 2017. This indicates that this topic is new and can be studied in more depth in the future. The two most cited articles include Govindan et al. [2015] and Wilhelm et al. [2016]. Govindan et al. [2015] summarized multi-criteria decision-making methods for green supplier evaluation and selection from 1997 to 2011. They found that the most widespread method is the analytical hierarchy process (AHP) and the most widely considered criteria for green supplier evaluation and selection is the environmental management system. Wilhelm et al. [2016] examined the conditions under which first-tier suppliers will act as agents who fulfil the lead firm's sustainability requirements and implement these requirements in their suppliers' operations based on agency and institutional theory. The findings from three in-depth case studies embedded in different institutional contexts highlight the importance for lead firms to incentivize each agency role separately and to reduce information asymmetries. In addition, the results reveal several contingency factors that influence the coupling of the secondary agency role of the first-tier supplier, including resource availability at the first-tier supplier's firm, the lead firm's focus on the triple-bottom-line dimension, the lead firm's use of power, and the lead firm's internal alignment of the sustainability and purchasing function. Other papers in this cluster also focus on the selection of suppliers and their role in the supply chain.

Other clusters, for instance Cluster #4 (resilience), Cluster #5 (case studies), Cluster #7 (complexity), and Cluster #11 (lean management) are also worth mentioning. In Cluster #4, some researchers focused on supply chain risk management with supply chain emergencies occurring. Supply chain resilience has been paid more and more attention. Companies seek how to improve the supply chain structure to enhance resilience [Bode et al. 2015]. Cluster #5 mainly studies the relationship between enterprise suppliers in specific industries and the entire industrial supply chain structure, such as the food industry, through real case data [Grimm et al. 2014]. Cluster #7 argued that the supply network is dynamic and complex, consists of different enterprises from multiple interrelated industries. The Complex Adaptive System perspective can help in enriching the supply chain management [Pathak et al. 2010, Surana et al. 2005].

The clustering results represent the main research patterns application of social network analysis in supply chain management. The description of clusters illustrates that “multi-objective optimization” is the hottest research topic, and the “green supply chain”, “low carbon supply chain” are the latest field of research.

Citation bursts analysis

Citation bursts can be utilized to discover the research trends of a research field [Chen 2006]. We used this algorithm to extract citation bursts, and all citation bursts were selected to be analysed to seek the new trends in the application of social network analysis in supply chain management. Table 3 presents the top 25 works of literature. By examining the articles that experienced a sudden increase in their citations during a certain time, we can roughly detect the present research interests and future trends of a certain knowledge domain [Wang et al. 2019]. According to the citation burst from Table 3, we will mainly outline the future direction in this section.

Table 3 shows the burst strength, begin and end years of the burst literature. The maximum citation burst strength of Borgatti and Li [2009] is 11.01, and Choi and Wu [2009] has the longest emergence time. The earliest citation burst was in 2007 [Choi and Krause 2006], the latest citation burst was in 2017 [Devika et al. 2014]. By analysing the content analysis of the burst literature, we found that the literature can be divided into three directions, namely, the design of the supply chain network, the structural characteristics of the supply chain network, and the selection and evaluation of suppliers.

The most popular and interesting trend is the design of supply chain networks. The design of the supply chain network is of great significance both academically and practically. Chaabane et al. [2012] proposed a sustainable supply chain design framework based on mixed-integer linear programming, considering the material balance constraint and life cycle assessment (LCA) principle of each node in the supply chain. By analysing 87 supply chain network design literature, Eskandarpour et al. [2015] found that current models rarely consider environmental and social factors and have little to do with uncertainty and risk factors. Devika et al. [2014] designed and demonstrate the sustainable closed-loop supply chain network sustainable closed-loop supply chain network. To reduce the total transportation cost of the tire supply chain, Sahebjamnia et al. [2018] established a multi-objective mixed-integer linear programming model for the network design of sustainable tire closed-loop supply chain. A meta-heuristic algorithm is developed based on four hybrid algorithms. The results show that the hybrid algorithm is an effective method to solve the underlying problems in large-scale networks.

The second direction discusses the structural characteristics of the supply chain by using the social network analysis. Some scholars believe that social network analysis is of great significance for understanding the complexity of supply chain networks [Wichmann and Kaufmann 2016, Galaskiewicz 2011]. Borgatti and Li [2009] described the main concepts of social network analysis, such as structural holes or intermediate centrality, and suggest that supply chain hard relationships (e.g., material and financial flows) and soft relationships (e.g., friendship and information sharing) are both critical (mutually embedded) in the supply chain environment. Choi and Kim [2010] believed that suppliers do not exist in isolation, but are embedded in a supply chain network, through which they are comprehensively evaluated. Kim et al. [2011] used the social network analysis index to construct the characteristics evaluation model of the supply chain network and applied the model to three automobile supply networks.

The final area focuses on supplier selection and evaluation. Choosing a good supplier is very important for sustainable supply networks and green supply network construction. More and more scholars have used different methods and models to select and evaluate suppliers. Govindan et al. [2013] proposed a fuzzy multi-criteria approach to an efficient model of supply chain supplier selection operations based on the triple bottom line approach (economic, environmental, and social aspects). Then the fuzzy number is used to find the index weight for qualitative performance evaluation, and the fuzzy TOPSIS is used to rank the suppliers. Grimm et al. [2014] examined the factors that influence the selection of secondary suppliers, and 14 critical success factors that influence the success of sub-supplier compliance with corporate sustainability standards were identified. In addition, due to the frequent occurrence of emergencies such as tsunamis, epidemics, and earthquakes in recent years, the supply chain disruption problem occurs from time to time, and the research on supply chain resilience has gradually received the favour of scholars [Scholten and Schilder 2015].

All in all, the citation burst, as an indicator of identifying emerging research trends provided the studies for us to predict future research directions. From the above analysis, it is clear that research on sustainable and green supply chain network design will continue to attract researchers in the coming years.

DISCUSSION AND CONCLUSION

The bibliometric review of applying social network analysis in the supply chain field has outlined the trajectory of the collective efforts and interests in this scientific domain from 2004 to 2021. The main contribution of this study lies in providing an efficient and quantitative way of identifying the thematic patterns and emerging trends of combing social network methods and operation filed. According to the results of publication years and journals analysis, co-citation analysis, clustering analysis, and citation bursts analysis, the following conclusions are drawn.

Table 3. Top 25 references with the most citation burst

References	Strength	Begin	End	2004 - 2021
Choi and Krause [2006]	6.69	2007	2011	
Choi and Wu [2009]	7.25	2009	2014	
Pathak et al. [2007]	4.45	2009	2012	
Borgatti and Li [2009]	11.01	2011	2014	
Choi and Kim [2008]	6.28	2011	2013	
Carter and Rogers [2008]	4.56	2011	2013	
Seuring and Muller [2008]	4.56	2011	2013	
Pagell and Wu [2009]	4.39	2012	2014	
Kim et al. [2011]	9.33	2013	2016	
Galaskiewicz [2011]	5.48	2013	2016	
Miemczyk et al. [2012]	4.21	2013	2016	
Hassini et al. [2012]	5.88	2014	2017	
Chaabane et al. [2012]	4.77	2014	2017	
Sarkis et al. [2011]	4.53	2014	2016	
Seuring [2013]	4.83	2015	2018	
Yin [2015]	4.77	2015	2016	
Brandenburg et al. [2014]	4.35	2015	2019	
Grimm et al. [2014]	5.7	2016	2018	
Govindan et al. [2013]	4.88	2016	2018	
Gualandris et al. [2015]	4.47	2016	2018	
Govindan et al. [2015]	4.09	2016	2019	
Eskandarpour et al. [2015]	5.57	2017	2021	
Carter et al. [2015]	5.1	2017	2021	
Pagell and Shevchenko [2014]	4.41	2017	2019	
Devika et al. [2014]	4.41	2017	2019	

Beyond that, sustainable supply chain and supply chain networks become the main theme of research. The top five most cited references and 11 clusters are obtained through co-citation and cluster analysis. The five most cited articles include Eskandarpour et al. [2015], Borgatti and Li [2009], Kim et al. [2011], Carter et al. [2015], and Brandenburg et al. [2014]. Eskandarpour et al. [2015] have the highest number of citations. Meanwhile, there are 4 clusters with the highest citation, namely cluster #0, cluster #1, cluster #2, and cluster #3, based on the results of cluster analysis. Cluster #0 is defined as multi-objective optimization, with more focus on supply chain design and network optimization. Cluster #1 is defined as a sustainable supply chain, which indicated that scholars pay more attention to the sustainable development of the supply chain. Cluster #2 is defined as a supply network, and the main structural characteristics of the supply chain network were investigated. Cluster #3 is defined as a circular economy, with more focus on sustainable and green supplier evaluation and selection.

Lastly, three research directions are obtained. We got 55 works of literature and the top 25 burst articles were presented through analysing citation bursts in this study. According to the result of the citation burst, three research directions were found. Firstly, the design of supply chain networks will be worth exploring. With the increasing complexity of the global economy and the frequency of emergencies such as earthquakes, volcanic eruptions, and novel coronavirus pneumonia, it is urgent to build a flexible supply chain network. Previous studies have explored the construction of resilient supply chain networks using different methods [Chaabane et al. 2012, Devika et al. 2014]. However, there is no unified research framework or design method. It is a good direction to combine big data analysis, machine learning, super network, and traditional methods to build a sustainable supply chain network. Secondly, another point worth noting is the structural characteristics of the supply chain by using the social network analysis. The structure of the supply chain network determines the characteristics of the network. Supply chain network indicators are used to characterize network structure. Different indexes can reflect different network characteristics. For instance, density reflects the connection degree of enterprises in the network, and centrality represents the position of enterprises in the network. Hence, it is vital that construct new indexes to describe network features. Thirdly, supplier selection and evaluation are also worth studying. Supplier selection has a great influence on the supply chain network. A good supplier can enhance the elasticity of the network and improve the operation efficiency of the supply network. Some scholars have used the multi-attribute decision-making method, TOPSIS, and analytic hierarchy process to evaluate suppliers [Govindan et al. 2013, Grimm et al. 2014]. Nevertheless, they are not comprehensive enough, and a comprehensive and complete supplier evaluation framework still needs to be explored.

In the light of the bibliometric analyses, this work is useful for obtaining an overview of the state of social network analysis in supply chain management. However, there are still some limitations that need to be studied in the future. On the one hand, the selection of 16 journals as data sources may not cover all works of literature, and the data is only from the Core Collection of Thomson Reuters, more data sources can be considered in the future such as EBSCO and Scopus. In terms of time scope, then, this paper includes literature from 2004 to 2021, future studies can update data over time and can be divided into different stages.

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ORIGINAL PAPER

DATA ANALYTICS AND GLOBAL LOGISTICS PERFORMANCE: AN EXPLORATORY STUDY OF INFORMATIZATION IN THE LOGISTICS SECTOR

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ABSTRACT: Background: Informatization has enabled global logistics and supply chains (LSC) to capitalize on data-driven analytics to improve logistics performance. At the country level, logistics performance is gauged through the logistics performance index (LPI), where globally 61.25% or 98 countries perform below the mean LPI score. Previous studies focused on logistics informatization in high and moderate LPI rank economies. The paper aims to conduct an exploratory case study in a low LPI performing country to assess the informatization practices of logistics entities and develop a logistics informatization continuum to unlock data analytics for other countries.
Methods: The study implements qualitative methods to develop strategic recommendations to reduce global logistics imbalance. We employ a two-layer methodology consisting of thematic analysis and a novel strategic choice approach (SCA) to involve stakeholders for recommendations on obstruction. For thematic analysis, 16 semi-structured interviews were conducted from logistics companies, also onboard 10 trade associations and government representatives for the SCA analysis.
Results: We observed many obstructions in informatization; low willingness on informatization, fear of information leakage by humans, low-reciprocity for collaboration, the myth of information and communication technologies (ICT) as an expensive tool, self-interest, and opportunistic behavior.
Conclusion: Information-centric and integrated LSC enables data-driven technologies for real-time decision making, vigilance, and data analytics to distinguished the success of a country's logistics performance.
Originality: This study explores the informatization conformity in the logistics sector to connect data analytics. We introduced a novel strategic choice approach in the technology domain for problem structuring. The paper further contributes by suggesting a logistics informatization continuum for low LPI countries to straighten digitalization in the logistics sector.

Keywords: Data analytics, Global logistics performance, Informatization, Logistics performance index (LPI), Thematic analysis, Strategic choice approach (SCA)

INTRODUCTION

Many scholars have attempted to expand logistics competitiveness or performance of countries to brighten the global logistics landscape [Kabak et al., 2020; Kinra et al., 2020; Moldabekova et al., 2021; Önsel Ekici et al., 2019]. Logistics performance is aggregated from logistics entities operating in that economy and is measured by LPI (logistics performance index) scores [Senir, 2021]. The recent integration of industry 4.0 technologies in logistics, particularly data analytics, has enabled to perform event forecasting, risks analysis, optimization of routes, increased visibility, efficient resource allocation, and much more to enhance logistics performance [Altuntaş Vural et al., 2020; Chen et al., 2021; Imam Yudhistyra et al., 2020; Lechler et al., 2019; Liu et al., 2020; Sahal et al., 2020]. However, to reap the benefits of data analytics, the former role of logistics informatization is indispensable [Gunasekaran et

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al., 2017; Önsel Ekici et al., 2019; Ramanathan & Ramanathan, 2021; Xu et al., 2021].

From a holistic view, 'informatization' is how information and communication technologies (ICT) contribute to the formation of information society for socioeconomic development [Rogers, 2000]. Informatization in a business environment is categorized into internal and external assimilation; internal assimilation offers firms the chance to improve productivity and efficiency by utilizing ICT applications at the management and operational levels, whereas how firms interact with their customers, partners, and suppliers related to external assimilation [Hanna & Qiang, 2010]. Srinivasan and Swink [2018] highlighted that regardless of how exhaustive or computerized the data-analytics paradigm becomes in future logistics and supply chains, the strategic effects of data analytics will depend on the ability of organizations to acquire and disseminate information. Kembro et al. [2017] also found that conquering logistics informatization is difficult and vulnerable due to relational, behavioral, and structural problems of logistics entities. However, previous studies reference the growth in informatization through technology factors [Lu et al., 2020], missing the conduct of logistics entities to explore the compliance of informatization in the logistics sector.

In addition, the global LPI statistics (Figure 1) reveal the distress logistics situation in terms of country-wise performance, where 98 out of 160 countries perform below the mean LPI score. Conversely, countries that followed informatization have unlocked data analytics for logistics competence are relishing top positions; for example, Germany [Kapkaeva et al., 2021], Sweden [Mirzabeiki et al., 2016], Indonesia [Kirono et al., (2019]. Despite the proximity of logistics performance in low LPI rank countries, the research context on practices of informatization in the logistics sector is overlooked by scholars. Moreover, Cruz-Jesus et al. [2018] provide evidence of global digital disparity via drivers of digital development. However, they have not included the former impact of an information society. This research filled these gaps by initiating an exploratory case study in the least LPI performing economy to observe informatization in the logistics sector. For this research, we consider a country with an LPI rank of 122nd, indicating that the logistics sector of the selected case performs below par [The World Bank, 2018a].

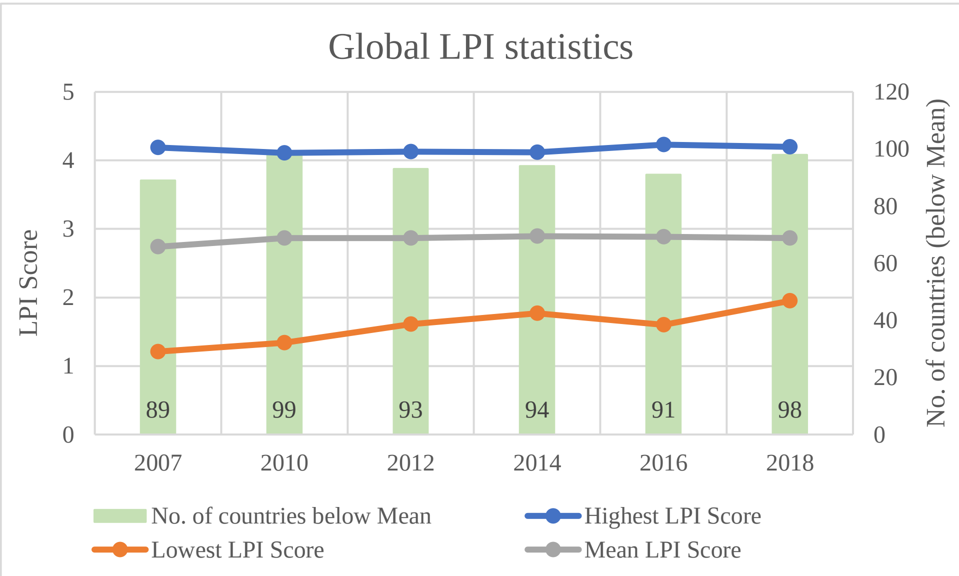

Fig 1. Global LPI statistics (based on country LPI score)

Informatization in logistics and supply chains under ICT, information sharing, and collaboration among logistics entities contribute to superior logistics performance [Kirono et al., 2019]. It allows descriptive & diagnostic analytics to examine historical trends and causes, and predictive & prescriptive analytics to forecast future events and suggest situation-specific actions [Maheshwari et al., 2021]. Data analytics brings in many practical implications for logistics performance, such as transport routing decisions [Chen et al., 2021; Liu et al., 2019; Rahimi et al., 2020], resource allocations [Zhang et al., 2020], shipment consolidation [Barreto et al., 2017], real-time tracking and visibility of goods [Dunke & Nickel, 2020] and offer customers with wide-ranging services at low costs [Park & Jeong, 2016]. Despite the imperative role of informatization in enabling data analytics for logistics performance, logistics entities' conduct has not gained much attention from practitioners and researchers. Therefore, an exploratory case study of a low LPI-ranking country is essential to support the disparity in global logistics performance.

This study was initiated with the research goal of exploring informatization practices of logistics entities. The research questions are 1) What is the understanding and willingness of logistics entities on logistics informatization? 2) What are the strengths and obstacles of logistics informatization in the logistics sector? Moreover, 3) How to foster logistics informatization? A two-layer methodology was used to carry out this research, consisting of thematic analysis to find themes for research questions and a strategic choice approach (SCA). SCA involves stakeholders in the decision-making process to develop more effective solutions and expectations [Schmidt et al., 2020]. Finally, we suggest the framework of informatization in the logistics sector as a benchmark for other low-LPI-performing countries. The later sections cover the literature review on data analytics, logistics performance, and informatization. The methodology section outlined the interviews and execution of SCA, followed by results, discussion, and conclusion.

LITERATURE REVIEW

Data Analytics and Global Logistics Performance

Pervasive globalization has raised the profile of global logistics as a determinant of socioeconomic development [Çelebi, 2019; Gani, 2017; Halaszovich & Kinra, 2020; Hausman et al., 2013; Luttermann et al., 2020; Soh et al., 2021]. Global logistics performances are limited to how nations move products or trades with other countries, and their local logistics environment matters [The World Bank, 2018a]. According to Christina Wiederer, Economist at World Bank and co-author of “Connecting to compete 2018”, even a minor disturbance in the supply chain of an economy has a propensity to affect the region and other countries.

Data analytics serves as a strategic source [Wang et al., 2016] to improve demand and supply visibility in global logistics and supply chains [Gunasekaran et al., 2017]. The success of logistics function is dependent on how a firm or nation operates at low costs, in-time, and higher service levels. Schoenherr and Speier-Pero [2015] highlighted that to ensure cost and service efficiency, operations and logistics managers must analyze abundant of data to make the right set of decisions. Where transport routing and resource allocation is the biggest challenge for logistics companies because much of the cost is spent on transportation goods in terms of fuel, vehicle rentals, human, and environmental costs [Mangina et al., 2020]. Another challenge that logistics entities and customers face is goods-in-transit deterioration and expiry risks [Chaudhuri et al., 2018]. Hopkins and Hawking [2018] data analysis suggests optimal transports routes to avoid traffic congestion and offers real-time visibility, elevating productivity and service levels [Yan et al., 2019]. Therefore, countries must unlock digitization and data analytics in the logistics sector [Bag et al., 2020; Önsel Ekici et al., 2019].

Informatization in the Logistics Sector

Logistics informatization refers to information and communication technologies and collaboration between logistics entities to make available comprehensive and transparent data for business decisions [Ramanathan & Ramanathan, 2021; Xu et al., 2021]. It significantly influences data analytics adoption, use, and continuation of organizations and supply chains [Gunasekaran et al., 2017]. Many countries have advanced logistics sectors that anchor informatization. Kapkaeva et al. [2021] conducted a case study at the port of Hamburg, Germany (LPI 1st position); informatization as a predecessor allows ports to operate exceptionally through a one-window platform to plan, execute, and monitor logistical activities, for instance, real-time call-in/call-out road and rail actors to pick or release the load. Another study by Mirzabeiki et al. [2016] in Sweden (LPI 2nd position) confirmed that when parties in a logistics system share information, it enables data analytics; to track and trace, speeds up operations, shipment timeliness, resource optimization, and accumulation of an authentic set of information. In Colombia (LPI 58th position), Suarez-Moreno et al. [2019] proposed an intelligent transport load optimization model leveraging shippers' collaboration that reduces vehicle trips by 50% and accumulates a decrease in logistics costs by 37%. Informatization in the logistics environment serves as a soft but significant contributor to performance. Unrestricted flow of information across logistics entities allows logistics professionals to capitalize on information through data analytics to achieve multiple strategic and operational benefits.

Flick on the benefits, good informatization practices is challenged by many constraints that restrict logistics entities to nurture the milieu of an information society. In a highly competitive environment, there would always be a possibility that entities share doubtful or false information [Najjar et al., 2019; Voss et al., 2006] to muscle the benefits of low-cost transactions or other interests [Jarvenpaa & Staples, 2000], another reason can be rational, capable, and trustworthiness issues [Tsai et al., 2020]. In lateral relations, entities perceived risks [Keith et al., 2004] that pose an openness to informatization.

Strategic Choice Approach (SCA)

The strategic choice approach (SCA) is a novel qualitative operational research approach used for problem structuring in a stressful environment [Friend, 2011]. It originated from IOR (Institute of Operational Research, Tavistock Institute London) in the 1970s [Friend, Norris & Stringer, 1988]. The unique trait of stakeholder involvement (judgments) differentiates it from other decision-making approaches to manipulate uncertainties [Friend, 1992]. It deals with three types of uncertainties; working or market environment, managerial or administrative values, and related choices by performing four processes shaping, designing, comparing, and choosing [Friend, 2011]. Several researchers from different fields used SCA for practical solutions, migration impact assessment [Kourtit & Nijkamp, 2011], architectural design [Todella et al., 2018], water distribution systems [de Sousa & Costa, 2020], but it was rarely applied in the management and business environment.

METHODOLOGY

The present study aims to assess the informatization practices of logistics entities. This paper employed the qualitative research method to examine a situation under natural and real conditions of the subject population or topic [Bryman & Bell, 2009; Creswell, 2009]. Long and Johnson [2000] proposed that a qualitative method would enable the investigator to obtain a greater perspective rather than analyze the external attributes of a theme and the limited focus of the research. The qualitative method allows the evaluation of the topic correctly in contrast to the quantitative method, and there is often an opportunity to gather very useful information [Merriam, 2009].

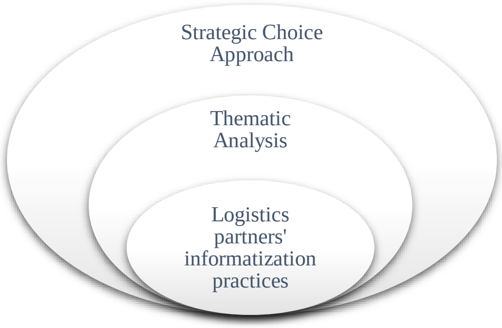

Fig 2. The two-layer research methodology

A two-layer methodology (Figure 2) is used with thematic analysis to study the operations of logistics entities and SCA for decision-making to curb these inadequacies. Semi-structured interviews were conducted with logistics entities, as mentioned in Table 1. The participants are approached on convenience sampling and chosen for this study based on qualifications and industry experience (minimum of 3 years of sitting position experience). The sample size for qualitative studies must meet data saturation [Dworkin, 2012]. Boddy [2016] stated that a minimum sample of 12 is sufficient for data saturation and population homogeneity. In the current research, data saturation is reached in 16 interviews of the participants. The length of each interview ranges from 45 to 75 minutes, considering the participant's interests in the research topic.

Table 1. Participants in the logistics industry

S. No.	Participant ID	Function	Organization type	Position
1	E2E-M1	Logistics service providers (E2E)	MNC	Manager logistics
2	E2E-M2	Logistics service providers (E2E)	MNC	Team lead operations
3	E2E-L1	Logistics service providers (E2E)	Local	Manager logistics
4	E2E-L2	Logistics service providers (E2E)	Local	General manager - International freight
5	E2E-L3	Logistics service providers (E2E)	Local	Director logistics & trade
6	T-L1	Transporter	Local	Manager operations & business development
7	T-L2	Transporter	Local	Business owner
8	T-L3	Transporter	Local	Manager logistics & business development
9	T-L4	Transporter	Local	Business owner
10	T-L5	Transporter	Local	Manager operations
11	T-L6	Transporter	Local	Senior manager operations & Business development
12	CARG-M1	Cargo handling / storage/ packaging services	MNC	Manager procurement
13	CARG-L1	Cargo handling / storage/ packaging services	Local	Branch head operations & cargo
14	PO-M1	Port operators (sea)	MNC	Section head logistics
15	FF-L1	Freight forwarder/clearing	Local	Key accounts manager
16	SL-M1	Shipping line	MNC	Officer operations & import

Thematic analysis is performed in the first stage of the study on the informatization assessment of logistics entities. Qualitative software ATLAS ti 8.4.24 is used. The themes emerging from the thematic analysis become input for the SCA, where the representatives of stakeholders (logistic entities) teamed up for decision-making to devise solutions. The strategic choice approach (SCA) is used to systematically consider practices and their significance in improving logistics performance, creating an environment for the successful adoption of data analytics in logistics. The stakeholders' representatives (Table 2) conduct decision-making analysis to devise progress to elevate the LPI based on the following guidelines:

What is the most important informatization activity of logistics partners?

- Strength – to take advantage
- Weakness – to mitigate or improve

Table 2. Stakeholder representatives in decision-making

Participant ID	Position	Organization type
DMP-1	Senior Logistician - Planning	National logistics (logistics strategic organization)
DMP-2	Member – Executive committee	Freight forwarders association
DMP-3	Member – Executive committee	Freight forwarders association
DMP-4	General Secretary	Transport association - I
DMP-5	Member – Executive committee	Transport association - I
DMP-6	Member – Executive committee	Transport association - II
DMP-7	Member	Supply chain association
DMP-8	Member	Supply chain association
DMP-9	Technology Practitioner - Logistics	IT solution provider for logistics
DMP-10	Member	Fleet operators' association
DMP-11	Convener - Standing Committee	Dry Port/Airport Affairs (Association)

FINDINGS ON INFORMATIZATION PRACTICES OF LOGISTICS SECTOR

All 16 interview participants are located in Karachi, Pakistan, where most economic activities occur due to the two busiest seaports with an annual import and export volume of 104.391 million tons [Ministry of Finance, 2020]. These participants / companies transport the shipment to and from Karachi with destinations all over Pakistan.

During the interview, not all, but many, of the participants believe that informatization among logistics entities or clients is beneficial to:

- Save operational time and delays
- Cost benefits
- Help collaborative business partners to provide high-quality services
- Bridge the gap and strengthen execution processes
- To make plans and schedules
- Improves work efficiency
- Ensure accuracy.

Also, according to the participants (Figure 3) the statements of the logistics entities or logistics business partners confirmed that not all information is good to share, so the information that has positive or negative repercussions is extracted in Table 3.

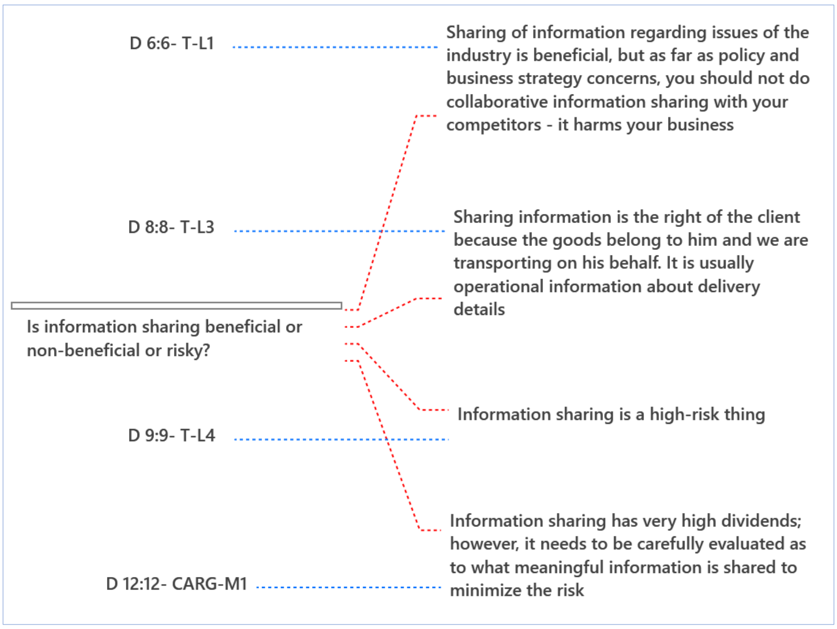

Fig 3. Logistics information sharing

Table 3. Nature of logistics information

Useful or shared information	Risky or harmful information
• Specimen of the shipment (e.g., volume, weight, commodity nature, load pickup time, and location). • Shipment tracking (email, phone call, online portal) • Market road situation • Feasible or allowed hours (time) to move the vehicle in some areas • Optimal routing • Offered services and capabilities • Collective issues (e.g. extra toll or taxes) • Legal information – shipment documents • Scenario-based information (e.g. hurdles, strikes, changes in shipment details)	• Business strategy and policy • Pricing • Cliental information • Legal information – contracts • “Cooperation” - How an entity is handling the shipment of two or more competitor clients

Apart from that, the informatization practices of logistics entities operating in the logistics sector are affected by many factors, as discussed below.

Willingness and Awareness of Informatization

Interviews with logistics companies concluded dissimilarity in willingness and awareness on the level of informatization. The categorization of how these companies perceive and act is presented in Table 4. The asset-owning companies are more concerned with executing the task; what to move, how to move, when to move and at what rates. For example, *“We provide transport service, and just do task execution. From where to pick load and where to release as decided at the time of the deal.”* (T-L4). The willingness and understanding of the benefits of brokering companies to share information are moderate and driven by client needs, business volume, and counterparts’ willingness: *"Compare business vs services… the one who is giving large business volumes then we do not hesitate to facilitate beyond our comfort zone."* (T-L3), *"Most of the counterpart transporters are very strong and have the large fleet, but they are not literate. They are more concerned with task execution. Their behavior is not good to update any information..."* (T-L2). Companies providing IT solutions (live asset Podlink) in the logistics sector depend on logistics companies to adopt information technologies for logistics operations. Live asset Polink refers to a free link or application to track and trace cargo/status or cargo or assets (trucks) across logistics and supply chains. For example, DHL and UPS shipment tracking facility. In documentation services, what information to share or not to share depends on the clients' will because they often want to hide information *"In clearing and forwarding processes, customers want to hide their sourcing or export parties, and this constraint will run across the logistics stream"* (FF-L1). Finally, the techno-logistic companies are open to sharing information at the micro-level in real-time basis *"…part of SOP to share information"* (E2E-M2). *"The strong you have willingness on informatization the more clear, visible and efficient task will be"* (E2E-L2).

Table 4. Categorization of Logistics companies

Category	Explanation	Type	Informatization willingness	Informatization Awareness
Asset owning	These companies only own assets such as trucks, warehouses, and other facilities.	Local	Reluctant and stereotype	Low
Brokering	Hire assets and works as middlemen	Local	Varies according to clients' requirement, volume and the willingness of the hired entities	Moderate
Asset live Podlink (technology providers)	Provides technology services, e.g., RFID, vehicle tracking, sensors	Local MNC	The level of information sharing depends on the client (logistics company)	High
Service and documentation	Offer shipment booking, clearance, forwarding services and documentation	Local	Customer-centric	Moderate to High
Techno-logistic	Own assets and equipped with technology.	Local MNC	Open to share	High

The Myth of Informatization as 'Expensive' by Customers and Logistics Companies

The behavior of customers and service partners are not favorable to opt logistics partners offering; real-time shipment information and innovative services. "*Mostly customers failed to trade-off IT-enabled information sharing benefits for businesses and prefer the traditional way of moving goods because of low fares"*, cited participant E2E-M2. Also, the companies are concerned about setup and operational costs and resources to implement and operate collaborative information systems, resulting in slightly higher fares. The cost perceptions of the studied population are varied for the supply and demand sides and are presented in Table 5.

Table 5. Customer-supplier cost perception on IT-enabled information sharing

Supplier side (logistics company) side	Customer side
• Low-cost transaction • Cost of IT system acquisition • Cost of hiring staff • System maintenance cost	• Opt for low rates • Only consider upfront service cost (low shipment charges)

Information Leakage: Human vs. Information Systems

Fear of information leakage has a strong effect on the decision of the logistics companies to share information. According to E2E-L1, *"Serving two clients who are competitors as well creates high responsibility in terms of information security… because of client-to-client rates and service variation"*. The participants were asked to compare human and IT systems to determine which is more susceptible to leak information. The majority of participants agreed on the difficulty of controlling intentional or unintentional information breaches by humans.

"…, for IT systems we can use protocols." (E2E-L2, CARG-M1 and CARG-L1)

"Chances of information is leaked and shared with irrelevant persons." (T-L6)

"…you cannot control humans, and chances are someone would reveal the inside story (information)." (T-L1)

"Humans leak information intentionally or unintentionally." (FF-L1)

The unintentional leakage by humans is caused by staff incompetence, training, and development.

"…because of a lack of confidence and education… no personal development of staff to overcome..." (E2E-L3)

Moreover, the participants (E2E-M1, E2E-L2 and T-L5) confirmed that we offer our collaborative logistics partners to sign information confidentiality contracts. Despite this, the human side is uncontrollable *"we cannot control employees moving from company A to company B. When they leave, information will go with them."* Stated by E2E-M1, E2E-L1 and T-L1. As a result, some companies perceived information as their proprietorship asset and were unwilling to even share it with the staff. T-L1 further added *"information proprietorship dilemma has caused many partners to collapse when the owner dies because the strategic business information and knowledge are constrained (withhold) in the head of business owners"*. Also, *"There is not any practice for securing proprietor information security."* (T-L2).

It concludes a lack of laws or compliance to secure owner/company information as intellectual property in the logistics sector. Furthermore, the government seldom takes any legal actions, which has made logistics companies reluctant to collaborate on information sharing.

Use of IT-Enabled Information Sharing System

IT-enabled information sharing systems are inevitable to adopt in the logistics business environment; they offer loads of socioeconomic opportunities; foreign direct investment (FDI) and exports. The interviewed participants asked about the current state of information sharing system utilization. Figure 4 describes the percentages of responses of the logistics companies to this question. 43.75% of companies are using information systems, while 56.25% do not have information system facilities. Those companies that have not yet implemented information systems exhibited a willingness of 44.44% to adopt in the future, the remaining 44.44% are stringent on conventional systems, and 11.11% do not responds.

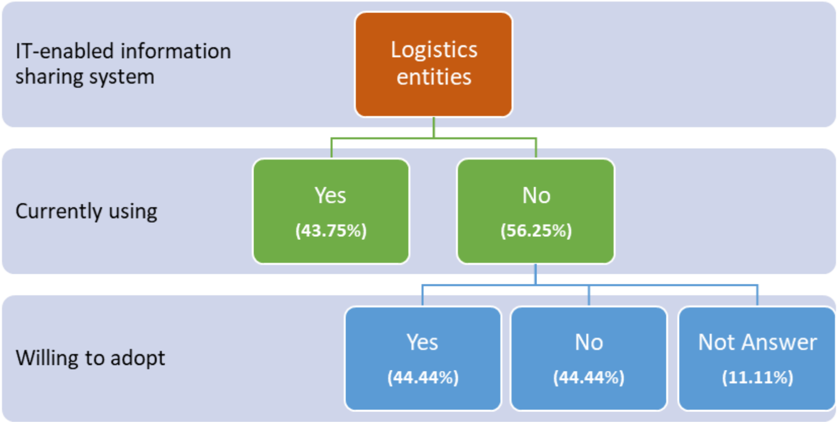

Fig 4. Utilization of an IT-enabled information sharing system

Impact of Cultural and Regional Belongingness

Almost all companies stated that there is no such occurrence of any regional or cultural belongingness obstacles while sharing information, except for language barrier.

"The business environment is like a unipolar thing, so there is no impact of cultural belongingness." (FF-L1)

"Not like that… whoever is giving good business and rates." (T-L3)

Some interviewed logistics entities further added that communication among educated versus non-educated persons or formal versus informal communication creates a reluctance to share information.

"… difference of perception and understanding occurs among educated and non-educated persons." (E2E-M1)

"Language barrier occurs, also the way of communication matters because they (non-educated) do not like formal conversations." (T-L2)

Reciprocity to Collaborate

Reciprocity refers to the collaborative sharing of information between logistics companies to achieve mutual benefits. In theory and practice, the reciprocity norms or rule of reciprocity can be explained as a give-and-take phenomenon or a person doing an action in a good gesture and receiving the same in return. Reciprocity is based on the relational and individual behavior of companies. In comparison, multi-national logistics companies confirmed that sharing information is part of their standard operations for all collaborative logistics partners or clients. For this reason, the transport performance is higher than that of local companies (Gezikol et al., 2020). This practice is rare in local companies except for Techno-logistic companies. The give and take phenomenon is mostly observed among local companies. Surprisingly, few companies are open and enthusiastic about acquiring a business and count on counterparts at the execution level.

"Information sharing is abided by SOPs, rules and regulation of the company." (SL-M1)

"…information is shared on giving and take and more specifically relational behaviors." (T-L2)

"… people take information from you, but in return, they do not share." (T-L1)

The level of altruism of logistics companies to share information with counterparts is very low. In addition, there is an impact of position or power, or the willingness of the dominant party to share or restrict information flow.

Information Quality – Sharing Limited Information, Hiding, or Inaccurate Information

There are positive and negative sides to not sharing all the information. It is optimistic about assessing the absorptive capacity of the recipient or counterpart to decide how much information is good to share. Another adequate reason is cautionary behavior to avoid leakage of competitive information.

"Share information according to person, like absorption capacity (educated vs non-educated and decision-making position in the company)." (E2E-M1 and CARG-L1)

"Situation matters, few things/information if we share with partner or client then they panic and worry because they do not have the vision of backdoor activities (process complexities)." (E2E-L3)

The practice to manipulate or hiding information is very common for personal gain, either to operate at a low cost or to make more money. Another pain point is misled or incorrectly shared information to hide internal efficiency by logistics companies. With such malpractices in the logistics sector, it is difficult for companies to trust their counterparts. On the one hand, self-interest or opportunistic behavior benefits individuals, but reduces logistics performance at the collective or national level. The quality of information has strong implications on decision making and execution to improve logistics operations, efficiency, cost control, customer services, and much more.

"Sometimes, we hide actual/real information with client or logistics partner. For example, we have to give a vehicle to a client and failed to arrange the vehicle, then we never clearly said to the client or former business partner that we failed to arrange, but we give a general statement like we have arranged a vehicle and it will reach principally today. This way, by hiding actual/real information, we gain or cover time lag." (T-L3)

"We do not share information with client or counterpart about any delays or hurdle in operations." (T-L5)

"Occasionally, yes." CARG-M1

Lastly, validation of interpretations is essential to establish the reliability of research outcomes (Sousa, 2014). The member check (participant feedback) validation process is performed to confirm the cohesion and credibility of the explanations (Birt et al., 2016).

APPLICATION OF THE STRATEGIC CHOICE APPROACH (SCA)

Step 1. Shaping the Problem

The weaknesses or problematic elements of the thematic analysis are extracted to form themes or shape the problem and compiled in Figure 5.

Step 2. Designing Alternatives

In the design phase, the issues are shared with the pool of decision-making participants (DMPs), as mentioned in Table 2. In the first step, all DMPs were contacted individually to propose solutions to each issue stated in Figure 5. The participants proposed 45 different solutions, sent back for voting following step 3 of the strategic choice approach.

Step 3. Comparison and Choice of Alternatives

The alternatives were shared with (decision-making participants) DMPs to suggest pragmatic solutions keeping in mind the SMART (specific, measurable, attainable, relevant, time-based) criteria approach. Therefore, quality solutions/goals can be obtained to create efficient and workable strategies [Bexelius et al., 2018].

Table 6 visualizes the responses of the DMPs to select alternatives/solutions that are viable with their agreeableness to streamline information sharing practices across the LSC. The 20 out of 45 alternatives with more than one participant vote are accounted as input for the code-document table analysis. From the analysis, "To adopt and promote information security culture" caught the attention of DMPs with the grounded level of 7 followed by "Contracts and

SOPs on information sharing practices – 5" and "Cost and performance benefits of IT-enabled systems – 5". Also, 4 alternatives obtained 4 votes aiming to suggest unification (national) language and use IT systems (digitalization) to curb language barrier and share information sharing benefits with success stories of industry player to increase the willingness of logistics companies. The remainder received 3 and 2 votes of DMPs.

Based on the feedback and suggestions of the DMPs concerning issues of informatization practices by companies, this study takes a stand to propose a framework of logistics informatization continuum (Figure 6) as a contribution to the existing literature. The framework would foster informatization practices and enable governments, scholars, and policy makers to devise strategies to improve data analytics to increase the level of logistics performance.

DISCUSSION AND IMPLICATIONS

This research envisioned exploring informatization practices in a low LPI-ranking country to elevate the country's logistics performance. Much of the published work is related to improving LPI by global institutions and researchers. The World Bank has contributed tons through periodic reports *"Connecting to compete"* to advise economies performing below par. Logistics infrastructure such as road, rail, warehousing, and transportation facilities are common problems among low-performing countries. However, the flow and quality of information through IT-enabled technologies gain more attention in *"Connecting to compete"* 2018 edition [The World Bank, 2018a]. The importance of information in a contemporary digital and data-driven environment incites authors to evaluate the impact of informatization on logistics performance in low-LPI-performing countries.

Intrinsically, this paper presents an examination of collaborative information practices that have an impact on the LPI ranking. Quite a few strengths or positive practices of logistics companies are identified from the findings; surprisingly, logistics companies perceived a low risk of information breach via IT systems confirmed trust in cyber security practices. First, the finding contradicts [Gunes et al., 2021] that modern logistics has a higher probability of cyber security risks. Furthermore, [Pfleeger & Caputo, 2012] believe that human behaviors can mitigate the pinch points of a cyber-security breach in IT systems. The current finding is advantageous for the adoption of data-driven technologies in the logistics sector. Second, there is no impact of cultural belongingness to share information or collaboration among companies, depicting the logistics market heading is to unipolarity for socioeconomic development. Differently, the literature underpins that cultural barriers exist in human interaction in the business environment [Li et al., 2007; Peltokorpi, 2006; Robertson & Swan, 2003]. This finding has opened new stimuli for practitioner and researcher, does unipolar business environments truly mitigate the impact of cultural belongingness.

The low willingness and awareness of informatization have clogged the process of exchange to obtain mutual benefits. As a result, logistics companies failed to equate costs with the reward of information exchange. The myth of information as an *'expensive'* thing has been established in the industry. According to George Armitage Miller (psychologist), information processing is a cognitive phenomenon [Miller, 1956] that refers to interpretation, evaluation, control, utilization, and storing of information by an individual or organization. The effective or ineffective result of information processing is based on an individual's or organization's capability to process information [Tushman & Nadler, 1978] has confirmed low data capabilities among logistics entities. To curb it, managers should not always rely on informatization as organizational resource (IT-enabled systems and information sharing), but leadership vision and commitment also matter [Gunasekaran et al., 2017].

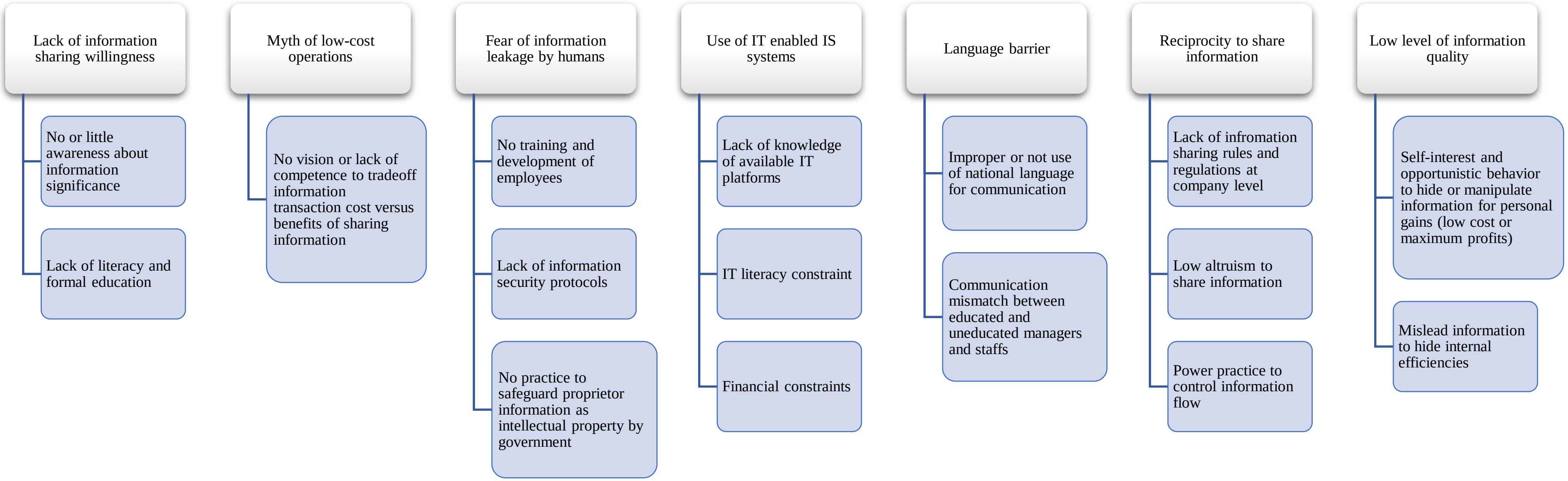

Fig 5. Informatization issues in the logistics sector

Table 6. Selection of solutions by DMPs (code-document table analysis)

Solutions	DMP-1 Gr=6	DMP-2 Gr=14	DMP-3 Gr=10	DMP-4 Gr=8	DMP-5 Gr=9	DMP-6 Gr=4	DMP-7 Gr=8	DMP-8 Gr=2	DMP-9 Gr=11	DMP-10 Gr=6	DMP-11 Gr=11	Totals
Contracts and SOPs on information sharing practices Gr=5	0	0	1	1	1	0	0	0	0	1	1	5
Cost and performance benefits of IT-enabled systems Gr=5	0	0	1	0	0	0	1	1	1	1	0	5
Cost reduction and information withholding by eliminating the role of middlemen via IT systems Gr=3	1	1	0	0	1	0	0	0	0	0	0	3
Employee training and development in information sharing Gr=3	0	1	1	0	0	0	1	0	0	0	0	3
Formation of a committee to deal with information breaches and intellectual property affairs Gr=3	0	1	0	1	0	0	0	0	0	0	1	3
Government supervision and support Gr=3	0	1	0	0	1	0	0	0	0	0	1	3
Government to provide financial assistance to adopt IT-enabled systems Gr=2	0	1	0	0	0	0	0	0	0	0	1	2
Improve business relationships Gr=2	0	0	0	0	0	0	1	1	0	0	0	2
Incentives on information sharing practices Gr=2	0	1	0	0	0	0	0	0	1	0	0	2

Information systems (digitalization) to reduce personal interactions Gr=4	0	1	0	1	1	0	0	0	1	0	0	4
Share real-world information sharing success stories Gr=4	0	1	0	1	1	0	0	0	0	0	1	4
Sharing the benefits of information sharing and utilization Gr=4	0	0	1	1	0	0	0	0	1	1	0	4
Spread awareness of information sharing through training and education Gr=2	1	0	0	0	0	0	1	0	0	0	0	2
To adopt and promote an information security culture Gr=7	0	0	0	1	1	1	1	0	1	1	1	7
Train SMEs on data analytics Gr=2	0	0	0	0	0	0	1	0	0	0	1	2
Train partner / counterpart on information sharing practices Gr=2	0	1	0	0	0	0	0	0	0	0	1	2
Unification of language in the logistics sector Gr=4	0	0	0	0	1	0	0	0	1	1	1	4
Use of blockchain to ensure information quality and automation Gr=3	0	1	0	1	1	0	0	0	0	0	0	3
Use of information sharing services to improve customer satisfaction Gr=3	0	1	1	0	0	0	0	0	0	0	0	2
Totals	2	11	5	7	8	1	6	2	6	5	9	62

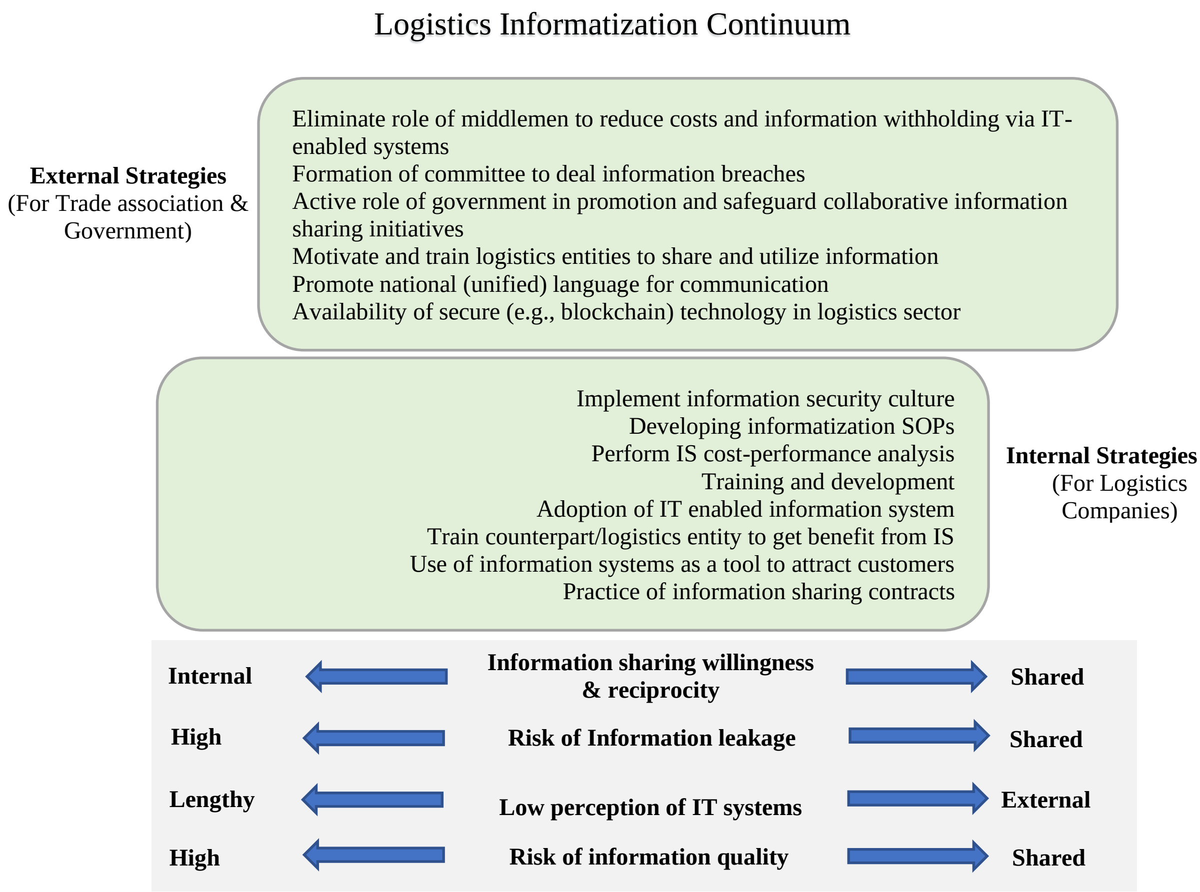

Fig 6. Logistics informatization continuum

The existence of information leakage by humans in interfirm business relations is consistent with prior studies; however, the triggers are different, profit maximization intention of parties [Kong et al., 2012; Liu et al., 2020], market competition [Fang & Ren, 2019; Zhang et al., 2012] inference [Zhang et al., 2011]. While the findings of the current study presented the reasons are human development and lack of information protection protocols and practices. The leakage by humans creates the dilemma of punitive or nonpunitive measures for managers to control information leakages effectively. Companies may opt for the non-punitive 4Cs framework (contain, control, contract, cultivate) posited by Tan, Wong and Chung [2016]. DMPs propose several inline solutions to mitigate the element of fear. They suggest implementing an information security culture (internal strategy) and a platform to report intellectual property breaches (external strategy). The regulatory support evades fears of low trust among the transaction parties [Benamati et al., 2021].

Furthermore, logistics companies' self-interest and opportunistic behavior to share misleading information made the informatization process distrustful for counterparts in using collaborative information in real-time decision-making and operations. The intentions investigated in this study are profit maximization and hiding internal inefficiencies. Many, unlike causes of opportunistic behavior, have been reported in literature from theoretical perspectives of transaction cost and relational exchange; for instance, trust [Zaheer & Trkman, 2017], business governance systems (relational and contractual) [Pomegbe et al., 2021] and asset specificity [Lui et al., 2009]. The contemporary developments in organizations and economies are data-intensive, so it is crucial to reach data/information justice [Heeks & Renken, 2018]. Also, information quality is essential for the successful adoption and satisfaction of an information system [Rouibah et al., 2020]. To address this, logistics industry suggested using secure technology (e.g., blockchain) to ensure information quality and contracts. Consistent with Wong, Sinnandavar, and Soh [2021], information asymmetry from opportunistic behavior can be treated through the induction of business process platforms.

Finally, managers and practitioners can use the SCA approach by encircling input from stakeholders help to infer practical solutions. Also, the proposed novel and pragmatic framework of the logistics informatization continuum can be generalized to increase the performance of low-LPI performing countries to fill the gap of socioeconomic disparity.

CONCLUSION

The logistics commence by the movement of freight or goods between the point of origin (seller) and the point of consumption (customer). In the middle, there are many logistics entities; for example, transporter, warehousing, freight forwarder, and clearing agent. When the logistics and supply chain is information-centric and integrated, fierce data-driven technologies serve as sources for real-time decision making, vigilance, low costs, productivity, risk mitigation, and customer satisfaction to distinguish the success of a country's logistics performance. Currently, the global LPI is suffering from the low performance of logistics systems. Our research has opened a rational avenue to address the possible inadequacies of the least-LPI performing countries.

The study has some limitations and suggestions for future researchers. The informatization issues may be quantitatively tested on a larger scale to other low LPI countries and confirm generalizability for correlated effects in different regions and income groups. Future researchers can also compare the implications of bridging information and collaboration in logistics and supply chains on the adoption rate of data-intensive technologies and the growth in average and least LPI scores.

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ORIGINAL PAPER

INDUSTRY 4.0 AND 3D PRINT: A NEW HEURISTIC APPROACH FOR DECOUPLING POINT IN FUTURE SUPPLY CHAIN MANAGEMENT

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ABSTRACT. Background: The paper is devoted to the analysis of the trends and roles of decoupling point in the revolution of new technologies and Industry 4.0. Ever-growing demands and market requirements pressure to optimize the operations and be agile in every area of action. The crucial thing is to create a stable supply chain considering both the cost perspective and customer orientation. Fluctuations, congestion, and unexpected events may have a critical impact on operations and strategy, causing shortages and reducing efficiency. The objective of proper supply chain management is to optimize stocks and use technology to build synergy, which is a key point to increasing competitiveness throughout the entire stream and meeting customer demands. In our research, we offer a perspective on the growing field of 3D printing that may open a way to redefine a decoupling point and create more efficient networks.

Methods: This paper uses an analysis of literature related to the decoupling point, presenting the ground rules and their importance in supply chain management. A comparison of theory, current state, and trends is intended to heuristically identify bottlenecks and risks as a case study for continuous improvements in global logistics. Presented data aim to define a way how the supply chain can evolve and use 3D print to create a new perspective on the decoupling point.

Results: This study provides an overview of the trends in supply chain management and presents figures on the most common structures of current networks. Analysis of theory and technology development presents the possible changes in the definition of the decoupling point.

Conclusions: Surging market requirements and the necessity of cost competitiveness make supply chains more difficult to manage. Unexpected fluctuations, force majeure events, and limited infrastructure capacity are adventurous for ensuring continuous operations. The research provides the insight into the development of logistics to reduce uncertainty and may define a starting point for further analysis of advanced supply chain management based on new technologies.

Keywords: supply chain, decoupling point, agile management, 3D print, Industry 4.0

INTRODUCTION

Supply chain management is under constant pressure to provide high efficiency of operations and processes at all levels of the stream. Many people perceive the construction of a supply chain as a network, which is a correct perspective, but mainly they consider only its most explicit elements, like crucial suppliers, service providers, brands, and general exterior appearance: it may cause an underestimating the role of continuous improvement and present some semblance about the easiness of supply chain management.

Oliver and Webber used the term supply chain management for the first time in 1982 in the article *Supply Chain Management: Logistics Catches Up with Strategy*. The authors defined it as a material flow that starts with suppliers and goes through processes to the final customer. This simple consideration is the essence of this term, pointing out that the supply chain starts in a place where the very first raw material is mined [Oliver and Webber, M 1982]. Their concept was motivated by surveillance of the US economy suffering from decreasing competitiveness related to the expansion of Japanese corporations over the world. For considering, it was highly recommended to think about management as a separation of basic functions like purchasing, manufacturing, sales, and distribution.

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In the beginning, in the opinion of some experts, this proposal could pose issues to ensure the smooth operation. Then Webber and Oliver specified the concept idea of the fields integration of mentioned under the definition of supply chain management, which reflects corporate responsibility and provides a coherent strategy. The aim of this methodology was a constructive approach to the planning, distribution, and control of the supply chain, leading the company to excellence in ensuring the highest customer satisfaction in the most efficient way [Camman et al. 2017].

The continuous development of the global industry in the coming decades made supply chain management a crucial element of strategy as well as a field where companies can find significant savings, which could strengthen their position and reduce costs. The above-mentioned definition is now just a fundamental idea for any further changes in terminology and focus. However, continuous evolution opens the way to ask questions about the contribution of SCM in Industry 4.0 and overall profitability.

This paper will provide a multifaceted analysis of trends and ways in which supply chain management, is going to take place in the future, considering the current global situation related to bottlenecks occurring as a result of economical and infrastructure circumstances. It requires a further discussion on how the decoupling point should be redefined if we start to use modern solutions in manufacturing.

DECOUPLING POINT AS FUNDAMENTAL FACTOR OF SUPPLY CHAIN CONSTRUCTION – THEORETICAL BACKGROUND

The decoupling point, strictly speaking – is a place in the structure of the supply chain where the largest inventories should be stored. Its main role is to be a buffer for the needs resulting from independent demand. Some define a decoupling point as a place within the value stream that determines a separation of dependent and independent demand. For enterprises, an independent demand is a direct demand for the products they produce. Therefore, dependent demand means the needs related to requirements for another item, i.e., components, parts, semi-finished products, or raw material necessary to make a final product [Ivanov and Schönberger 2017].

In practice, orders received from the customer right away become an independent demand, defining the exact quantity of the product required to fulfill the order. Calculating the dependent demand is possible thanks to knowledge of the product structure and carryover stocks. This interrelation is reflected in the Bill of Materials (BOM).

The dependent demand is calculated by the MRP modules, which use planning parameters to maintain supply processes. Therefore, the decoupling point and its location are determined by the market and the supply chain in which companies exist – the concept of its definition is directly related to the reduction of inventories by producers and thus to the reduction of time differences during the execution of orders between the chain links [Wieczorek 2015].

According to Olhager, the decoupling point is considered in four ways, depending on the production model (or strategy) of a company:

- MTS (Make-to-stock) - products are stored in the finished goods warehouse, and customer orders are managed directly from stock. In this case, the products are located near the customer,
- ATO (Assemble-to-order) - components and subassemblies kept in stock by the manufacturer in a varying degree of complexity. An assembly process starts on customer’s demand,
- MTO (Make-to-order) - stock of material or parts is at a low level of complexity. A production process launched on customer’s demand,
- ETO (Engineer-to-order) - when the customer places an order, no inventory other than know-how (knowledge, technology, etc.) is available. Procurement and production processes are a consequence of the firm order.

Relation of a decoupling point to a production model

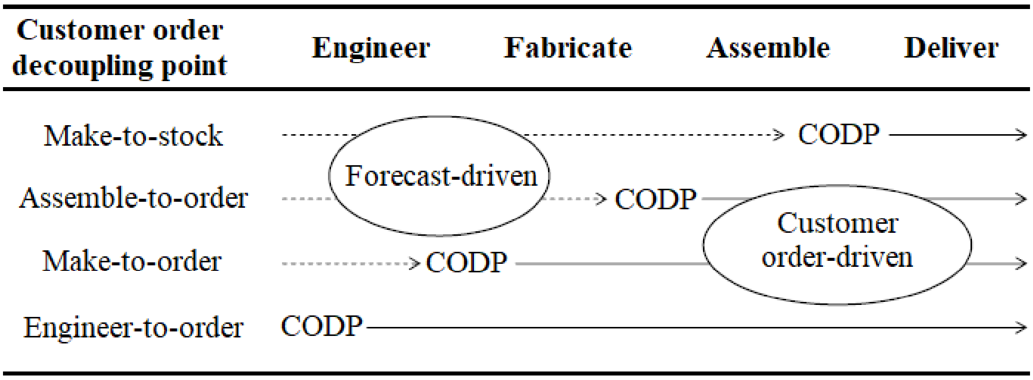

Fig. 1. Scheme of the the relation of decoupling point to a production model. Source: [Olhager 2012].

The findings of some studies suggested that companies should be more dynamic when considering their decoupling point strategy. According to available research, the further the information decoupling point is moved upstream, the better improvement in the dynamic behavior of the supply chain [Mason-Jones and Towill 1999]. It suggests that there is the best attainable performance when the operating mechanisms of stock management and production deployment are located at the factory.

At that time, it is also important to note that the product delivery strategy is inextricably linked to the type of goods produced by a particular manufacturer. Downstream of CODP production is related to specific customer orders (pull). On the upstream end, manufacturing processes are driven by forecasts (push). However, MTS allows providing maximally short delivery lead times and anonymity of customers, however, requiring the high accuracy of forecasting methods and increasing inventory costs for finished goods [Köber and Heinecke 2012].

In times of growing competitiveness, producers try to find the most profitable way to provide a reliable service and availability of the products to their customers. The research question of the present article is the prediction of how Industry 4.0 and new technologies can support the supply chain and manufacturing to meet the challenges of the market. We hypothesize that the next decades can redefine the CODP and eliminate wastes throughout the stream. In the following paragraphs, we will present the possible impact of 3D printing on the future shape of supply chains.

INDUSTRY 4.0 – MODERN VISION OF MANUFACTURING

Long-standing interest has been in the implementation of new technologies in manufacturing and customer service. Industry 4.0 as a term describing this vision was established in 2011 and since then we can find several definitions of its principles. For instance, from a supply chain perspective, the most important seem to be:

- Real-time Big Data algorithms and using them to improve OEE
- Service orientation offering online architecture
- Worldwide communication network supporting industrial & economic partnership

These principles can be achieved thanks to the implementation of state-of-the-art methods such as artificial intelligence (AI), robotics, or 3D printing [Vogel-Heuser and Hess 2016].

First, the findings of some studies focus on the horizontal structure of the network to create a flexible and effective chain being able to utilize a huge amount of information (Big Data) and reacting faster to changes [Tjahjono et al. 2017].

Second, from a manufacturing perspective it is important to integrate engineering disciplines and exist in an automated interdisciplinary production system toward the usage of integrated models [Feldmann et al. 2015].

Finally, equipment will be characterized by the application of high-end tools and machines. It leads to the creation of an environment where robots cooperate effectively with workers providing high flexibility and efficiency [Stock and Seliger 2016].

INDUSTRY 4.0 IN SUPPLY CHAIN MANAGEMENT

Although Industry 4.0 by many people is mainly related to manufacturing, the principles are crucial for effective cooperation of particular links within the supply chain. Research provides that functions of the supply chain may be distinct depending on the product or services. However, they are necessary to integrate and coordinate all processes to match the supply and demand throughout the 4 main levers: buy, storage, move and sell [Tjahjono et al. 2017].

Subsequently, further findings offer an opportunity to define the supply chain in Industry 4.0 as "smart logistics" considering a modern approach to products and services. This new paradigm is supported by the idea of digitalization that considers the coexistence of people and systems to manage information flows and improve operations [Barreto et al. 2017].

Therefore, the requirement was to define the structure of the modern supply chain and describe the basic relations between its elements. Another research proposed a definition that says about a set of resources interacting with their network and shifting physical activities into digital ones to reduce the consumption of resources, support productivity, and finally provide real-time feedback as well as full visibility of the process. Not only does it consider the internal supply chain, but also includes all external relations, supporting the digitalization of tools in all stages of the network [Queiroz et al. 2019].

Integration of resources within the Critical Digital Supply Chain

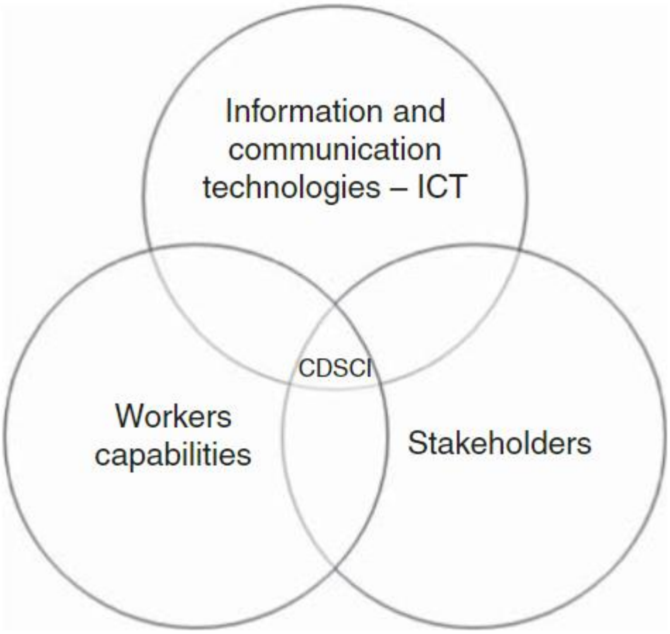

Fig. 2. Scheme of resource integration within Critical Digital Supply Chain: [Queiroz et al. 2019].

Specifically, according to the next study, to perform a digital supply chain, decentralization of the systems and cooperation based on the Internet of Things (IoT) are required, which independently manage the multiple-root data distributed in-network. Thanks to that, it is possible to create interoperable tools using the same IT standards to build synergy and provide the best performance [Weber and Weber 2010].

Modern tools and analytics allow one not only to improve the operations but also to implement statistical models and simulate future data. Thanks to it, there is possible a revolutionizing of the business spectrum and increasing competitiveness. It is important to mention that Industry 4.0 is not just a scientific approach to manufacturing and logistics, but conclusions from many types of research indicate this as a framework combining the solutions being implemented by real users. From this perspective, Industry 4.0 defines the business-applied solutions, supporting them with a scientific background, and analyzing results to guide how they should be developed in the future. Although there is the assumption that this idea is based on computer-aided tools, researchers' conclusions present the opinion that it is still largely based on the human decision-making process and efforts [Szymańska et al. 2017]

DUALISM OF DEVELOPMENT – NEW TECHNOLOGIES AND ENVIRONMENTAL RESPONSIBILITY

Increasing market requirements and globalism of manufacturing processes are strongly supported by tools related to Industry 4.0 and Logistics 4.0. Daily work and operations are possible thanks to solutions like RFID or sophisticated ERP systems that control all processes of companies. Research in this field provides that the Internet of Things, big data, and new technologies can increase productivity and enhance competitive edge in the supply chain. Modern solutions support end-to-end structures, adding value to material management, manufacturing, distribution, and customer service, which integrates even stronger the particular links and helps to save costs [Raman et al. 2018]

Technology and ever-growing demands caused regions to start to cooperate and finally globalized the market. With regard to Industry 4.0, globalization means the integration of international markets for commodities, labor, and capital. The benefits of this structure were significant from a cost perspective, geopolitical stability, and promotion of economic cooperation [O'Rourke 2019].

The companies wanted to achieve the best results and build their competitiveness on reduced costs. They realized then that production in Asia is much cheaper than domestic one. In 1978 the average wage in China was 3% of the average US wage at that time. Reforms in the 1990s caused an increase in these costs, but did not stop a rapid increase in demand for manufacturing in this country [Li et al. 2012]. This was possible because of the cheap energy available in China, as the country is the biggest producer of coal and its biggest consumer.

On the other hand, another finding provides that China is not ready to implement Industry 4.0 solutions because of problems like inefficient unit labor production, the imperfect standard system of industrialization, weak innovative capacity and lack of core talents, poor digital infrastructure, high energy consumption, high pollution, and low added value. China must improve its traditional manufacturing and implement modern solutions to meet the requirements of the future economy. There is need to say that idea of Industry 4.0 is considered to make countries more and more closely linked, so the Chinese manufacturing sector should start working on systematic development that involves government, universities, and research units [Feng et al. 2018].

However, in recent decades, the increase in production in Asia caused a huge demand for transportation from this region to other continents. This gap has been fulfilled by containerization, which significantly increased productivity in cargo handling. In 1984 the first container ships of around 4500 TEU were built. Companies that became the major container lines have understood that economy of scale will increase competitiveness and force agility to react. Second, they expected future growth in container volumes as a result of increased trade. And finally, there was a common understanding that there is a need for the development of port infrastructure to operate the larger ships [Cullinane and Khanna 2000].

According to United Nations and Clarksons Research, in recent years, we reported a significant increase in the proportion of mega-container ships in the global fleet. It shows that vessels with a capacity of more than 10.000 TEU constituted in 2021 almost 40% of the fleet, compared with 6% in 2011. Subsequently, there is a correlated decrease in the share of vessels less than 10.000 TEU. This trend is presented in Figure 2.

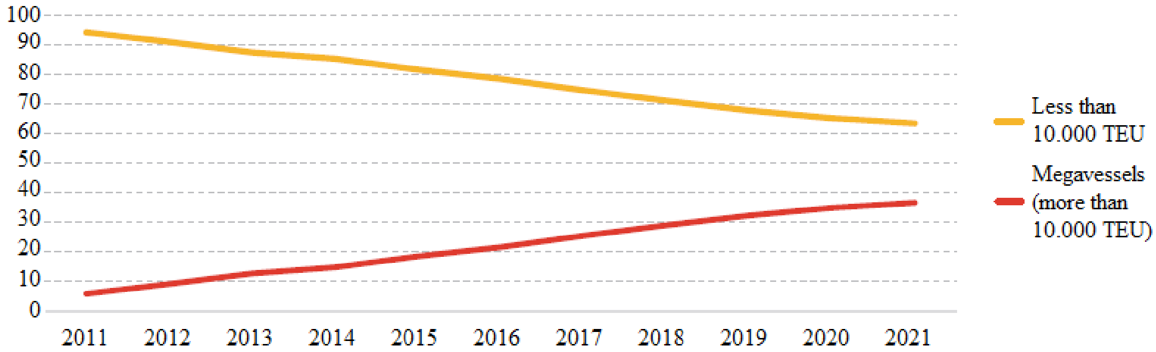

Fig. 3. Percentage share of mega-vessels in the global container ship fleet carrying capacity by TEU, 2011-2021: [LOGISTICS, D.O.T. AND. U.N.C.O.T.A. DEVELOPMENT 2021]

This presented change in fleet proportion is a natural consequence of the ever-growing containerized trade, which increased from about 40 million TEU in 1996 to 160 million TEU in 2021. Asia is a global leader as a hub for container port traffic with 2/3 of the throughput and half of 20 largest ports located in China. It intensifies cost pressure or inefficiencies. Additional bottlenecks or force majeure events such as COVID-19 have shown that global trade and supply chains are prone to disruptions, which lead to increased production costs and consumer prices. From a geopolitical point of view, protectionism between China and its trading partners may also be concerning because it may affect not only affect international relations but also decelerate global trade. China, as a developing country, is increasingly consuming its products, creating a domestic supply chain. The semiconductor crisis has proved how the shortage of raw material in one region can be critical for global industry causing a stop of production in automotive manufacturing [LOGISTICS, D.O.T. AND. U.N.C.O.T.A. DEVELOPMENT, 2021].

What does dualism actually mean? According to the opinions of researchers, neoliberal globalization is focused on profit and market more than considering any environmental aspects [Lehman 2009]. In recent decades, we realized what is the impact on the environment caused by manufacturing and transportation. The threat of climate change makes pressure on global supply chains to improve not only the factors important for businesses (e.g., lead times or costs) but also to reduce pollution. It was clearly stated that reforms and business models have widened the inequality between developed and developing regions [Free and Hecimovic 2021].

The new circumstances and the global situation intensify the consideration of defining a new supply chain order. One of the solutions would be the diversification of operations across other geographical areas. In this case, China's role in global manufacturing would be diminished and operations could be moved to Vietnam, Indonesia, Mexico or Europe, which may strengthen regional networks and increase resilience against growing geopolitical uncertainty [Free and Hecimovic 2021]. Technologies like 3D printing, AI, or Big Data will be very important for supply chains because they can redefine the framework of supply chain operations, increase the potential of local manufacturing, and simplify the networks reducing the complexity of assembly. The available research provides that there is a required change in decision-making processes to adapt companies to the reality of Industry 4.0 reality and understand all challenges and barriers related to it [Tsolakis et al. 2021].

3D PRINTING AS A PART OF FUTURE SUPPLY CHAINS

3D printing is not a new idea. The first reference to the technical capabilities of additive manufacturing can be traced back to the 1980s. However, the discussion of this technology was brought up again when the process costs have become affordable [Chan et al. 2018]. Additive printing is still a developing field, but the current state offers the use of a wide range of materials and techniques, which allow producing some goods used in multiple areas [Longhitano et al. 2021].

This technology is crucial importance for R&D activities. It can be integrated with scanning and allow one to digitalize of the product. At the same time, 3D printing can minimize the risks in product design, because 3D samples can be prepared in many configurations. It allows the customer to review the models without an expensive investment in tooling. Subsequently, there are possible cost savings as well as lead-time reductions. Furthermore, an expected is expected evolution in structure and identification of companies that offer services in this field. Companies can move from Original Equipment Manufacturer (OEM) to Original Design Manufacturer (ODM). This supports an easier way to create a new brand and produce products in small quantities with relatively affordable capital [Chan et al. 2018].

Increased environmental responsibility is also one of the advantages of additive printing. Thanks to the simplification of the manufacturing processes, the stages of production are reduced. Consequently, it improves the number of wastes that could be generated during operations. Additionally, while traditional business models are concentrated in geographical locations to achieve economic of scale, 3D printing can eliminate the distance between the production and consumption point. This concept is strongly supported by IT which allows the transfer or exchange of data [Singh and Agrawal 2021].

However, the findings provide that the full potential of 3D printing has not yet been yet achieved. This technology is used mainly by small manufacturers, which can fill a gap in market demand on a local scale. From a functional perspective, its services can be separated into three categories: generative, facilitative, and selective. Therefore, the advantages of additive manufacturing can cause complementing, replacing, or even creating new supply configurations. This may be possible due to offering high flexibility in terms of volumes, product customization and complexity [Rogers et al. 2016].

REDEFINITION OF DECOUPLING POINT IN INDUSTRY 4.0 FRAMEWORK

The decoupling point known in the current shape and understanding is strictly related to the economy based on the wide networks within the supply chains. Globalism that we mentioned in the previous paragraphs caused a major increase in complications, and disruption being a result of the increased complexity of the processes whilst trying simultaneously reduce the costs of warehousing or transportation.

The dynamic development of technologies and the growth of living standards have created the need to produce more sophisticated and individualized products. It truly impacted supply chain and manufacturing operations because mass production (e.g. in automotive) has become even more complicated. From an economic standpoint, suppliers sourced to produce the components are located, in large part, in Asia, which is an important disadvantage if assembly plants are located in Europe or US.

Increased prices for goods, the deteriorating geopolitical situation, and the limited infrastructure capacity are the reason for high uncertainty within global supply chains. The current industry has many challenges to overcome these issues. Industry 4.0 in our opinion, will change the understanding of logistics processes, but should also redefine the business models in terms of decoupling point.

3D printing technology can allow implementation of the new stages of decoupling point:

1. PTO (Print-to-Order) – printing of standardized products based on the available projects. Usually simple or fast-moving goods, tools, and service parts.
2. PTA (Print-to-Assemble) – printing of product with adjustable parameters or available in several variants. The process is driven by production orders or purchase orders. The variable of product is specified in the BOM existing in pre-defined various options.
3. ETP (Engineer-to-Print) – product is designed, printed, and tested based on the individual demand of the customer. Defined for unique and/or advanced products with a high level of customization.

Our concept presents new insight into a gap in understanding of the decoupling point in Industry 4.0 considering its evolutionary context. This framework could be used by supply network designers to make a decision about the business model and build an efficient end-to-end supply chain. Proposals or potential adjustments to this concept may be a part of a later discussion.

DISCUSSION AND CONCLUSION

The main objective of this paper was to analyze how supply chain and manufacturing can evolve thanks to the implementation of tools that are part of the Industry 4.0 framework. We agree with researchers that digitalization and modern solutions have an enormous potential to become the game changers in the re-definition of the supply chain.

At the same time, we understand the changes in the global market, also considering geopolitical factors. In our opinion, extensive networks can be a reason for many disruptions and negatively affect continuity of operations. The limited capacity of ports, busy shipping lanes, and increasing individualization of products are challenging for companies these days. In our view, although modern IT solutions are widely used by users, bottlenecks and potential uncertainty are related to physical operations and transportation, which have their natural limitations.

Constantly developing the field of 3D printing will be crucial to overcome these constraints and strongly support the cost perspective of businesses. We can easily define the following advantages of this solution for future supply chains:

1. Reduction of components/links within the supply chain: a simplification of networks, eliminating the processes or suppliers which extend the supply chain unnecessarily.
2. Optimization of processes - 3D printing can narrow down a list of materials needed to produce the same products. It means that a particular company could manufacture different products made of the same raw material. Processes may be driven by firm order and support variability of production.
3. Cost reduction:
   a. Warehousing – significant reduction in stock narrowing them down to raw material needed to print the final goods. Possible optimizations in storage methods and better utilization of space
   b. Transportation - the moldable and loose nature of raw material can improve container utilization.
4. Increased agility of the processes and business models – availability of raw material can significantly improve the inhouse operations and allow to react quickly to changing demands. For Engineer-to-Print, it means a potential elimination of lead times for material and the possibility to focus on the development of the product.

Potential limitations are related to the technology of 3D printing and currently existing models of supply chains. The complexity of the goods and the shape of the networks require progressive development and analysis of business models. It is truly important to consider this evolution as a complex task that involves not only the supply chain, but also purchasing, engineering, product development, and manufacturing. We propose further discussion regarding the transitional stage between the current and future state.

At the moment, two global automotive companies, Renault and Stellantis – are considering developing the idea of refactoring used cars. Their future manufacturing facilities will be supposed to receive cars, proceed with a scanning procedure to detect all mechanical damages as well as hidden defects (e.g., within electric systems), and replace defective elements with new ones. To be effective, this concept must be supported by new technologies, because the advancement of construction and unpredictability of potential damages do not allow one to keep scenario of serial production of components.

FUTURE RESEARCH

Our findings have focused on the supply chain perspective and presented how the decoupling point can evolve in terms of the Industry 4.0 framework. Future research should consider the transitional stage to effectively use available technology, not impacting current businesses. The coming studies should also examine the influence of new approaches on decision-making. From a global perspective, it would also be required to analyze whether this concept may improve the sustainable growth of particular regions, also supporting also environmental responsibility.

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ORIGINAL PAPER

CARRYING THE BURDEN OF THE PANDEMIC: THE RELATIONSHIP BETWEEN INTERNAL MARKETING, BURNOUT, AND JOB SATISFACTION IN COURIER SERVICE INDUSTRY

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ABSTRACT. Background: The main purpose of this study is to examine the effect of internal marketing practices applied in the courier services industry on the job satisfaction of employees and the moderating effect of burnout in this relationship.
Methods: To test the hypothesis, an online survey was conducted on a sample of 376 respondents from the Turkish courier industry. Research data was collected by a web-based survey distributed with the assistance of TUMTIS (All Transport Workers' Union) managers.
Results: The results show that internal marketing practices have a positive and significant effect on job satisfaction, and burnout has a moderating effect on this relationship. The most interesting finding is that, in the case of high level of burnout, the relationship between internal marketing and job satisfaction is significant and negative.
Conclusion: This is one of the few studies that considers the courier service industry from the perspective of employees, not customers. The findings could offer an elaborate understanding of how burnout affects the relationship between internal marketing and job satisfaction in the courier service that provides a bridge between companies and customers. The results of this study have a wide array of managerial implications for the courier service industry.

Keywords: Burnout, Courier Services, Internal Marketing, Job Satisfaction, Moderating

INTRODUCTION

In today's world, where traditional marketing has replaced relational marketing, internal marketing practices aiming to increase the satisfaction of both employees and customers have gained importance in both commercial and academic fields. According to the internal marketing approach, employee satisfaction is essential for the satisfaction and loyalty of external customers [George, 1990]. Therefore, organizations should inform, educate, train, reward, and motivate their employees, who are identified as internal customers, to satisfy the needs, requests, and expectations of their external customers [Doukakis and Kitchen, 2004]. In recent years, internal marketing research has concluded that internal marketing activities are effective in various concepts such as service quality, corporate identity formation, competitiveness, job satisfaction, organizational commitment, organizational citizenship, and customer satisfaction [Finney and Scherrebeck, 2010].

Today, the most important of the sectors where internal marketing practices gain importance is the courier service. A courier is a typical third-party logistics provider, and they help deliver packages. The growth of online sales and e-commerce and the growing habits of consumers to buy online have effectively changed the demand for such delivery services [Dablanc et al., 2017]. As a result of the fast and rapid growth of e-Commerce, the market environment in the courier services industry has changed dramatically. The bulk of the courier service industry is still reliant on manual labor-intensive processes. Consequently, human

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factors play a crucial role in any process in this sector [Riyanto et al., 2019]. Additionally, store clerks, delivery drivers and warehouse workers are being pushed to be "ideal workers" in the middle of the Covid-19 pandemic, risking exposure to the virus in the public while leaving their families behind. They have continued to commute to work, taking the risk of exposure to the virus and transmitting it to their families [Thomason and Williams, 2020]. The workers in the courier sector, who must deal with excessive workload and stress, emerge as one of the groups most affected by this epidemic. However, several studies have been conducted specifically on internal marketing, job satisfaction, and burnout during the Covid-19 pandemic, and so far there have only been a few studies on courier workers [Riyanto et al., 2019]. On the other hand, studies on courier service have focused on the service of logistics services [Bienstock et al., 2008] and cargo services [Wang, 2007]. The researchers have reviewed the sector from the customer's point of view, but neglected the employees. This one-sided perspective is one of the main constraints of the literature on the courier service industry. This study tries to fill this gap in the literature by considering the sector from the perspective of employees, not customers.

The main purpose of this study is to examine the effect of internal marketing practices implemented in the courier service industry on the job satisfaction of employees and the moderating role of burnout in this relationship. These findings could offer an in-depth understanding of how burnout impacts the relationship between internal marketing and job satisfaction in the courier service that provides a bridge between companies and customers. The research provides suggestions for managers and marketing professionals on what kinds of internal marketing practices should be carried out to reduce the burnout levels of courier sector employees and increase their job satisfaction. The rest of the study is organized as follows. In the following section, the conceptual framework based on internal marketing, job satisfaction, and burnout is discussed, and the research hypotheses are developed. The researchers move on to the research methodology, data collection, and findings. Finally, the implications of the findings are explored taking into account limitations and foresight for future research.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

Internal Marketing

While the previous marketing strategies considered only external customers of organizations as a field of application, today's modern marketing strategies have also realized the importance of organization employees [Rafiq and Ahmed, 2000]. Internal marketing, which focuses on the relationship between the organization and employees, is seen as an important approach towards providing effective external marketing and service quality [Yang, 2010]. According to the internal marketing approach, employee satisfaction is essential for the satisfaction and loyalty of external customers [George, 1990].

Foreman and Money [1995] dealt with internal marketing elements in three dimensions: (1) vision, (2) development, and (3) reward. Vision refers to the sharing of the desired image about the future of the organization to employees. The award refers to performance evaluation and rewarding the successful employees. Development refers to the training of employees to adapt to the developing internal and external environment. Yildiz and Kara [2017] argued that these dimensions are not sufficient and claimed that other characteristics will meet the needs and expectations of the employees. Some of these elements include career advancement opportunities, equal treatment, and the receipt of employee opinions. Studies have indicated that internal marketing has positive effects on the business attitude and behavior of employees in organizations [Wu et al., 2013].

Relationship Between Internal Marketing and Job Satisfaction

Job satisfaction is described as an individual's emotional state due to his or her job experiences [McAllister et al., 2017]. In the present world where knowledge is at the forefront, the most critical and costly resource to the owner is the human itself. One of the conditions for this costly and critical resource to contribute positively to the organization is that individuals have positive feelings toward their job [Qu, 2021]. Although job satisfaction establishes positive relationships with positive concepts in many studies, it also constantly establishes negative and significant relationships with negative concepts [Soyer et al., 2009].

Job satisfaction should not be considered independent of the organization's structure, functioning, handling, and intensity of the work. In addition, job satisfaction not only makes the employee feel good, but also contributes to the performance of the organization. Many studies in the literature have investigated the relationship between internal marketing and job satisfaction in various contexts [Wu et al., 2013]. The positive impact of internal marketing practices on employees' job satisfaction has been confirmed in the context of various sectors such as hotel employees [Hwang and Chi, 2005], teachers and academic staff [Ting, 2010] and healthcare workers in hospitals [Chang and Chang, 2009]. However, no study has examined the impact of internal marketing practices on the satisfaction of courier workers' jobs. Based on the aforementioned discussion, the following hypothesis is formulated:

H1: Internal marketing practices of businesses are positively related to job satisfaction.

Moderating Effect of Burnout

Burnout is described as a syndrome that features emotional exhaustion, cynicism, or self-alienation, and decreased professional efficiency [Maslach and Jackson, 1981]. Burned-out individuals can easily cry, experience situations such as not being able to control their emotions, feeling helpless, or hopeless [Kim et al., 2007]. Burnout can also show behavioral symptoms such as anger control problems and aggression. The burnout process does not always cover the same period for all individuals.

Burnout has a negative impact on organizational commitment, turnover intention, and work performance, in addition to adversely affecting an individual's physical and mental health [Parker and Kulik, 1995]. With burnout, individuals lose their excitement and stagnate over time. This situation can interfere with the performance and career development of individuals [Eroglu, 2014]. When exposed to a long-term stressful work environment, burnout has a negative interaction with physicians' job and life satisfaction [Maslach and Jackson, 1981]. More broadly, there has been evidence of a connection between job satisfaction and burnout, with a sense of job dissatisfaction leading to burnout [Kim, 2012]. In this context, the effect of internal marketing activities on job satisfaction can be interrupted when burnout is activated. Based on the aforementioned discussion, the following hypothesis is formulated:

H2: Burnout has a negative effect on job satisfaction.

H3: Burnout moderates the relationship between internal marketing and job satisfaction.

RESEARCH METHODOLOGY

Sample and Procedure

In this study, research data was collected by a web-based survey (because of the fatal condition of the COVID-19 pandemic), which was distributed with the help of TUMTIS (All Transport Workers' Union) managers. The distribution of the questionnaires and the data collection process were carried out in two phases. In the first phase, all participants and union managers were informed about the confidentiality of their information and the feedback of the survey. In the second phase, all participants and union managers were informed about the purpose of our investigation. The surveys were distributed by using a group chat board of different team communications applications. Moreover, to keep confidential, all surveys were coded. However, a link to a survey was distributed to union members who encouraged and informed them, and 472 people responded that data that were not fully or appropriately filled out were omitted from the analyses. Similarly, the results of participants were 376 including 335 men (89%) and 41 females (11%).

Measures

The researchers used an online survey divided into two parts. Internal marketing, burnout, and job satisfaction are all variables of study measured in the first section. In the second section of the questionnaire, there are items related to demographic information. With the help of bilingual experts, all scales were adapted into Turkish and then retranslated into English to provide consistency. Participants responded to all items, apart from demographic variables, on a 5-point Likert scale ranging from "strongly disagree" (1) to "strongly agree" (5).

The internal marketing scale was developed by Yildiz and Kara [2017], to incorporate the needs and expectations of the service sector employees. The scale has 11 items (e.g., "This organization provides attractive physical conditions to its employees", "This organization provides an achievable vision to its employees"), that measure the level of organizing the workload of employees, supporting career development, providing vision, improving their physical conditions, and treating them equally. In this study, Cronbach's α for the internal marketing scale was 0.95. The validity of the construct was evaluated using confirmatory factor analysis. The results demonstrated that the fit was acceptable ($\chi 2/df$ = 2.16, RMSEA = 0.06, TLI =0.98, CFI =0.99).

The burnout scale used in this study was reorganized from the scale originally developed by Pines and Aronson [1988] with 21 items and modified by Malach-Pines [2005]. The modified version of the scale has 10 items (e.g., "Disappointed with people", "Difficulties sleeping", "Tired"), that measure an individual's level of physical, emotional, and mental exhaustion about their job. In this study, Cronbach's α for the burnout scale was 0.96. The validity of the construct was evaluated using confirmatory factor analysis. The results showed that the fit was acceptable ($\chi 2/df$ = 2.19, RMSEA = 0.06, TLI =0.99, CFI = 0.89).

The job satisfaction scale used in this study was reorganized from the scale originally developed by Hackman and Oldham [1975] and modified by Basim and Sesen [2009]. The modified version of the scale has 5 items (e.g., "I am proud of my job", "When I work intensively, I feel happy"), that measure an individual's level of job satisfaction. In this study, Cronbach's α for the job satisfaction scale was 0.93. The validity of the construct was evaluated using confirmatory factor analysis. The results showed that the fit was acceptable ($\chi 2/df$ = 1.96, RMSEA = 0.05, TLI =0.99, CFI = 0.89).

Cronbach's alpha values (which show good internal reliability when > 0.70) [Kline, 2005] were also analyzed and found good internal reliability. Average variance extraction (AVE; acceptable when > 0.50) [Fornell and Larcker, 1981] was calculated to assess convergence validity and composite reliability (acceptable when > 0.70) [Fornell and Larcker, 1981] to analyze construct reliability (see internal marketing, 0.68; burnout, 0.76; job satisfaction, 0.79). The relationships of all variables with each other were analyzed using Pearson's correlation analysis. Correlations between.30 and.50 are considered low, between .50 and .70 moderate and above.70 high [Tabachnick and Fidell, 2007].

Data Analysis

The analysis of data from this research was performed with PROCESS, which is an available SPSS computer macro. The PROCESS macro is based on bias-corrected bootstrapping to construct confidence intervals. This process deals with the issue of bias resulting from the asymmetric and nonnormal sampling distributions of an indirect effect [Preacher and Hayes, 2008]. The Hayes PROCESS is currently the most putative method in moderation tests in psychological research and management sciences.

Specifically, the first model of the templates for PROCESS for SPSS and SAS was used as recommended by Hayes [2017] in the current study. Further testing moderated the effects of burnout, Model 1 was used with bias-corrected bootstrap confidence intervals (BC; 95% CI) based on 5000 bootstrap resamples. The conceptual and statistical diagram of Model 1 is illustrated in Figure 1. Model 1 allows us to analyze with parameter estimates from a moderation analysis of burnout in the effect of internal marketing on job satisfaction levels. The Johnson-Neyman technique, which determines the regions of significance of an association when the moderator is a continuous variable, was used to examine significant interactions [Hayes, 2017].

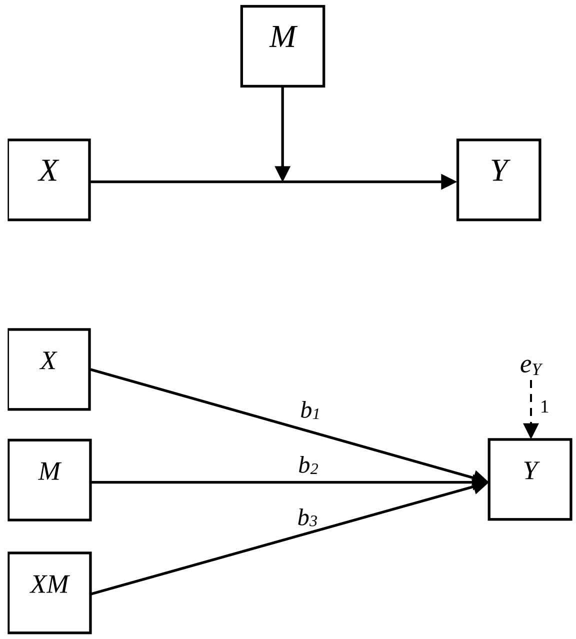

Fig 1. Conceptual and Statistical Diagram of Model 1. Conditional effect of X on Y = b1 + b3M. Source: Hayes (2017).

RESULTS

Descriptive Statics

The researchers reported the descriptive statistics for all study variables in Table 1. As expected, internal marketing was positively correlated with job satisfaction, and burnout was negatively correlated with both variables of this study.

Testing the Moderation Models

To explore whether the burnout experience moderated the relationship between internal marketing and the job satisfaction for cargo carrier workers, a moderation model was examined with a moderator of the effect of X (IM) on Y (JS) by M (Burnout), using PROCESS 3.5v (Command model 1).

The model pointed out that internal marketing was a significant and positive effect on job satisfaction, and burnout was a significant and negative effect on job satisfaction. Therefore, to address Hypothesis 1 (Internal marketing positively and significantly affects job satisfaction), it was found that internal marketing practice had a positive and statistically significant effect on job satisfaction (95% CI: [0.0352, 0.2078]). Then, to address Hypothesis 2 (burnout negatively and statistically significantly affects job satisfaction), it was discovered that burnout of workers had a negative and significant effect on their job satisfaction (95% CI: [-0.8517, -0.6778]). Finally, to address Hypothesis 3 (burnout moderates the relationship between internal marketing and job satisfaction), PROCESS Model 1 was performed. The results indicated a burnout that moderating the relationship between internal marketing and job satisfaction (95% CI: [-0.3754, -0.2043]). The results of the moderating effect are depicted in Fig. 2. Additionally, the results of the hypothesis analyses were shown that Table 2.

Table 1. Means, standard deviations, and correlations

Variable	M	SD	1	2	3
1. Internal Marketing	3.30	1.03	-		
2. Job Satisfaction	2.95	1.21	**.233****	-	
3. Burnout	3.10	1.24	**-.228****	**-.689****	-

**p<0.01

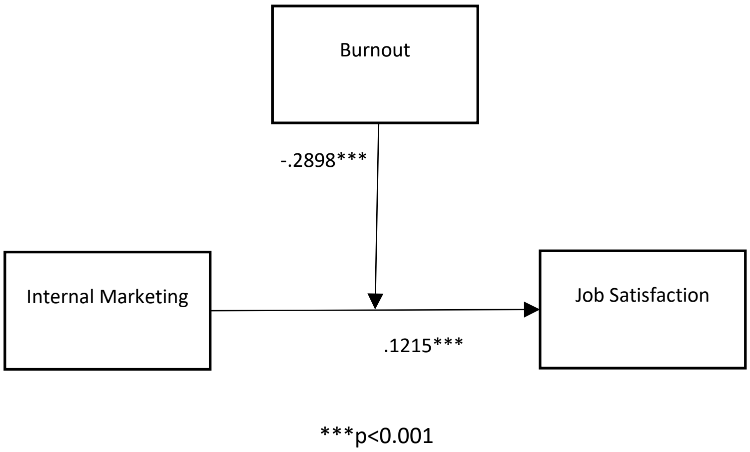

Fig 2. Results of moderation

Table 2. Moderation effect result

Variable	B	S.E	t	p	95% CI	
					LLCI	ULCI
IM	0.1215	0.0439	2.7670	0.0059	0.0352	0.2078
Burnout	-0.7647	0.0442	-17.2909	0.0000	-0.8517	-0.6778
IM x Burnout	-0.2898	0.0435	-6.6640	0.0000	-0.3754	-0.2043

There is also a need for the consideration for distribution of gender skewness; thus, Model 1 processes also execute on a compromised male sample. The results for the male-only sample still indicated that the internal marketing practice had a positive and significant effect on job satisfaction (B = 0.1364, SE = 0.0498, t(335) = 2.7388, p = 0.0065, 95% CI: [0.0384, 0.2343]). Likewise, it was found that burnout of workers had a negative and significant effect on their job satisfaction (B = -0.7561, SE = 0.0482, t(335) = -15.6756, p = 0.0000, 95% CI: [-0.8509, -0.6612]), for the sample with only men. Finally, moderation analysis shows that burnout moderating the relationship between internal marketing and job satisfaction (B = -0.2842, SE = 0.0483, t(335) = -5.8898, p = 0.0000, 95% CI: [-0.3792, -0.1893]). These results indicated that the skewness of the gender distribution of the sample did not lead to bias in the results.

A simple slope analysis revealed that when burnout was low (16th percentile), a significant positive association was found between internal marketing and job satisfaction b= 0.4730, SE= 0.0715, t= 6.6146, p= 0.0000, 95%CI [0.3324, 0.6136]. Similarly, at moderate levels of burnout, a significant positive association was found between internal marketing and job satisfaction b = 0.1445, SE= 0.0443, t= 3.2591, p= 0.0012, 95%CI [0.0573, 0.2317]. On the other hand, when burnout was high (84th percentile), the relationship between internal marketing and job satisfaction was significant and negative b= -

0.2309, SE= 0.0657, t= -3.5126, p= 0.0005, 95%CI [-0.3601, -0.1016].

Figure 3 shows the interaction effects. When the low level of burnout is, the relationship between internal marketing and job satisfaction is significant and positive. When burnout is low and internal marketing is high, job satisfaction also increases. Furthermore, the relationship between internal marketing and job satisfaction is significant and positive at the moderate level of burnout. When burnout is moderate and the level of internal marketing increases, the level of job satisfaction increases slightly. However, when at the high level of burnout, the relationship between internal marketing and job satisfaction is significant and negative. Job satisfaction decreases slightly, even though internal marketing increases when burnout remains high.

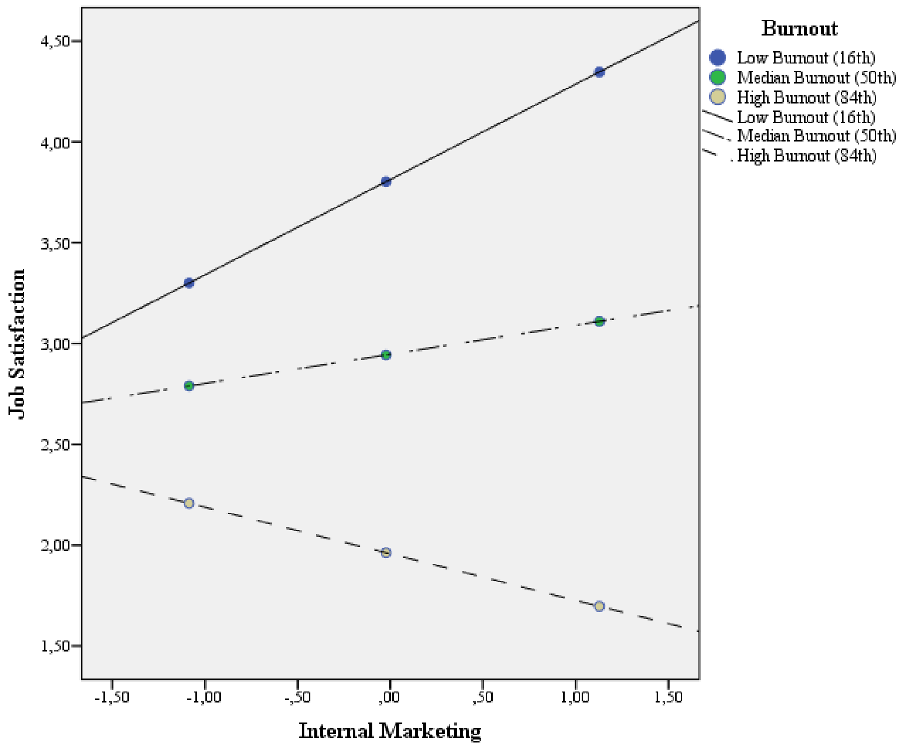

Fig 3. Burnout moderates the relationship between internal marketing and job satisfaction.

DISCUSSIONS AND CONCLUSION

Today, internal marketing practices aiming to increase the satisfaction of employees, as well as the satisfaction of customers, have become increasingly important. According to the internal marketing approach, employee satisfaction is essential for the satisfaction and loyalty of external customers [George, 1990]. Many studies have investigated the positive relationship between internal marketing and job satisfaction in various sectors [Wu et al., 2013; Hwang and Chi, 2005; Ting, 2010; Chang and Chang, 2009]. However, no study has examined the impact of internal marketing practices on the satisfaction of courier workers' jobs. Many studies on courier service have focused on the service quality of logistics and cargo services [Bienstock et al., 2008; Wang, 2007]. The researchers have reviewed the sector from the customer's point of view, but neglected the employees. The starting point of this study has been to break this one-sided point of view. The current research aimed to explore the association between internal marketing and job satisfaction and the moderating role of burnout on this relationship in the courier service that provides a bridge between companies and customers. Our findings contribute to the stream of research on burnout and specifically on its destructive effect on job satisfaction despite internal marketing practices.

The findings indicated that internal marketing was positively correlated with job satisfaction, which is consistent with previous studies [Wu et al., 2013; Ting, 2010; Chang and Chang, 2009]. As expected, the results indicate that burnout was negatively correlated with job satisfaction. Based on these results, it can be explained that while internal marketing positively affects the job satisfaction of courier service employees, burnout negatively affects it. In this case, managers should play an active role and provide the necessary conditions to meet the needs and satisfaction.

The most important result of this work is that the of employees of burnout level moderates the relationship between internal marketing and job satisfaction. The relationship between internal marketing and job satisfaction according to three different levels of employee burnout [low, medium, and high) is shown in Figure 3. When at the low level of burnout, the relationship between internal marketing and job satisfaction is positively significant. When burnout is low and internal marketing is high, job satisfaction also increases. When burnout is moderate and the level of internal marketing increases, the level of job satisfaction increases slightly. Interestingly, when the high level of burnout is, the relationship between internal marketing and job satisfaction is significant and negative. Job satisfaction decreases slightly, even though internal marketing increases, while burnout remains high. This may be because employees who encounter internal marketing practices during the pandemic period can interpret this as an increase in their workload or their expectations. However, the last thing employees want during the pandemic period is to increase their workload. Another possible reason for this interesting finding may be organizational cynicism. Organizational cynicism is a sense of dissatisfaction with the organization, and employees assume that the organization's management lacks justice, honesty, and transparency [Ozler and Atalay, 2011]. In employees with a high level of organizational cynicism, internal marketing practices may cause burnout by creating adverse effects. Moreover, it is considered that the concept of organizational dissidence explained within the framework of unobtrusive control theory [Tompkins and Cheney, 1985] may also help explain our intriguing findings. With this dissent, employees can send indirect messages to the organization by doing the opposite of what the organization expects. In addition, employees may have negative assumptions about the reasons behind the organization's positive practices. They may also show dissent in this situation. Future studies are needed to test different factors such as organizational cynicism, organizational dissent, and organizational citizenship behavior.

Although it is beyond the scope of this study, the demographic characteristics of the participants showed that most of the courier industry are men (89%). In this case, managers should employ work women to encourage employment equality, and policymakers should play an active role in increasing the female labor force participation rate for the courier service industry.

When interpreting the conclusions of this research, there are some limitations to take into account. First, the researchers used a small convenience sample that might not have accurately represented the entire courier service industry. Second, most of the employees in our sample are male. This issue also limits the generalizability and external validity of the results. Third, our study mainly conducted a cross-sectional study. However, the pandemic process has changed everything from work conditions to their mood and economic situation. Thus, longitudinal research can provide more insights into the level of burnout and job satisfaction of courier service employees.

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ORIGINAL PAPER

LAYOUT DESIGN OF OUTPATIENT DEPARTMENT: SIMULATION STUDY AND IMPLEMENTATION

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ABSTRACT. Background: Hospital layout is one important factor affecting hospital service quality and, consequently, patient satisfaction. Generally, the layout is designed based on the experience of the hospital specialists without any systematic approaches.

Purpose: Due to the increasing number of patients, the case study hospital has built a new multi-floor building to move its Outpatient Department (OPD) to operate there. Therefore, this study aims to apply the Activity Relationship Analysis (ARA) and simulation to design a new OPD layout.

Methodology: Data of the previous system were analyzed using the ARA. The results were then used to design three scenarios (A, C, and D) and the other three scenarios (B, E, and F) were proposed by hospital specialists. Then, six layouts were evaluated using simulation tests and the efficiencies of the designs were measured by an average total service time per patient.

Results: The simulation results showed that the average total service time of scenario A, D, E, and F were lower than scenario B and C. While the average total service time at the sub-service unit of D was the longest compared to scenario A, E, and F. These results demonstrated that scenario A, E, and F were the most efficient layouts. However, when considered thoroughly by the hospital specialists, scenario A was eventually selected.

Conclusion: This study can contribute to scientific literature as it demonstrates the application of the ARA and simulation in the design of the multi-floor layout, an aspect under-researched in existing studies. This study also provides the practical implication suggesting that these techniques should be used together in the layout designs because they can help to determine the correctness and efficiency of the layout design before actual implementation.

Keywords: activity relationship analysis, simulation, hospital layout design, outpatient department

INTRODUCTION

Hospital layout is one important factor affecting the hospital service quality [Arnolds and Gartner, 2018; Benitez et al., 2019; Elshafei, 1977; Gosavi et al., 2016; Jamali et al., 2020; Sower et al., 2001; Ward et al., 2005; Zhao et al., 2009], especially the Outpatient Department (OPD) layout that includes several service units. An efficient OPD layout can promote the efficient flows of staff and patients by minimizing distances of travel, making efficient use of spaces, and providing optimal functional adjacencies. Accordingly, the efficient OPD layout can reduce the patient's waiting time and increase the level of patient satisfaction with the hospital service quality [Boonmee et al., 2021; Luo et al., 2017; Tsui and Fong, 2018].

Many approaches are used in the facility layout design [Boonmee and Kasemset, 2019], for example, Activity Relationship Analysis (ARA), simulation, optimization, heuristics, lean manufacturing, decision-making analysis, SERVPERF theory, and SHELL model. In addition, some of these approaches have been combined to design the facility layout in many previous studies, for instance, optimization and simulation [Vahdat, 2019], lean manufacturing, SERVPERF theory [Soriano-Meier, 2011], and heuristics and ARA [Motaghi et al., 2009].

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The case study hospital of this research is a community hospital located in Chiang Mai province, Northern Thailand. The hospital provides healthcare services to approximately 600-700 patients per day. While the number of patients is constantly increasing, the hospital has built a new building to improve its services and prepare itself for the increasing number of patients. The hospital decided to move its OPD to operate in the new building and increased service capacity from single-floor to double-floor operation. This hospital previously designed its OPD layout based mainly on the experiences of the hospital specialists without any systematic methods. As a result, it wanted to apply systematic approaches in the design of its new OPD layout.

The hospital aimed to design its new OPD layout to minimize the service time and, subsequently, the waiting time of the patients. The design of the layout thus needs to consider the relations and share of resources (e.g., facilities and human resources) between service units. Among many design approaches, the ARA is a technique that considers the degree of closeness and relations between service units in the layout; therefore, this technique was selected and applied in the layout design in this research. This research also applied the simulation technique in the selection of the appropriate layout because the simulation technique can help to evaluate the efficiency of the alternative layouts before actual implementation.

Although the ARA and simulation are widely used in the facility layout design. Two main gaps can be identified. Firstly, the simulation is rarely applied in the hospital layout design because most studies use it mainly for evaluating the performance of the healthcare operational system [Boonmee et al., 2020; Gallagher et al., 2016; Günal and Pidd, 2011; Katsaliaki and Mustafee, 2011; Kasemset et al, 2021; Murphy, 2013; Sepúlveda, 1999]. Secondly, limited studies combine these two approaches in the design of the multi-floor layout, especially the hospital layout. Therefore, the objective of this research was to use the ARA and simulation to design, propose and evaluate the most efficient OPD layout for a case study hospital.

THEORY

Activity Relationship Analysis (ARA)

The ARA is one technique in Systematic Layout Planning (SLP) [Francis, et al., 1992]. It is often applied in the initial stage of the SLP to design the facility layout [Muther, 1955] and includes two main tools, namely Activity Relationship Chart (ARC) and Activity Relationship Diagram (ARD).

Firstly, the ARC is a tabular means of displaying the degree of closeness among all pairs of activities, areas, or departments [Muther, 1955]. The degree of closeness can be evaluated using quantitative data – such as frequency of movements – or qualitative data – such as perspectives of specialists [Affifah, 2019]. The symbols, including A, E, I, O, U, and X, are used to represent the degree of closeness, where A is Absolutely necessary; E is Especially important; I is Important; O is Ordinary closeness; U is Unimportant; and X is Undesirable.

Secondly, the ARD is a block diagram developed from information in the ARC [Tompkins, 2010; Sugandhi and Bharule, 2016]. It reflects the strength of the relationship between activities, areas, or departments to be placed into the layout by a number of joining lines [Muther, 1955]. For instance, four joining lines (degree of closeness = A) indicated a need to have two activities located close together, while one line (degree of closeness = O) indicates a lesser priority on placing the activities close to each other.

Simulation

A simulation is a process of designing a model of a real-world system and conducting experiments to evaluate the model performance before actual implementation [Law 1998; Boonmee and Kasemset, 2019]. The simulation is often used in improvement activities because it helps to deal with complicated systems and requires few assumptions [Nanda and Sudhir, 1996]. It is also used to learn non-existing systems to predict the outputs of actions and developments that are expensive to conduct experiments in the real world [Lagergren, 1998; Boonmee et al., 2020]. The steps of the simulation are as follows: formulate the problem and plan the study; collect the data and formulate the simulation model; check the accuracy of the simulation model; select the simulation software and construct a computer program; test the validity of the simulation model; plan the simulation to be performed; conduct the simulation runs and analyze the outputs statistically; and present recommendation to management [Hillier and Lieberman, 2015].

The output analysis is one important step in the simulation study [Kelton et al., 2010]. The simulation results are simply the observed samples of the random variables. This inference or predictions about a system can be done either by hypothesis testing or confidence interval (CI). CI indicates the range of likely value of the measure at any significant level (α) [Hillier and Lieberman, 2015]. The output from the simulation runs provides statistical estimates of the desired performance measure for each system configuration of interest. (1- α) % CI on mean is calculated based on equation (1) (Montgomery and Runger, 2014).

$$\bar{x} - t_{\frac{\alpha}{2},n-1} S/\sqrt{n} \leq \mu \leq \bar{x} + t_{\frac{\alpha}{2},n-1} S/\sqrt{n} \quad (1)$$

Where α = Significant level, n = Sample size, $\bar{x}$ = Sample mean, μ = Population mean, S = Sample standard deviation, $t_{\frac{\alpha}{2},n-1}$ = the upper bound 100α/2 percentage point of the t distribution with n-1 degree of freedom, the lower bound of mean is $\bar{x} - t_{\frac{\alpha}{2},n-1} S/\sqrt{n}$, and the upper bound of mean is $\bar{x} + t_{\frac{\alpha}{2},n-1} S/\sqrt{n}$.

The comparison can be conducted at any α-level when intervals of outputs are not overlapped, compared situations can be claimed that they are significantly different.

METHODS

Data collection

The OPD service system of the case study hospital is separated into two main groups: medical and supporting service units. The medical unit consists of examination rooms for six departments, including Pediatric (PED), General Practitioner (GP), Medicine (MED), Ear nose and throat (ENT), Surgical (SUR), and Orthopedic (ORTHO). While supporting service units include pre-checking, registration, Vital Sign (V/S) checking, history taking, X-Ray, laboratory (Lab), medical procedure room, payment, and pharmacy. Data of the existing service system were collected, including service- operation flows, operation time, number of patients and arrival rates, number of officers (including doctors, nurses, technicians, and support operators), existing OPD layout (one floor), and related limitations. Data of the new area were considered, including the new floor plan of the OPD area (two floors), the number of rooms, and the distance between each unit. The patient's operation flow was presented in Figure 1.

Simulation Model

Collected data were used to develop the simulation model using Arena software. Data input to the simulation model mainly applied 3 standard statistical distributions: constant (CONS), triangular (TRIA), and uniform (UNIF) distributions for each operation time as presented in Figure 1. For example, one patient at pre-checking may spend one of three operation times as 5 (min), 10 (mode), or 15 (max) seconds as TRIA distribution. The characteristic of each standard distribution can be found in Kelton et al. (2010).

The simulation model is separated into four sections (shown in Figure 1) as follows:

Section 1: This section represents the general primary operations when patients arrive at the hospital for OPD. The patient arrival rate is different depending on each period from 7:00 AM to 4:00 PM. To create patients for the simulation model, the arrivals are created based on exponential distribution with different mean values for each hour.

There are three types of patients: (1) New Patient (NP), (2) Registered Patient with Appointment (RPA), and (3) Registered Patient without Appointment (RPOA). All patients have to pass three operations: pre-checking, registration, and V/S checking, respectively.

Section 2: In this section, each type of patient is assigned to different operation flows. RPA have the highest priority and they are sent to three possible operations – diagnosis, lab testing, or X-ray – following the detail of their appointment records. While NP and RPOA are sent directly to do history taking.

Section 3: This section is the diagnosis section at the OPD. Patients are assigned to a specific diagnosis separately based on each medical unit, including PED, GP, MED, ENT, SUR, and ORTHO. After finishing the diagnosis by doctors, patients may be assigned to have more lab testing, X-ray, or medical procedures, then they might return to have diagnosis again.

Section 4: When patients finish their medical service at OPD following section 3, they normally go to carry out the payment, receive medicine at the pharmacy, and then go out of the system. In case of additional treatment is needed, patients may be admitted to the In-Patient-Department (IPD) or transferred to other hospitals for further treatment.

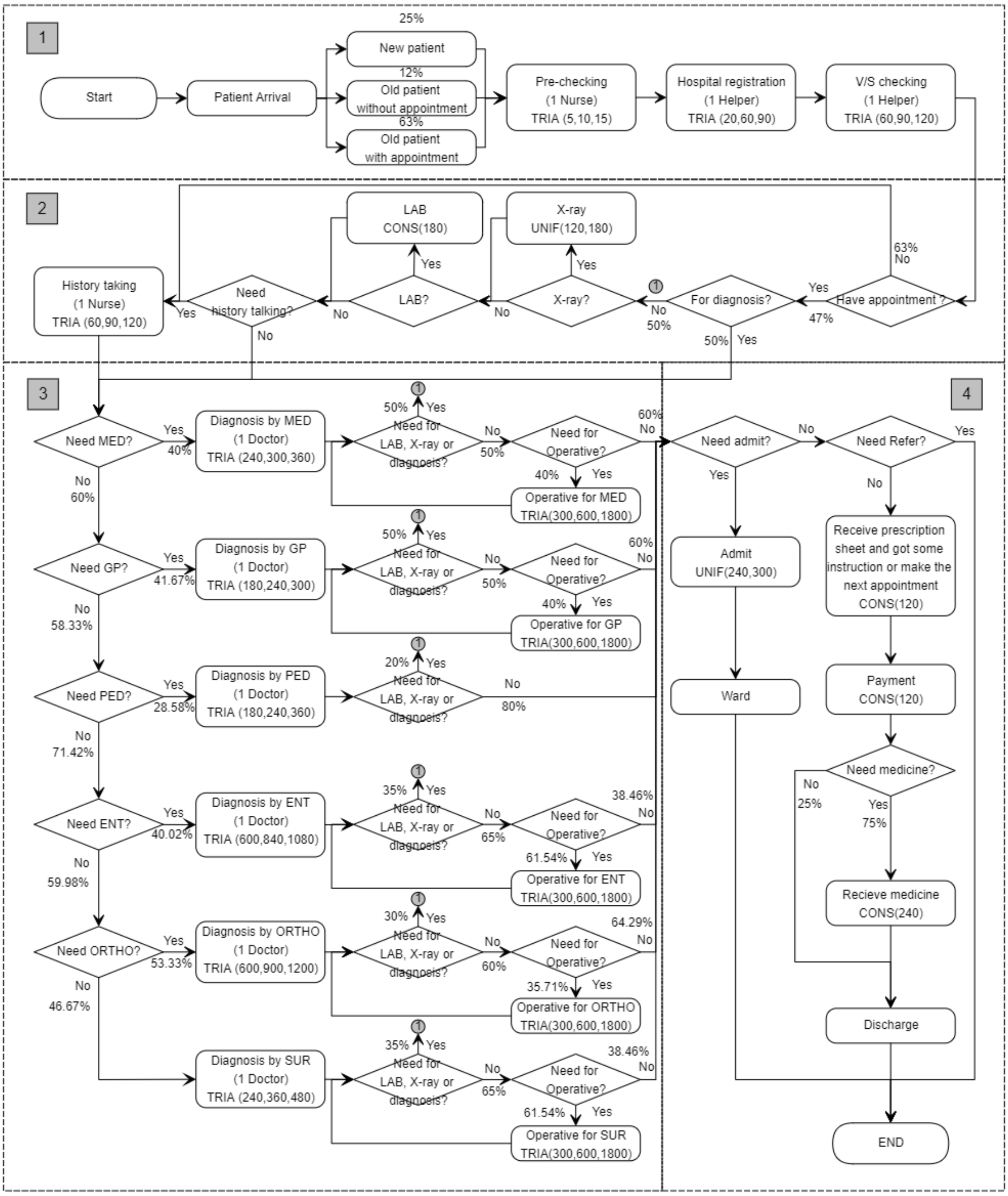

Fig. 1. Operational flow chart at OPD (time unit: second)

Verification and validation of the model were conducted when the simulation test ran with a run length of 9 hours and 64 replications. Test results were also discussed together among the researchers and the hospital management team. From September to November 2019, the number of patients served at OPD was approximately 660 persons per day, so the results from simulation presented the number out as 652 to 663 persons per day using a 95% CI of the mean. The results from the simulation were not significantly different compared with the real data at the significance level (α) 0.05 because the 95% CI of mean included the value from the real system. In conclusion, the proposed simulation model can be used to represent the real system.

Test scenarios and limitations of the new area

The layout of the OPD in the new area is separated into two floors. The first floor consists of seven examination rooms, one Lab, one X-ray, two medical procedure rooms, one registration centre, one pharmacy, and one financial counter. The second floor consists of eight examination rooms, one Lab, and two medical procedure rooms. Examination Rooms need to be assigned exactly to each department as follows: 4 rooms for MED; 2 rooms for GP; 2 rooms for ENT; 2 rooms for ORTHO; 1 room for PED; and 1 room for SUR.

To assign examination rooms, ARC and ARD were used to evaluate the relationship between rooms. The relationships between rooms were rated using the degree of closeness: A, E, I, O, and U. A means that two rooms have to be located close to each other. E means that two rooms should be located close to each other, but after putting A. I and O are considered after E respectively, while U shows an unimportant relationship which can be last considered, and the rooms can be located independently.

From Figure 2, considering all departments, pairs of departments with relationships can be ranked as MED-GP (E level), MED-PED (O level), PED-GP (O level), SUR-ORTHO (O level), SUR-ENT (O level), and ORTHO-ENT (O level). Accordingly, MED and GP should be located close to each other, but ignoring this is still acceptable. In addition, all departments can be classified into two groups: MED-PED-GP and SUR-ORTHO-ENT. Not only the degree of closeness was considered, but the discussion among hospital specialists was also taken into account for designing test scenarios. Subsequently, six scenarios were designed in Table 1.

Table 1. Detail of each test scenario.

Scenario	1st Floor (7 rooms)	2nd Floor (8 rooms)	Note
A	**MED – 4 rooms*** **GP – 2 rooms*** **PED – 1 room**	**SUR – 1 room** **ENT – 2 rooms** **ORTHO – 2 rooms**	MED – 4 rooms GP – 2 rooms ENT – 2 rooms ORTHO – 2 rooms SUR – 1 room PED – 1 room - **Bold letters** indicate the plan according to the results from relationship analysis. - (*) indicates pair of MED and GP. - Scenario B, E, F were designed based on the hospital specialists' perspectives.
B	MED – 3 rooms* GP – 2 rooms* ORTHO – 2 rooms	MED – 1 room SUR – 1 room ENT – 2 rooms PED – 1 room	
C	MED – 2 rooms **ENT – 2 rooms** **ORTHO – 2 rooms** **SUR – 1 room**	**MED – 2 rooms*** **GP – 2 rooms*** **PED – 1 room**	
D	GP – 2 rooms **ENT – 2 rooms** **ORTHO – 2 rooms** **SUR – 1 room**	MED – 4 rooms PED – 1 room	
E	GP – 2 rooms ENT – 2 rooms ORTHO – 2 rooms PED – 1 room	MED – 4 rooms SUR – 1 room	
F	GP – 2 rooms ORTHO – 2 rooms SUR – 1 room PED – 1 room	MED – 4 rooms ENT – 2 rooms	

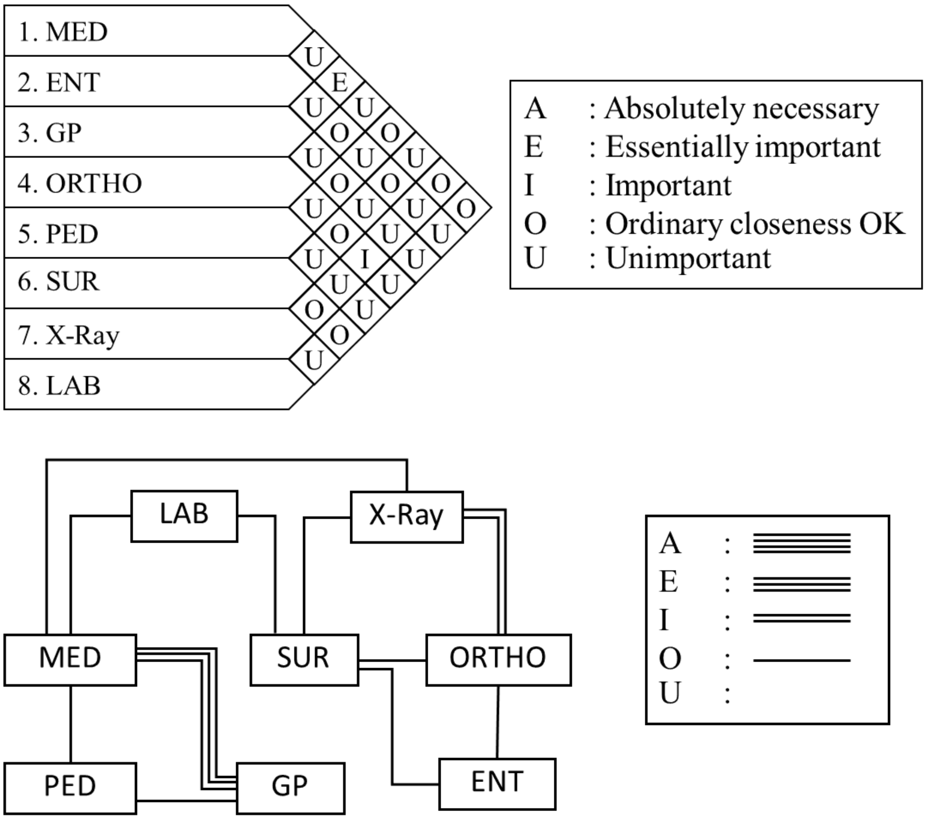

Fig. 2. Activity relationship chart and relationship diagram of OPD

RESULTS

Simulation tests were conducted with the same initial parameters, 9 hours per day with 64 replications, 95% CI of mean total time in the system of all scenarios, as compared in Figure 3.

As shown in Figure 3, scenarios B and C were dominated by F because F has less mean time than B and C significantly, scenarios B and C can thus be eliminated. While scenario A, D, E, and F were further considered because their intervals overlapped (which means they are not significantly different). Then, performance measurements for all departments were compared using 95% CI of mean comparison as in Figure 4.

The comparison results (shown in Figure 4) presented no significant differences among A, D, E, and F for most departments excluding PED. If considering only PED, the mean time of scenario D is longer than the scenario A, E, and F significantly. Hence, the scenario D was dominated. Thus, the appropriate solutions were A, E, or F.

Considering A, E, and F, similar design issues can be noticed as follows.

- 4 rooms of MED should be located on the same floor.
- PED should be located on the 1st floor.

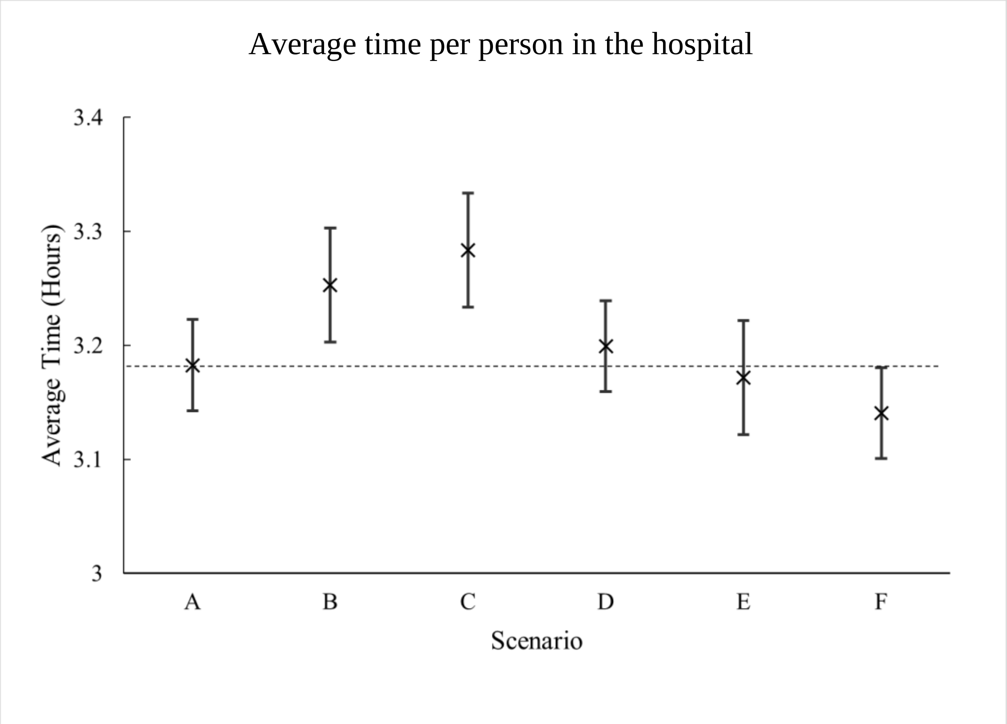

Fig. 3. 95% CI of mean total time in system comparison.

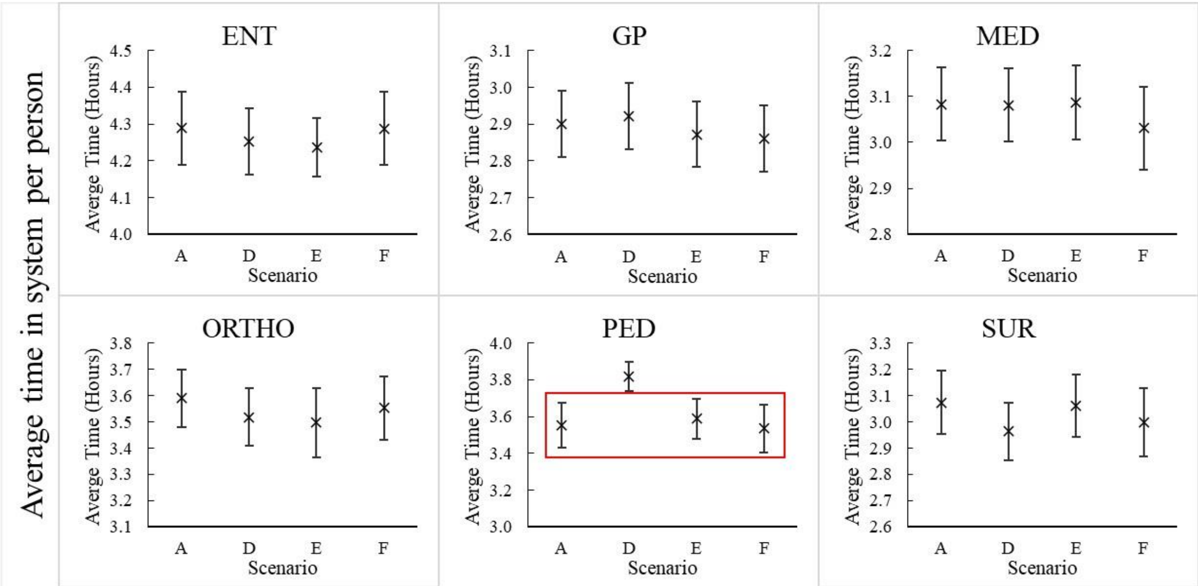

Fig. 4. The interval plot of average time in a system A, D, E, and F (95% CI).

DISCUSSION

From the simulation tests, scenarios A, E, and F were selected to be the appropriate solutions. Therefore, these three layouts were presented to the hospital management team for final decision and selection. From the meeting among researchers and the hospital team, layout A was selected to be implemented. It is because in scenario A, MED and GP – the units that work together highly frequently – were placed close to each other on the same floor. Then, the 1st floor includes MED (4 rooms), GP (2 rooms), and PED (1 room), while the 2nd floor includes SUR (1 room), ENT (2 rooms), and ORTHO (2 rooms).

For the real implementation of the scenario A, the following issues were considered:

(1) The proportion of patients between the 1st and 2nd floors were imbalanced at a ratio of 75.2% and 24.8%.

(2) All rooms on the 1st floor are occupied and three rooms on the 2nd floor are available for future service extension.

(3) Support units including X- ray, registration centre, pharmacy, and financial counter were set on the 1st floor. When the number of patients increases, some supporting units should be added, especially X-ray, which currently operates with high utilization (more than 95% from simulation results).

Practice Implementation

Since the end of 2019, the new building of the hospital case study has been operated and scenario A was implemented. Nevertheless, the hospital has more service data of OPD, the plan was therefore adjusted from scenario A as follows:

(1) For the 1st floor, the rooms for GP were increased from 2 to 4 rooms and the rooms of MED were decreased from 4 to 3 rooms because every patient who comes to the hospital without obvious symptoms will be served at GP before they are sent to other departments. Thus, GP was determined to have more examination rooms on the first floor. PED with a less strong relationship compared to GP and MED was moved to the 2nd floor due to the limited number of rooms on the 1st floor (7 rooms).

(2) For the 2nd floor, the rooms for SUR and ENT were the same as scenario A, which were 1 and 2 rooms, respectively. The rooms for ORTHO were increased from 2 to 3 rooms. Including 1 relocation room of PED, the 2nd floor utilized 7 of 8 rooms. The remaining one room was occupied for the new department since the hospital extended the OPD service unit.

(3) In addition, to reduce the overcrowding problem, support units including the registration centre and financial counter were set up on the 2nd floor to serve the patients.

CONTRIBUTION, IMPLICATIONS AND LIMITATIONS

This study can contribute to academic literature because it demonstrates the application and combination of the ARA and simulation technique in the design of a multi-floor OPD layout. This aspect is limited in existing studies because most studies focus mainly on the application of these techniques in a single floor layout design.

In terms of the practical implication, the results of this study show how the ARA and simulation successfully help to design the hospital layout which can be applied in other contexts. As known, to design the hospital layout based mainly on the experience of the hospital specialists, all important aspects may not be included in the design, such as the relations and flows between different service units. Once the layout is implemented and not suitable for the hospital, it is difficult to modify and, if modified, it is costly. On the other hand, when the design techniques, such as the simulation and ARA, are applied, all aspects are considered systemically. In addition, the simulation can help to determine the correctness and efficiency of the design before actual implementation. The simulation can further help to investigate any effects resulting from the change of some conditions. For example, if the number of patients increases, the simulation runs can demonstrate whether or not the designed layout is still suitable for those number of patients or it needs to be modified.

In hospitals, especially in developing countries like Thailand, the patients normally go to the hospital without appointments with the doctors and they sometimes need medical investigation and treatment from different healthcare service units at a time. This situation may lead to a high unplanned number of patients in the hospital waiting for medical treatment. Hence, the ARA technique that considers the relations between different service units and the use of hospital resources is suggested to be used in the layout design of this kind of hospital, as demonstrated in this research.

Different hospitals may have differences in the relations between healthcare service units, the use of resources, and the limitations of areas. The OPD layout designed in this research was also based on those of the case study hospital. According to these different conditions, further studies that apply approaches similar to this research may have different layouts depending on the conditions of the hospitals they consider.

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ORIGINAL PAPER

FORECASTING NEEDS OF THE OPERATIONAL ACTIVITY OF A LOGISTICS OPERATOR

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ABSTRACT. Background: The paper considers the issue of operational needs of logistics operator connected with the implementation of demand forecasting tool in his activity. The aim of this article is to present research results on the ability to meet the expectations of distribution centre managers at the operational level. To achieve the main goal, three research questions concerning general requirements and possibilities of meeting the requirements set by managers working for a logistics operator were also defined and related to operational needs.

Methods: The research analysed the operational requirements of a logistics operator using a survey conducted among managers dealing with the operational work that is performed in the operator's warehouses. Then, the possibility of implementing and operating a forecasting tool based on the ARIMA algorithm in the logistics service of a confectionery manufacturer was analysed, providing the verification of usefulness of such a tool and the level of its adjustment to operational requirements.

Results: The forecasting tool is especially useful in the operator's activity in order to support the resource planning process of warehouse operation. However, managers set high requirements regarding the verifiability of the operation of such a tool, which is not completely available in the current situation. The article also shows the future development paths of this tool.

Conclusions: The article shows possibilities related to the use of a forecasting tool in activities related to the provision of services in contract logistics. This allows for verification of the needs and capabilities of the logistics operator who would forecast the demand to support the operations it carries out.

Keywords: 3PL, logistics operator, demand forecasting, distribution network

INTRODUCTION

In distribution networks and other economic practices, it can be concluded that an event will occur if [Alevizos et al. 2018]: it has already occurred in the past, its occurrence frequency would indicate it, or is indicated by a strong correlation with another event or events that have already occurred or are going to occur. The phenomena occurring in the systems can be defined by means of quantitative (expressed in quantities) and qualitative (expressed in descriptive terms) variables. Forecasting is the process of determining the most likely prediction of the future level of demand with a given set of assumptions [Moon, 2000] consisting in statistical inference integrated with the analysis of events, phenomena and facts that have happened in the past. The methods and types of forecasting are a frequently discussed area in the literature. There are many criteria and many attempts to group the methods in it. And so: one of the more general characteristics of forecasting models assumes their division into 3 main, most significant types: judgemental forecasts,, cause-and-effect forecasts and forecasts based on the analysis of time series. The main purpose of forecasting is to support decision-making processes, and the forecast itself is an action that is to prepare other activities, and therefore lead to the path choice the enterprise wishes to follow.

Forecast is considered a necessary source of information for the preparation of logistics plans [Panahifar et al. 2015], including plans related to distribution and cooperation in distribution networks, and inventory in both distribution

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networks and supply chains should usually be treated as the final mechanism to balance supply and demand [Szozda and Świerczek 2016; Westcott 2004]. Forecasting is considered to be one of the key elements of organisational management and one of the risk categories [Kramarz, 2013; Morris et al. 1988] in material flows. It affects the determination of production capacity and methods of production and provision of services and thus also affects elements such as the number of employees, the level of costs, etc. indirectly. The risk factors related to forecasting are: their imprecision, seasonality, product differentiation, short product life cycle, small customer base, and information distortion [Kim et al. 2012; Subramaniam, 2021]. Demand fluctuations may imply problems with inventory management and create a tendency to maintain excessive inventories (this briefly applies to each type of inventory, i.e., cyclical, safety, in transit, and speculative inventory [Barlas and Gunduz 2011]. Forecasts are always burdened with some errors. They never describe a given phenomenon with 100% accuracy. The uncertainty of demand forecasts arises from facts indicating that enterprise will never have complete information on buyers, competitors' initiatives may affect the actions taken, and the environment is uncontrolled by the company and may change [Alevizos et al. 2018]. Forecasting is undoubtedly useful in the case of Make-To-Stock (MTS), but it can also be used in the case of Make-To-Order (MTO) to forecast e.g. standard components [Kalantari et al. 2011]. Forecasts in the distribution network determine the quantity of goods to be purchased, produced, or delivered. Forecasts create related processes and operations. Forecasting is of particular importance as one of the means that is used in the process of managing a business, because wrong identification of future trends can have devastating implications for the enterprise. For example, overestimating demand can result in high costs of maintaining excess inventory and high marketing costs for disposal [Martin et al. 2020]. Whereas, for example, underestimating can have such effects as lost sales, loss of reputation and lower level of sales tasks. Knowing about future supply quantities significantly improves planning in all areas of logistics, and the use of flexible and precise forecasting procedures gives the opportunity to obtain good results even in capricious markets, where the practice of ordering through intermediaries distorts the demand of end participants (Subramanian, 2021). One of the functions of the enterprise that forecasting supports is planning and resource management. It is often considered a strategic decision of the company in the area of material resource planning [Wacker and Lumus 2002], but also for human resource planning for work in logistics and production systems [Berk et al. 2019].

However, it should be remembered that the quality of the forecast depends on the process in which the forecasts are formed, as well as its accuracy and [Panahifar et al. 2015]: division of responsibility for forecasts, creation of appropriate forecast formats (horizon, division into periods, frequency of updating , level of detail), methods for measuring said accuracy, and providing a method for converting the forecast to a demand forecast for the entire network and individual elements. As is known, making a forecast is a multistage process [Williams and Waller 2011], which leads to the identification of an appropriate forecasting method on the basis of which further plans will be built. The forecasts themselves are usually input into the demand management system. Demand management is also defined as the process of estimating future demand volumes in order to synchronise activities within a certain enterprise (manufacturing, trading, or service) [Croxton and Lambert 2002]. Demand management facilitates the optimisation of the available capabilities [Broberg and Persson 2015], and is also considered by some authors to be one of the basic processes of the Supply Chain Management (SCM) concept. Many problems that occur in distribution networks directly are believed to be the implication of malfunctioning demand management processes [Fahroiglu and Alvardo 2001]. Thus, it can be concluded that a well-chosen demand management system has a positive impact on the enterprise, but also on its suppliers and customers [Croxton 2002]. The goal of demand management is not so much to generate sales as to provide a set of activities for the most advantageous options [Świerczek 2019; Croxton and Lambert 2002] and focusing on balancing customer requirements with the capabilities of the distribution network.

The aim of this article is to present research results on the ability to meet the expectations of distribution centre managers at the operational level. The starting point is a survey conducted among managers on preferences and expectations in relation to forecasts (what characteristics should the forecast have). The main research questions posed in the article:

RQ1: What requirements does a logistics operator have of the forecasting system in the perspective of its implementation in its operational activities?

RQ2: What benefits to the operational activity of a logistics operator can the implementation of a system for the automatic creation of demand forecasts bring?

RQ3: Is it possible to meet the identified operational requirements of a logistics operator by implementing a forecasting tool in the current form of the operator's operations?

The purpose of the article and the responses to the individual research questions were analyzed on the basis of an analysis carried out at the chosen logistics operator.

METHODS

For the purposes of this article, 60 people who act as operational managers related to warehouse, copacking, and co-manufacturing processes were analysed. The group of chosen managers emerged from the 71 managers who work in the chosen logistics operator. The main research group (71 workers) is the workers which have experience in the logistics management field above 1year and at least 4 years of experience in the work in warehousing logistics. Managers are handling with the processes connected with the operational warehousing activity which are provided by logistics operator like co-packing managing, picking managing and so on. The authors assumed the significance level at 0,05, predicted fraction size as 50% and allowed error as 5% - according to this assumption, the 60 surveyed managers are the enough research sample to conduct the research. These people are directly involved in the operational work in the warehouse and carry out their continuous control. The aforementioned managers are part of the organisational structures of the 3PL logistics operator (third-party logistics). 43 managers (72%) operating in Poland, 11 managers (18%) operating in the Czech Republic, and 6 managers (10%) operating in Slovakia were examined.

The aforementioned logistics operator provides logistic services related to the operation of warehouses, logistic processes, copacking, co-manufacturing, cross-docking and the creation of new logistic solutions for production enterprises. Logistics operator is the international company that provides logistics services (mainly warehousing and creating the added value) for its contract partners (usually manufacturers). Figure 1 shows a simplified diagram of the flows from the producer to the end customer using the operator.

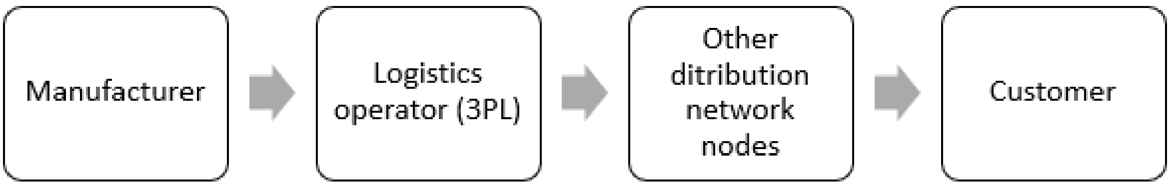

Fig 1. A simplified diagram of material flows in the distribution network using the use of a logistics operator

Source: own elaboration

The logistics operator does not take ownership of the products that are in its warehouse. It conducts logistic flows for the producer as part of contract logistics. The main steps in the article are shown in Figure 2. In this article, terms such as: logistics operator, 3PL, third-party logistics and logistics service provider will be used with the same meaning.

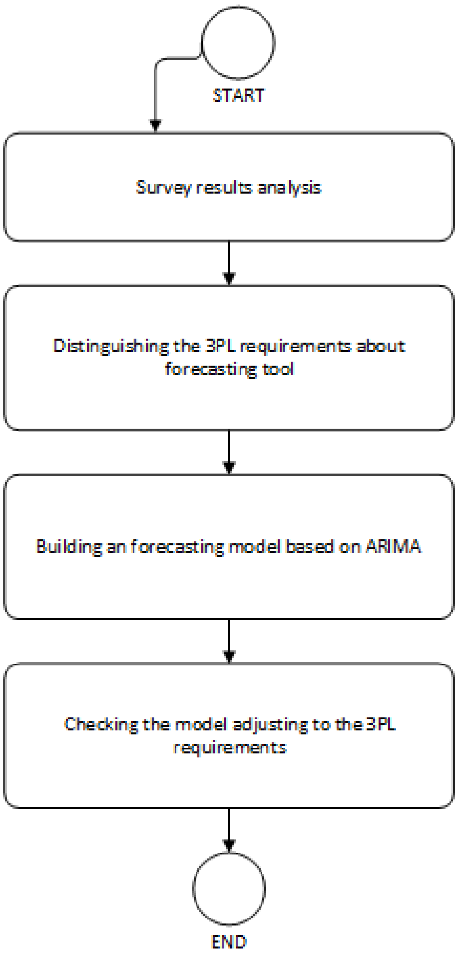

Fig 2. Main research steps

Source: own elaboration

The research was conducted in two stages:

1. Based on the results of the survey, the requirements (expectations of a characteristic) that should be met by the forecasts were defined. In the analysis of the survey results, the following significance level was adopted: 0.05.

2.For the chosen producer (showing the largest variety of products), it was examined to what extent it was possible to meet the expectations of managers.

The first stage concerned the creation and execution of a survey among managers who deal with the management in the operational area of the logistics operator's operations directly. The following questions were created:

Question 1. What degree of aggregation of the forecasting data would correspond to the preferences of operating activities?

Question 2. In what area do you see the greatest chances of using the forecasting tool?

Question 3. What is the maximum error rate for one week (as a percentage) for which the forecast can be considered useful?

Question 4. Please indicate a single most important criterion for the assessment of the forecasting tool in your opinion.

Question 5. Please specify the amount of time that you currently spend daily on inventory planning.

The questions were aimed at identifying the needs of a logistics operator in terms of the possibility of using a forecasting tool in its operational activities and identifying the tool main requirements of the users in the area of data aggregation, the maximum error rate, as well as the measure that should be adopted to measure forecast errors. Furthermore, the survey asked how much time respondents currently spend on planning inventory resources, to also show the potential of using a forecasting tool to improve the resource planning process.

The research in stage 2 covered the following issues: selection of an automatic forecasting model, testing of the selected model, and conclusions on the fit of the model to the operational requirements of a logistics operator. The tests used a cloud-based tool which made the development of forecasts possible based on the ARIMA model supported by elements of machine learning developed by the authors of the programme. The results of these calculations are presented in the article, and then the results were confronted with the operational requirements identified during the survey.

RESULTS

The responses obtained through the survey were analyzed. The first question was related to the degree of aggregation of the forecast, which related the preferences of managers on this topic (Table 1).

Table 1. Answers to question No. 1.

Question 1. What degree of aggregation of the forecasting data would correspond to the preferences of operating activities? [multiple choice questions]		
Responses	**Number of responses**	**Shares in total responses**
Daily forecast for total boxes	47	78,33%
Weekly forecast for total boxes	36	60,00%
Daily forecast of boxes for individual SKUs*	13	21,67%
Weekly forecast of boxes for individual SKUs	16	26,67%
Daily forecast of boxes for individual SKUs, broken down by end recipients	16	26,67%
Weekly forecast of boxes for individual SKUs, broken down by end recipients	13	21,67%
Forecast for amount of pallet space	33	55,00%
Forecast in cubic metres	12	20,00%
Other	3	5,00%
*SKU – Stock Keeping Units		

Source: own elaboration

Boxes are understood as the smallest logistic item that is manipulated in the warehouse. When analysing the answers, the respondents most often stated that the most useful forecast from their point of view would be an aggregated forecast for the total quantities issued from the warehouse, without the need to disaggregate it into a forecast of the size of individual SKU (Stock Keeping Units) or issues to individual destination points (end recipients). The aggregated data was reflected by the largest number of responses, i.e. :

• Daily forecast for total boxes (78.33%).

• Weekly forecast for total boxes (60.00%).

• Forecast for the amount of pallet space (55.00%).

More than half of the respondents indicated only the daily forecast of total boxes, to a significant degree (X-squared = 18.15, df = 1, p-value = 1.021e-05 in one-tailed, 1-sample proportions test with continuity correction) . In the case of weekly forecast, about half of the respondents considered this form of aggregation to be preferred (X-squared = 2.0167, df = 1, p-value = 0.1556 in two-tailed, 1-sample proportions test with continuity correction). Similar results were obtained regarding the forecast for the amount of pallet space (X-squared = 0.41667, df = 1, p-value = 0.5186 in the two-tailed, 1-sample proportion test with continuity correction). Other forms of aggregation are significantly preferred by less than 50% of the respondents.

Other responses related to the aggregation of the forecast results concern the responses related to the forecast in cubic meters. Considering that by adding parameters related to palletisation and dimensions of the boxes, it will be possible to extend the forecast in the future after the count of boxes with the forecast for the amount of pallet space or cubic space, according to the authors, the best solution in the first step would be to develop a collective forecast for the number of boxes, which are issued from the warehouse on individual days. The answers to the next question are presented in Table 2, and these were single choice answers.

Table 2. Answers to question No. 2.

Question 2. In what area do you see the greatest chances of using the forecasting tool?		
Responses	**Number of responses**	**Shares in total responses**
Planning of warehouse resources (number of employees, equipment) for working shifts.	47	78,13%
Planning of transport operations.	8	13,00%
Planning of the warehouse assortment (e.g., support for classic ABC / XYZ methods)	3	5,00%
Correcting forecasts provided by customers	1	2,00%
Other	1	2,00%

Source: own elaboration

The second question concerned the main area of application of a forecasting tool in the operational activity of a logistics operator. Most of responses (78.33%) were related to the use of the forecast results as a tool to support the planning of warehouse resources. Planning of warehouse resources is understood as the need to define in advance an appropriate number of warehouse employees, the necessary warehouse infrastructure (e.g. forklifts, data collectors) to support ongoing warehouse operations. As shown from the results of the questionnaire, the forecasting tool should focus primarily on the fulfilment of this need. The next question was about the maximum error rate that is acceptable in operational activities. Based on the answers of the respondents, it can be concluded that:

• Up to 2% forecast error will meet 100% of operational needs.

• Up to 3% forecast error will meet 92% of operational needs.

• Up to 5% forecast error will meet 88% of operational needs.

• Up to 10% forecast error will meet 50% of operational needs.

• Up to 20% forecast error will meet 7% of operational needs.

Based on the results obtained, errors of 5%, 3%, and 2% were adopted as the key accuracy levels for the forecasts.

The next table (Table 4) contains answers to the fourth question.

Table 3. Answers to question No. 3.

Question 3. What is the maximum error rate for one week (as a percentage) for which the forecast can be considered useful?		
Responses	**Number of responses**	**Percentage of requirements meeting (forecasts lower or equal to response)**
Up to 2%	5	100,00%
Up to 3%	2	91,67%
Up to 5%	23	83,33%
Up to 10%	26	50,00%
Up to 20%	4	6,67%

Source: own elaboration

Table 4. Answers to question No. 4.

Question 4. Please indicate a single most important criterion for the assessment of the forecasting tool in your opinion.		
Responses	**Number of responses**	**Shares in total responses**
The smallest possible deviation of the forecast values (in total) for a given week of dispatches compared to the real value (MAE* for 1 week).	9	15,00%
The smallest possible deviation of the forecast values (in total) for two weeks in advance compared to the real value (MAE for 2 weeks).	11	18,33%
The smallest possible average of the daily percentage differences between the forecast and the real dispatch levels of each week (MAPE** for 1 week).	25	41,67%
The largest possible number of well-matched (with the smallest percentage of deviations) forecasts in individual weeks.	14	23,33%
Other	1	1,67%
*MAE - Mean Absolute Error **MAPE - Mean Absolute Percentage Error		

Source: own elaboration

This question involved the development of a criterion for the evaluation of a forecasting tool. From the analysis of the results and the comparison of the results with previous responses, it can be concluded that the forecasting tool should return the forecast on a daily basis, and errors should be considered in the perspective of a week; it is related to the fact that warehouse resources must be planned at least one week in advance, and large modifications of daily resources are not acceptable. In Question number four, most responses revealed that the lowest MAPE error criterion was for 1 week. Therefore, the authors will use the forecast assessment criteria related to the minimisation of the weekly error along with the minimisation of the differences generated by the daily forecasts that relate to the actual data. Table 5 shows the answers to the next survey question.

Table 5. Answers to question No. 5.

Question 5. Please specify the amount of time that you currently spend daily on inventory planning.		
Responses	**Number of responses**	**Shares in total responses**
Up to 10 minutes	12	20,00%
Up to 30 minutes	28	46,67%
Up to 1 hour	13	21,67%
Up to 1.5 hours	5	8,33%
Up to 2 hours	2	3,33%
More than 2 hours	0	0,00%
Other	0	0,00%

Source: own elaboration

This question was to determine the amount of time each day managers spend on inventory planning. By using the sum of the products and dividing it by the sum of the expected results, it can be estimated that the correct creation, implementation and integration of a forecasting tool will reduce the workload of managers by 29.83 minutes. In turn, this translates into the possibility of reducing their working time on a weekly scale (with a five-day work system) by about 149.15 minutes, and on a monthly basis (assuming an average four-week working month) by about 9.94 hours. It is worth emphasising that although resource planning is not an activity that generates added value, it is necessary for correctly implemented warehouse processes, and therefore its shortening will positively affect the entire operational activity of a logistics operator.

Implementation of the forecasting model to the activities of a logistics operator is possible [Kmiecik 2021], but it requires adjusting the tool to the operator's existing IT infrastructure; in addition, it is also possible for the operator to take over the distribution network coordination function consisting in the use of a forecasting tool, including for conducting stock management actions [Kramarz and Kmiecik 2022]. However, an important part of the operation of a logistics operator will be the ability to adjust the operation and results of the forecasting tool to its current needs, in accordance with the requirements of operational managers. The forecasting tool would be used to aid the current logistics operator's efforts to plan warehouse resources by providing the necessary demand information in advance. This tool would have to:

• Provide the possibility of aggregating forecasts in at least three levels: daily forecast for the total of boxes, weekly forecast for the total of boxes, forecast for the amount of pallet space.

• Provide the ability to create forecasts with the MAPE forecast error at the lowest possible level.

• Be based on minimising the weekly MAPE in the forecast analysis.

The authors of this article decided to use a forecasting algorithm based on the ARIMA model to construct the forecasts. This choice was dictated by the fact that ARIMA models are those that are among the most frequently chosen in research for forecasting demand [Sohrabpour et al. 2020; Chu and Zhang 2003], even as a basis for more sophisticated models related to neural networks [Omar et al. 2016]. The authors created a forecasting tool on a ready-made model based on ARIMA (Figure 3)

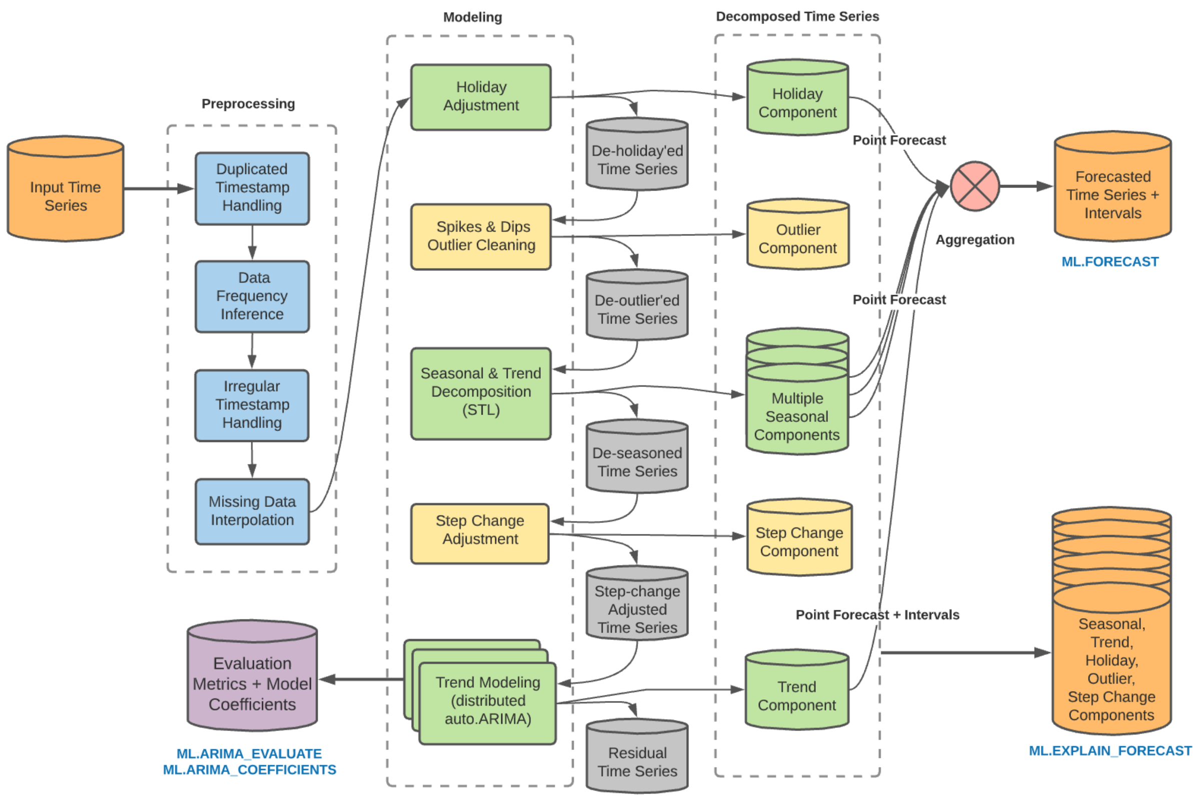

Fig 3. Operation of the selected ARIMA-based model

Source: Google Cloud Documentation (https://cloud.google.com/bigquery-ml/docs/reference/standard-sql/bigqueryml-syntax-create-time-series) [accessed: 10/02/2022]

The model used allows for applying auto frequency to input data, dealing with irregular time intervals, duplicate data, analysing and reducing outliers, and applying the holiday effect.

The analysed data cover a total period of 594 days (86 full weeks) and concern products of a producer operating in the confectionery industry. Data consist of the date related to the activity of the logistics operator in the warehouse, the number of cardboard boxes dispatched, and the amount of pallets that have been prepared and released from the warehouse to the recipient (Figure 4). The data therefore allow for aggregation of the forecast at the level of total boxes and total pallets on a daily and weekly basis.

The analysis was based on the calculation of forecasts in a weekly horizon, assuming that the input data for the analysis was updated once a week. The test period was the last 20 weeks (Figure 5).

The calculation was performed each time using the training set, to which another week was added to calculate the MAPE until the test data limit was reached, i.e. 20 weeks. The matching of the forecasts created in this way is shown in Figure 6.

Additionally, to better show the adjustment of ex post forecasts to the historical time series, Figure 7 only shows graphs reflecting the test periods of time series and the size of forecasts in relevant periods, without taking into account weekends and holidays for which no dispatches were observed and for which no dispatches were planned.

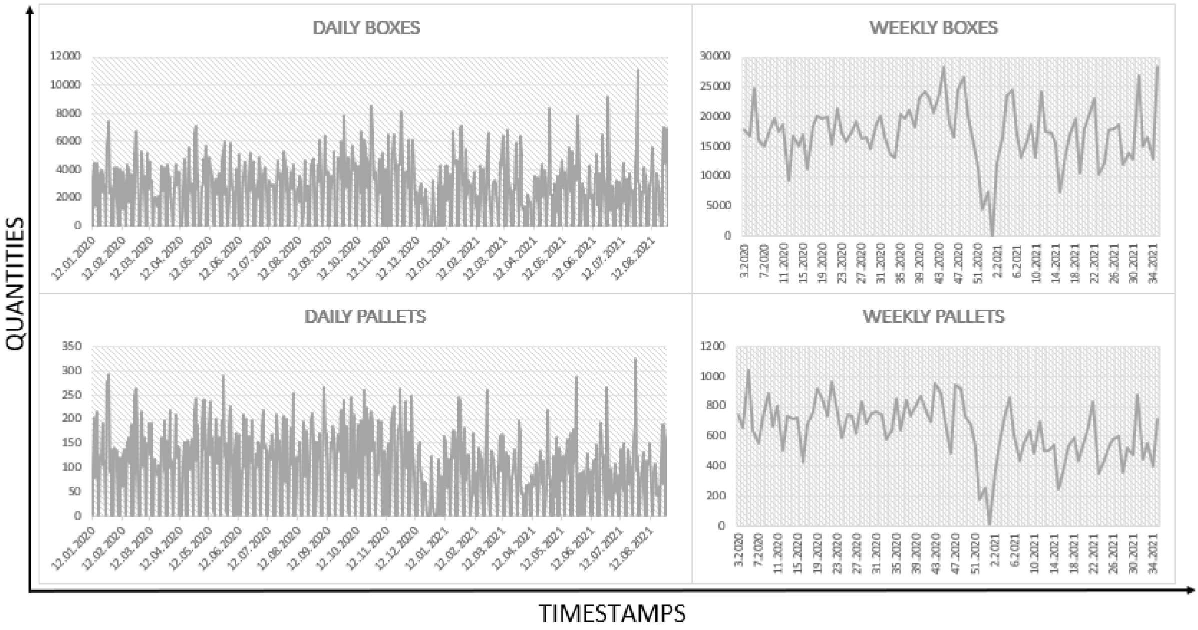

Fig 4. Time series used in the analysis

Source: own elaboration

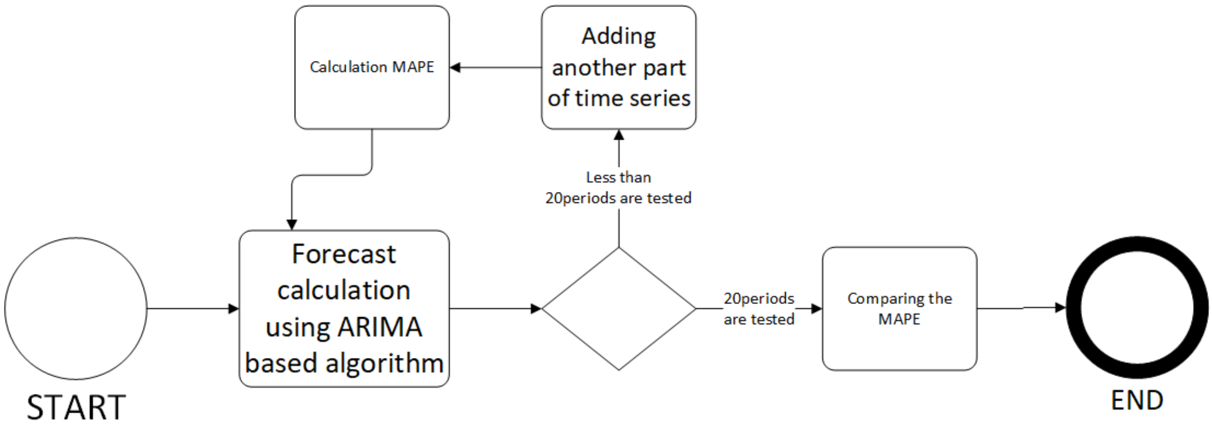

Fig 5. Simplified diagram of the analysis

Source: own elaboration

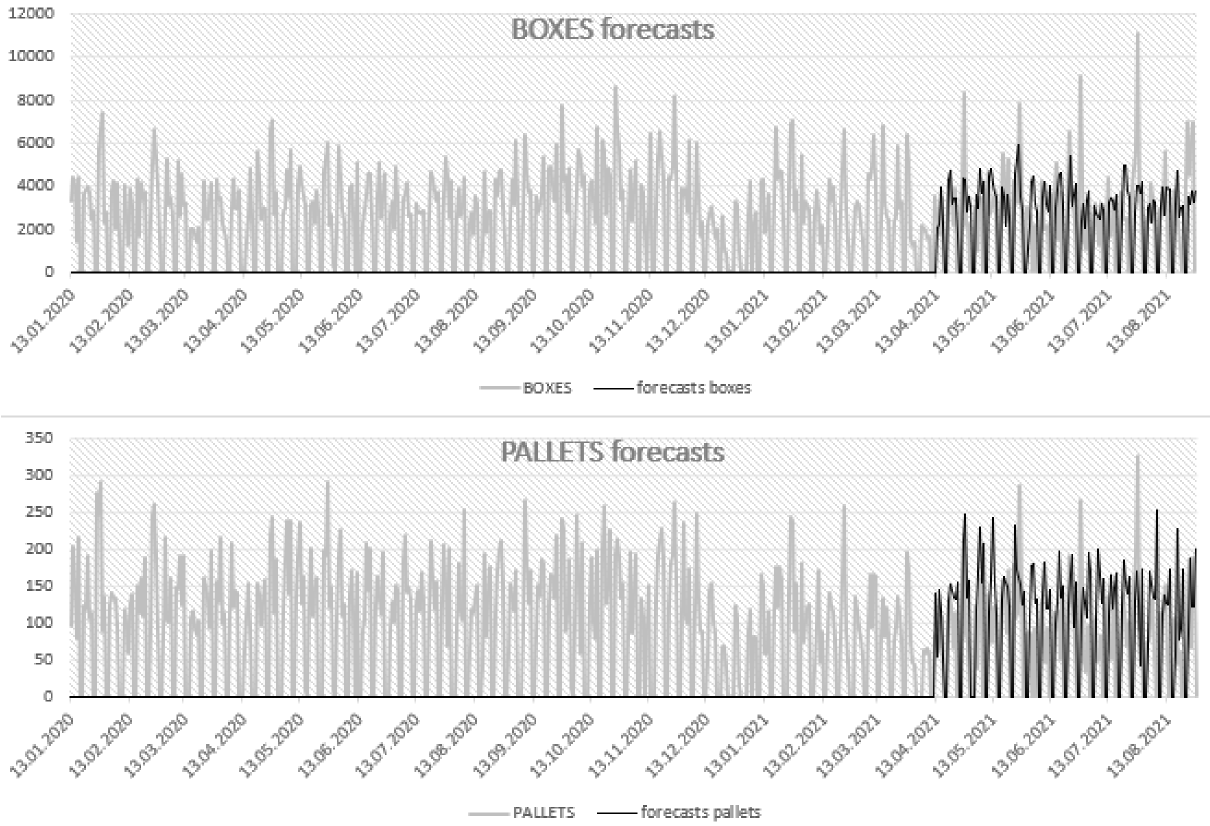

Fig 6. Matching forecasts in boxes and pallets

Source: own elaboration

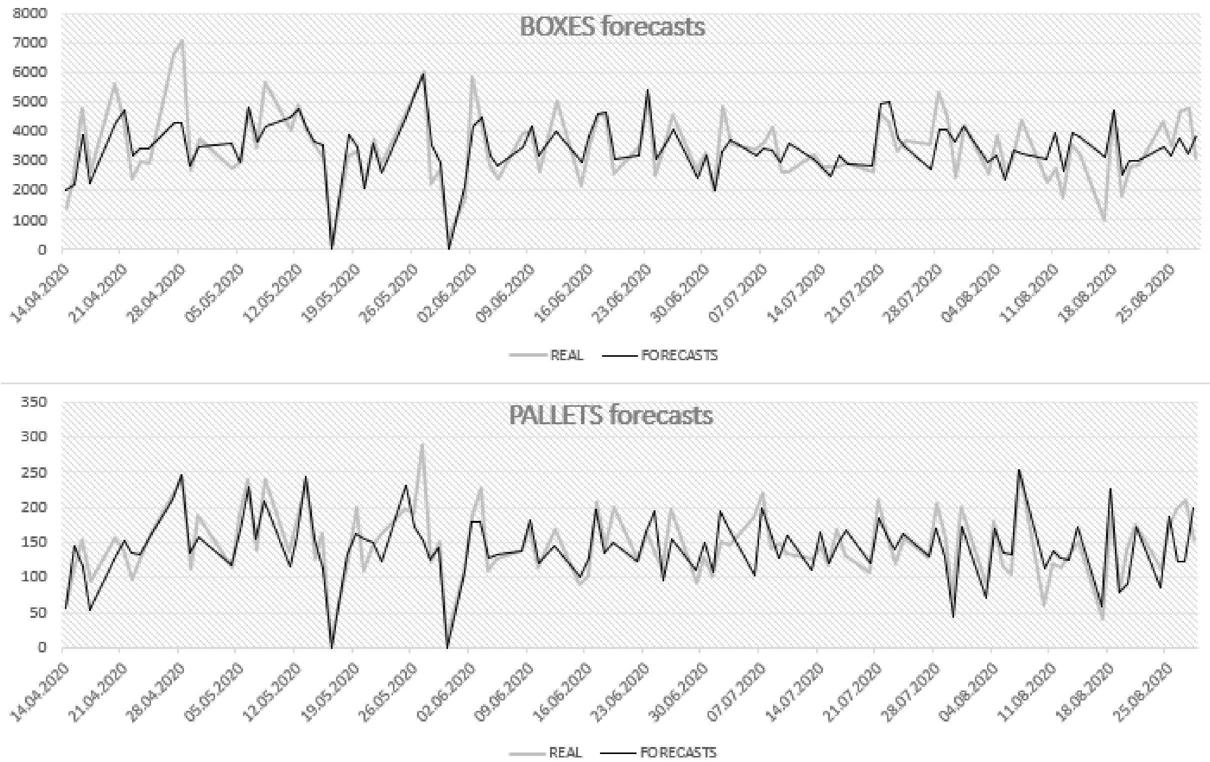

Fig 7. Matching forecasts to test data without weekends and holidays

Source: own elaboration

As the analysis shows, the algorithm used is good at detecting fluctuations in demand and detecting the trend in the time series. According to the requirements presented on the basis of the analysis, the MAPE survey was aggregated into weekly periods (Figure 8).

Based on drawing and analysis, it can be concluded that the average MAPE size covering 20 weeks for boxes is 13.51%, and for pallets 13.04%. Forecast results for both data aggregation units are similar, which indicates the repeatability of the algorithm's operation and its best results accomplishment that could be achieved with the given assumptions. The best forecast result in the test period, which would meet operational requirements in 88%, was achieved in 5% of the forecasts (Table 6).

As the analysis shows, in the current configuration, despite the seemingly high result and a good match of the forecasting algorithm to the data, as much as 15% of the created forecasts would not meet the operational requirements and only about 40% of the forecasts would meet approximately 50% of the requirements.

Table 6. Comparison of weekly MAPE and operational requirements

Characteristics of forecasts	Percentage of forecasts in test periods	
	BOXES	PALLETS
Meet the requirements of 100%	0.00%	0.00%
Meet the requirements of 92%	0.00%	0.00%
Meet the requirements of 88%	5.00%	5.00%
Meet the requirements of 50%	40.00%	35.00%
Meet the requirements of 7%	85.00%	85.00%
Don't meet the requirements	100.00%	100.00%

Source: own elaboration

DISCUSSION AND CONCLUSIONS

The forecasts developed by a logistics operator in its operational activities may be of greatest importance in the area of supporting warehouse resource planning. The currently proposed forecasting algorithm meets the assumption of creating automatic forecasts and the assumption related to the possibility of aggregating forecasts in terms of daily and weekly forecasts. Additionally, the proposed solution makes it possible to create forecasts for boxes and pallets, in accordance with operational requirements. The article also shows a comparison of MAPE for the created forecasts. The results were mainly related to the average weekly errors and compared with the operational requirements of the logistics operator. The biggest issue with operating the forecasting tool is the problem of insufficient adjustment of forecasts to operational requirements (Figure 9).

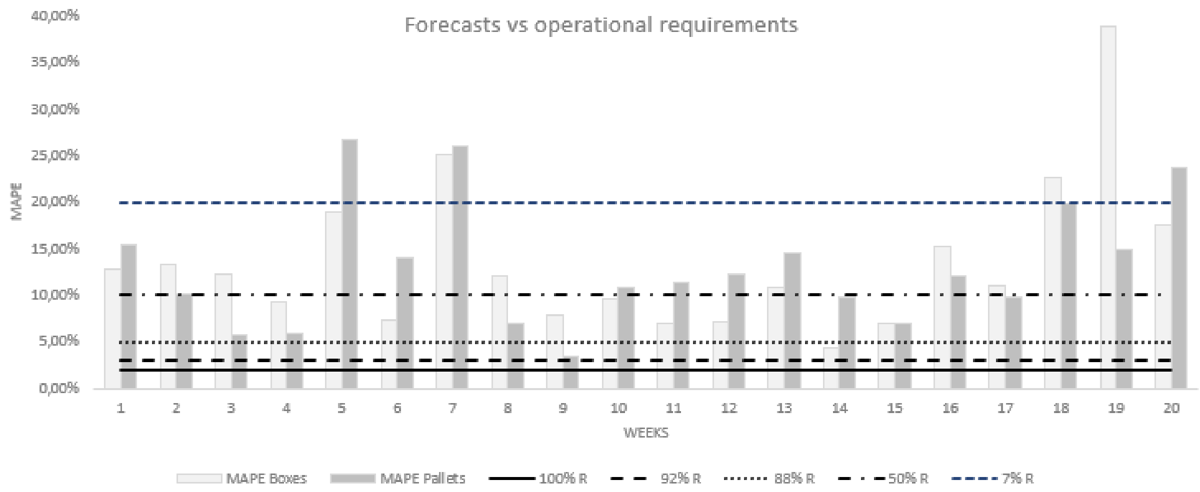

Fig 8. Forecasts compared to identified requirements

Source: own elaboration

The algorithm considered did not meet the requirements set for it by the managers working for the selected logistics operator during the testing period. The reason for this state of affairs, and at the same time directions for further considerations and improvements in this area, could be the following.

• Insufficient quality of input data for the forecast model. The operator relies on disturbed data on the size of the end customer's demand, this is due to the place that the operator occupies in the distribution network and the ineffective system of information flow between various links in the network. This problem could be solved by developing appropriate methods of cooperation and the use of modern methods related to the improvement of information flow.

• Unrealistic requirements of managers with regard to the current possibilities of predicting the size of demand and its consequences. Currently, the operator does not use any forecasting tool, and the results related to underestimating or overestimating the size of demand are not collected and analysed, and thus are not easily measurable. Perhaps the forecast results provided by the current solution would be sufficient to improve the current state of resource planning. A way to test this state of affairs could be to conduct a pilot study using the current solution and to check the results and benefits it brings in practice.

• Poorly functioning forecasting algorithm. This can be solved by implementing other forecasting algorithms into the calculations and selecting a more tailored algorithm based on their matching to the established algorithm training areas. Additionally, an option related to, e.g., searching for the appropriate time window for creating a forecast training area may be considered here [Wolny and Kmiecik 2020].

However, the usage of ARIMA models gives the opportunity to create the proper forecasting system. ARIMA models are often explored in the research [Sohrabpour et al., 2021; Chu & Zhang, 2003], even as a basis for more advanced forecasting attitudes connected, for example, with artificial neural networks [Bayraktar et al., 2007]. It seems that the proper prospect for development will also be to use an ARIMA with support of generic programming [Skohrabpour et al., 2021] or with additionally ANOVA analysis [Bayraktar et al., 2007]. The logistics operator has a strong predisposition to start with the demand forecasting [Kramarz and Kmiecik, 2022], but operators are the most frequently associated with forecasting due to the fact that operators often forecast the financial profitability of some projects [Wang et al., 2018]. Very often, operators are considered as units that forecast demand in the area of transport operations or forecasts of cross-docking activity [Grzelak et al., 2019], but it is not an implementation approach from the perspective of the usefulness of this function for the entire distribution network, and is more based on the appropriate use of data occurring in 3PL companies. In summary, it is possible to create a forecasting tool used by a logistics operator to forecast demand for operational needs. The logistics operator itself, implementing a forecasting tool, would operate under risk conditions. Minimizing this risk would mainly consist of improving the methods that the operator would use to create forecasts and in developing the operator's analytical skills in the field of demand forecasting. However, the area to focus on is the area related to the possibility of reducing the forecasting errors that such a solution generates.

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ORIGINAL PAPER

A COMBINATION K-MEANS CLUSTERING AND 2-OPT ALGORITHM FOR SOLVING THE TWO ECHELON E-COMMERCE LOGISTIC DISTRIBUTION

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ABSTRACT. Background: The rise of e-commerce in the community makes competition between logistics companies increasingly tight. Every e-commerce application offers the convenience and choices needed by the community. The Two-Echelon Vehicle Routing Problem (2E-VRP) model has been widely developed in recent years. 2E-VRP makes it possible for customers to combine shipments from several different stores due to satellites in their distribution stream. The aim of this paper is to optimize a two-echelon logistics distribution network for package delivery on e-commerce platforms, where vans operate in the first echelon and motorcycles operate in the second echelon. The problem is formulated as 2E-VRP, where total travel costs and fuel consumption are minimized. This optimization is based on determining the flow in each echelon and choosing the optimal routing solution for vans and motorcycles.

Methods: This paper proposes a combination of the K-means Clustering Algorithm and the 2-opt Algorithm to solve the optimization problem. Many previous studies have used the K-means algorithm to help streamline the search for solutions. In the solution series, clustering is carried out between the satellite and the customer in the first echelon using the K-means algorithm. To determine the optimal k-cluster, we analyzed it using the silhouette, gap statistic, and elbow methods. Furthermore, the routing at each echelon is solved by the 2-opt heuristic method. At the end of the article, we present testing of several instances with the different number of clusters. The study results indicate an influence on the determination of the number of clusters in minimizing the objective function.

Results: This paper looks at 100 customers, 10 satellites, and 1 depot. By working in two stages, the first stage is the resolution of satellite and customer problems, and the second stage is the resolution of problems between the satellite and the depots. We compare distance and cost solutions with a different number of k-clusters. From the test results, the number of k-clusters shows an effect of number and distance on the solution.

Conclusions: In the 2E-VRP model, determining the location of the cluster between the satellite and the customer is very important in preparing the delivery schedule in logistics distribution within the city. The benefit is that the vehicle can divide the destination according to the location characteristics of the satellite and the customer, although setting the how many clusters do not guarantee obtaining the optimal distance. And the test results also show that the more satellites there are, the higher the shipping costs. For further research, we will try to complete the model with the metaheuristic genetic algorithm method and compare it with the 2-opt heuristic method.

Keywords: two echelon vehicle routing problem, e-commerce, logistic distribution, K-means clustering, 2-opt algorithm

INTRODUCTION

Since e-commerce is present in the community, trading habits have changed. Now people can shop only from home. E-commerce facilitates and finds solutions to shopping in the community. Technological developments have changed the logistics distribution model. In real life, people need innovative logistics delivery offers to minimize shipping costs [Rana et al. 2019]. Moreover, the 2E-VRP model has been widely developed to streamline logistics distribution [Leon, Cristina 2020]. This model is

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widely used to combine delivery with satellites in the stream (Li et al. 2020). The 2E-VRP model has been increasingly developed by Breunig et al. [2019], Redi et al. [2020], Yan et al. [2020], Li et al. [2021], and Zhang et al. [2021]. 2E-VRP is a simplified form of the multi-echelon VRP problem. Where in this model do the work in two stages. Uniquely, this model requires a satellite as a temporary stopover for goods. Satellites can be developed to sort and merge shipments from multiple depots. This allows customers to combine shipments from several different depots.

In logistics delivery in cities, most shipments use vans [Chen et al. 2021] and motorbikes [Lee et al. 2020] to deliver small items. This article will discuss two types of vehicles used, namely vans in the first echelon and motorbikes in the second echelon. In the logistics competition, logistics companies must provide options to customers in dealing with shipping costs [Erniyati, Citra 2019, Rahman, Asih 2020]. One of them is to combine shipping. Customers do not need to order goods repeatedly. The Two Echelon Vehicle Routing Problem (2E-VRP) model is recommended for this case. This study aims to minimize travel costs, satellite loading and unloading costs, and fuel consumption.

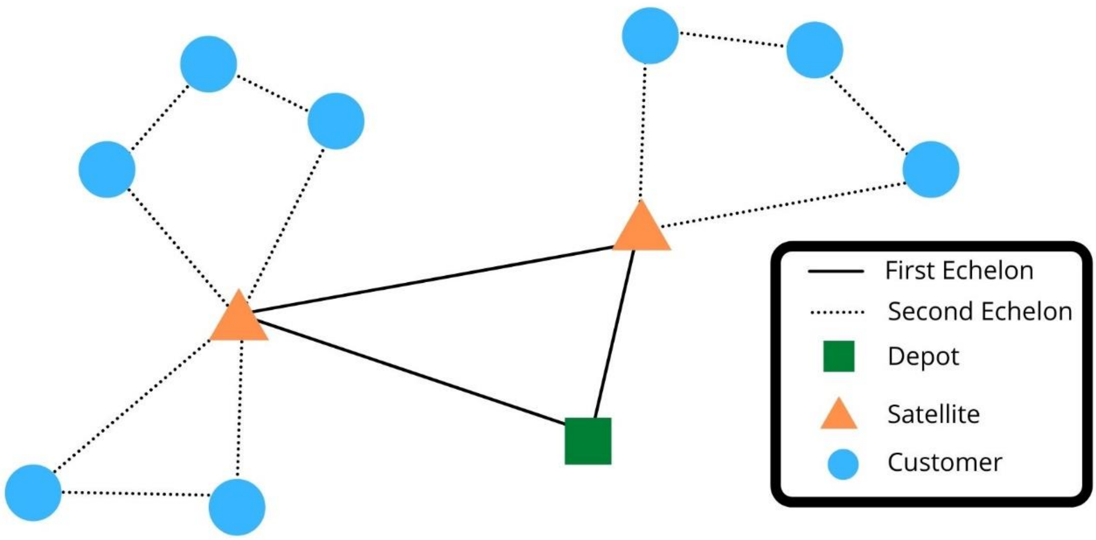

Fig 1. Illustration of 2E-VRP

In general, the 2E-VRP model can be seen in Figure 1. The flow in the first echelon is represented as a relationship between the depot and the satellite. At the same time, the flow in the second echelon is represented as a connection between the satellite and the customer. The first echelon uses vans to distribute goods to each satellite. The van will depart from the depot around the satellite and return to the depot. The van has the capacity to transport goods. In the second echelon, the vehicles used are motorcycles. The vehicle departs from the satellite visiting the customer and will end up on the satellite again. Motorcycles have the capacity to carry logistics.

Motorcycle vehicles can only able to carry a small number of logistics. Therefore, it is necessary to cluster between satellites and customers so that the vehicle will send priority to customers in its cluster. Many studies on VRP have conducted clustering first, including Sabo et al., [2020], Rizkallah et al. [2020], Akhand et al. [2017]. In this research, we use K-means to cluster in the second echelon. In determining the optimal cluster, it can be analyzed using the silhouette method [Saputra et al. 2020], elbow method [Shi et al. 2021], and the gap statistic method [El-Mandouh et al. 2019].

After the clustering process is performed, the routing problem is solved using the 2-opt heuristic method. Many studies in the VRP field use the 2-opt method, including Barma et al. [2019], Kovacs et al. [2020], Xia et al. [2021], Agardi et al. [2021], and McNabb et al. [2015]. At the end of this paper, we will test the benchmark data to optimize distance and total cost.

METHODOLOGY

In this research, there are two stages in the completion. The first to solve problems in the second echelon first then solve problems in the first echelon.

Initial Stage

Before performing the clustering stage, enter the latitude and longitude location points from the set of satellites and customers. Then calculate the distance between the points using the Euclidean distance.

$$\text{Distance}=\sqrt{\left(S_{sx}-S_{cx}\right)^{2}+(S_{cx}-S_{cy})^{2}} \quad (1)$$

The first step is to cluster first using K-means before going to the routing stage. It is necessary to analyze how many clusters are used. We analyzed using the silhouette method, gap statistics, and SSE values to determine optimal and natural clusters [Ikotun et al. 2021]. After obtaining the most optimal k clusters, the next step is to cluster using the K-means algorithm with the satellite as the centroid. In terms of seeing the process, it can be seen in the pseudocode of K-means, which can be seen below.

Pseudocode K-means Algorithm

Inputs:

1. Number of clusters,
2. Satellite and customer location data.

Output: A set of k clusters.

Procedures:

1. **Choose** any k point objects from the customer set, the satellite point as the center of the initial cluster;
2. **Repeat**
3. **Back** selects each point from the set of customers to the cluster with the most similar point distance, based on the average value of the distance of the points in the cluster;
4. **Improve** cluster facilities, namely calculating the average point distance value for each cluster;
5. **Stop** if there is no change

After obtaining a set of k clusters, the set of k clusters between satellites and customers, the customer objects in the cluster will be visited by vehicles from the satellite.

Advanced Stage

After obtaining k sets of clusters, the destination will be obtained by the vehicles in each cluster. This paper uses the 2-opt heuristic method to solve the routing problem. The 2 opt method is widely used in completing routing [Englert et al. 2014, Hougardy et al. 2020]. The pseudocode of the 2-opt can be seen as the pseudocode below.

Pseudocode 2-opt Algorithm

Input: Satellite and customer location points

Output: The Shortest Distance

Procedures:

1. **Choose** a point starting from any point
2. **Do** a tour by looking for the nearest point as done in the Nearest Neighbor method
3. **Move** two new sides to different sides with the same point.
4. **Compare** the previous total distance with the new one ;if it is a new tour, it is better to choose a new tour.
5. **Repeat**
6. **Stop** if the old tour is better than the new one.

The heuristic algorithm above calculates the routing in the first echelon and the second echelon. Once obtained, it will enter the last stage to minimize the objective function, which is the last step in this paper.

Final Stage

After obtaining optimal routing, the next step is to minimize travel costs, satellite loading and unloading costs, and fuel consumption. In this final stage, we will also test the 2E-VRP model in 100 customers, ten satellites, and one depot with different values of k clusters and make a hypothesis on how significant the effect of clustering is on the total distance generated.

PROBLEM DESCRIPTION AND MATHEMATICAL MODEL

Problem Description

In this 2E-VRP model, two types of vehicles are used; namely, the first echelon uses a van and the second echelon uses motorcycles to send packages to customers. There are two levels of work. The first level is called the first echelon, which is denoted , and the second level is called the second echelon, which is denoted by . is the nodes of the depot, is the set of satellites, and is the set of customers. The purpose of this research is to minimize travel costs, satellite loading and unloading costs, and fuel consumption. 2E-VRP can be denoted as graph G= (S,A). Notation is a set of direct edges, which is called a route that connects between each node. is the distance traveled by vehicles using vans in the first echelon is the distance traveled by vehicles using motorcycles in the second echelon. is the decision variable for the number of depots used. is the satellite decision variable the number of kth satellites used. Cvan and Cmot are the capacities of vans and motorcycles. mvan and mmot are the set of vans and motorcycles. The summary of the 2E-VRP model is explained as follows:

1. There are two types of vehicle, namely vans and motorbikes.

2. In the first echelon, the vehicles used are vans, and in the second echelon, motorbikes are used.

3. In the first echelon, the vehicle departs from the depot, moves to surround the satellite, and then returns to the depot.

4. In the second echelon, vehicles depart from each satellite to visit customers and return to the depot.

5. Each customer is served by one motorcycle vehicle in the second echelon.

6. Each customer is served by one satellite.

7. The objective function of this model is to minimize travel costs, satellite loading and unloading costs, and fuel consumption.

Mathematical Model

$$\min \sum_{i\in L_1}\sum_{j\in L_1} CV_{ij}^{van}\mu_{ij}^{van}x_{ij}^{van} + \sum_{k\in S_s}\sum_{i\in L_2}\sum_{j\in L_2} CV_{ij}^{mot}\mu_{ij}^{mot}y_{ijk}^{mot} + \sum_{k\in S_s} UL_k \sum_{j\in S_c} D_k + \sum_{k\in S_0}\sum_{i\in L_1}\sum_{j\in L_1}\zeta_{ij}\mu_{ij}^{van}x_{ij} + \sum_{k\in S_S}\sum_{i\in L_2}\sum_{j\in L_2}\eta_{ij}\mu_{ij}^{mot}y_{ijk}^{mot}, \quad (2)$$

With

$$D_k = \sum_{j\in S_c} d_j z_{kj}, \forall k\in S_s, \quad (3)$$

$$\sum_{j\in L_1} x_{0j} \le m^{van}, 0 \in S_0 \quad (4)$$

$$\sum_{i\in S_s} x_{ik} = \sum_{i\in S_s} x_{ki} \ \forall k\in L_1, \quad (5)$$

$$\sum_{k\in S_s}\sum_{j\in S_c} y_{kj}^{mot} \le m^{mot}, \quad (6)$$

$$\sum_{j\in S_c} y_{kj}^{mot} \le m_{s_k}^{mot} \forall k\in S_s, \quad (7)$$

$$\sum_{j\in S_c} y_{kj}^{mot} = \sum_{j\in S_c} y_{jk}^{mot} \forall k\in S_s, \quad (8)$$

$$\sum_{i\in L_1, i\neq j} R_{ij}^{van} - \sum_{i\in L_1, i\neq j} R_{ji}^{van} = \begin{cases} D_j & \text{if j not a depot} \\ \sum_{i\in S_c} - d_i & \text{otheriwise} \end{cases} \ \forall j\in L_1, \quad (9)$$

$$\sum_{i\in S_s\cup k, i\neq j} R_{ij}^{mot} - \sum_{i\in S_s\cup k, i\neq j} R_{ji}^{mot} = \begin{cases} z_{kj}d_j & \text{if j not a satellite} \\ -D_i & \text{othewise} \end{cases} \ \forall j\in L_2, \ \forall k\in S_s \quad (10)$$

$$R_{ij}^{van} \le C^{van}x_{ij}^{van}, \forall i,j\in L_1, i\neq j, \quad (11)$$

$$R_{ijk}^{mot} \le C^{mot}y_{ijk}^{mot} \ \forall i,j \in L_2, i\neq j, \forall k\in S_s, \quad (12)$$

$$\sum_{i\in S_s} R_{iS_0}^{van} = 0, \quad (13)$$

$$\sum_{j\in S_c} R^{mot}_{jS_s}=0, \tag{14}$$

$$y^{mot}_{ij} \le z_{kj}\ \forall i\in L_2, \forall j\in S_c,\ \forall k\in S_s, \tag{15}$$

$$y^{mot}_{ji} \le\ z_{kj}\ \forall_i \in L_2, \forall j\in S_c, \forall k\in S_s, \tag{16}$$

$$\sum_{i\in L_2} y^{mot}_{ij}=z_{kj} \forall k\in S_s, \forall j\in S_c, \tag{17}$$

$$\sum_{i\in L_2} y^{mot}_{ji}=z_{kj} \forall k\in S_s, \forall j\in S_c, \tag{18}$$

$$\sum_{i\in S_s} z_{ij}=1\ ,\ \forall j\ \in\ S_c, \tag{19}$$

$$y^{mot}_{kj} \le \sum_{l\in L_1} x_{kl}\ \forall k\ \in\ S_s, \forall j\ \in\ S_c, \tag{20}$$

$$y^{mot}_{ij}\in \{0,1\}, z_{kj}\in \{0,1\}, \forall k\in L_1, \forall i,j\in S_c, \tag{21}$$

$$x_{kj}\in \mathbb{Z}^+, \forall k,j\in L_1, \tag{22}$$

$$R^{van}_{ij}\ge 0, \forall i,j, \in L_1, R^{mot}_{ijk}\ge 0, \forall i,j\in L_2, \forall k\in S_s \tag{23}$$

In equation (2), the model's objective function is to minimize travel costs, loading and unloading costs on satellites, and fuel consumption. Moreover, it is added to equation (3) to ensure that the number of customer requests is the same as the goods taken from the depot. Constraint (4) explains that the number of vehicles departing from the depot does not exceed the number of vehicles in the first echelon. Constraint (5) confirms that the vehicle departs and ends at the depot. Moreover, this equation also ensures that the number of vehicles entering and exiting each satellite used is the same as the number of vehicles departing the depot. Constraint (6) ensures that the number of routes used in the second echelon does not exceed the number of vehicles in the second echelon. Constraints (7) ensure that the capacity of the goods on the satellite does not exceed the capacity of the satellite. Constraint (8) guarantees that only one satellite serves the customer. Moreover, this equation also explains that the vehicle starts and ends at the satellite. Constraints (9) guarantee that the number of shipments in the first echelon must be in accordance with all customer requests. Constraints (10) guarantee that the number of deliveries in the second echelon must match all customer requests. Constraints (11) and (12) ensure capacity limits in the first and second echelons. Constraints (13) and (14) guarantee no sub-tour in the first and second echelon. Constraints (15) and (16) guarantee that if customer j is served by satellite k, it will return to that satellite. Constraints (17) and (18) guarantee that a vehicle starting from a used satellite will end up returning to that satellite. Constraints (19) ensure that each customer's request is served by one satellite. Constraint (20) guarantees that the route in the second echelon will start after the service in the first echelon has been completed. Constraints (21), (22), (23) are limiting decision variables.

RESULT AND DISCUSSION

The completion of the 2E-VRP model went through two stages of work. The first step is to complete the routing in the first echelon. This study will analyze the 2E-VRP problem where clustering first performs routing. This research observes one depot, ten satellites, and 100 customers. We can see in Figure 2 the location of the depot, satellite, and the customer.

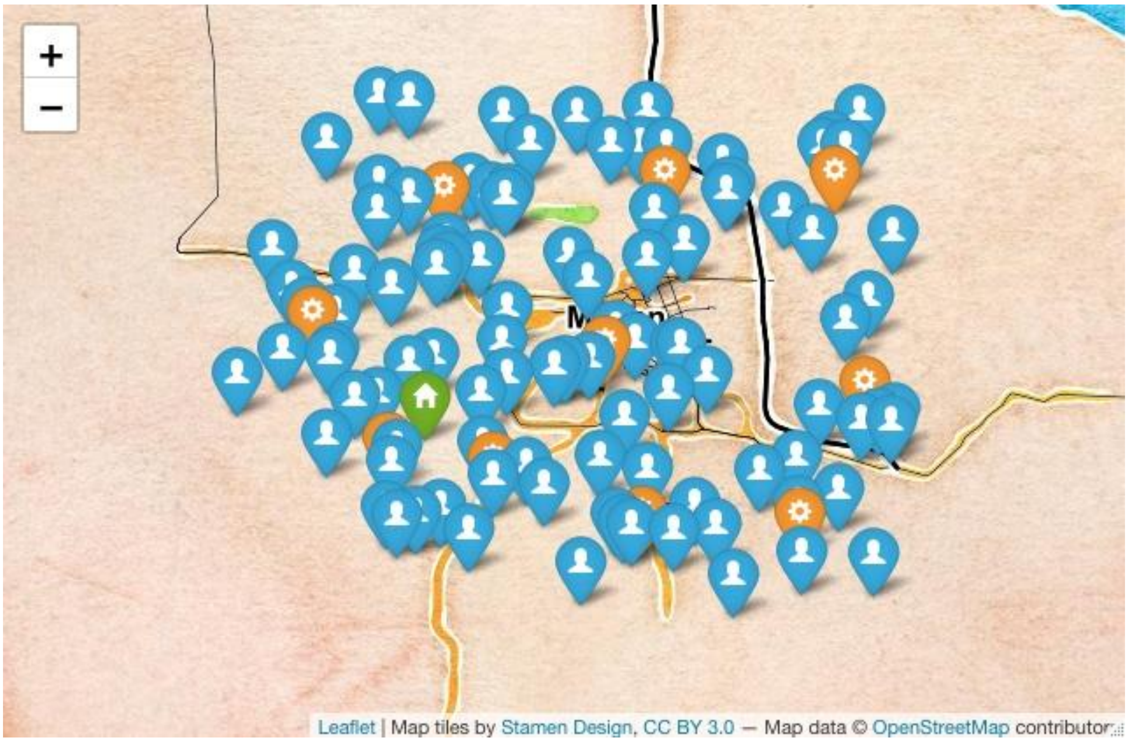

Fig. 2. Location of the depot, satellite and customer

Figure 2 shows that the depot uses a green home icon, an orange cog icon represents a satellite, and a blue user icon represents a customer. In 2E-VRP, the problem is solved using a 2-step solution. In the first step, first solve the problem in the second echelon, namely the problem between the satellite and the customer. In the next step, we solve the problem in the first echelon. Before routing the second echelon, we first perform a cluster analysis. This analysis helps find locations that have homogeneous properties with satellites. So that vehicles from each satellite can plan destinations close to the satellite. Therefore, proper cluster analysis is needed before determining the route of travel. The analysis in this study uses RStudio to present clusters and routing. This analysis determines clusters using K-means. K-means are widely used to find the ratio of the average distance between points [He et al. 2016, Kassem et al. 2019]. In Figure 3, several possible clustering positions will be presented. Figure 3 shows the K-means cluster using k=2,4,6,8,10.

In order to obtain a more natural number of k clusters, we analyze using the silhouette method. A better average silhouette width will result in a natural and optimal grouping. The silhouette plot obtained from analyzing the Euclidean distance from points in the second echelon, namely satellites and customers, can be seen in Figure 4.

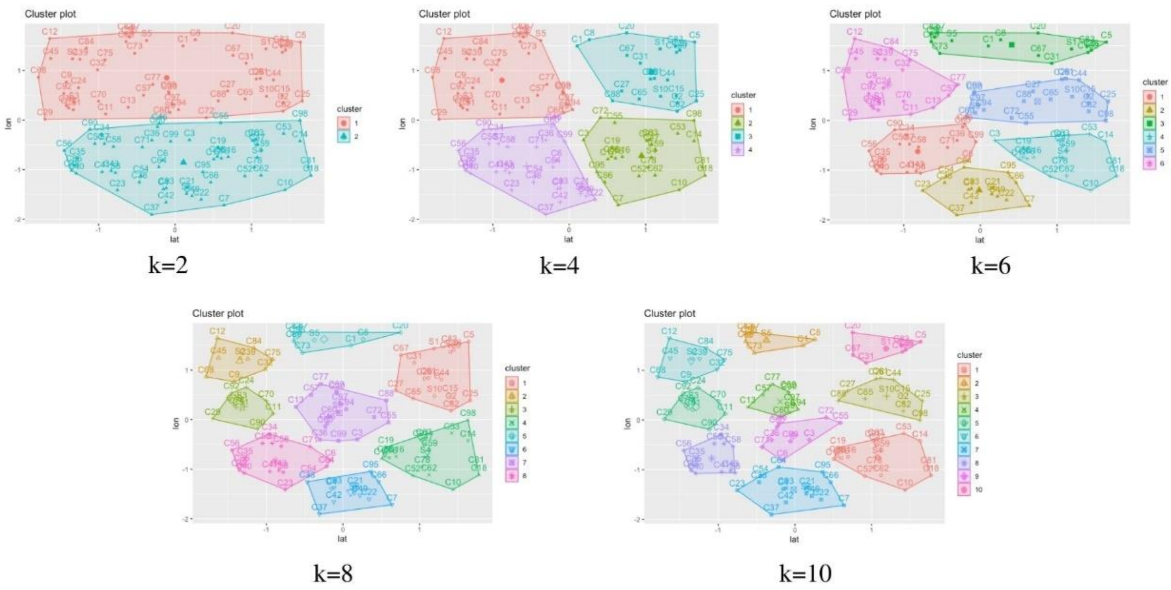

Fig. 3. Clustering using K-means determines the distance group from each satellite and the customer

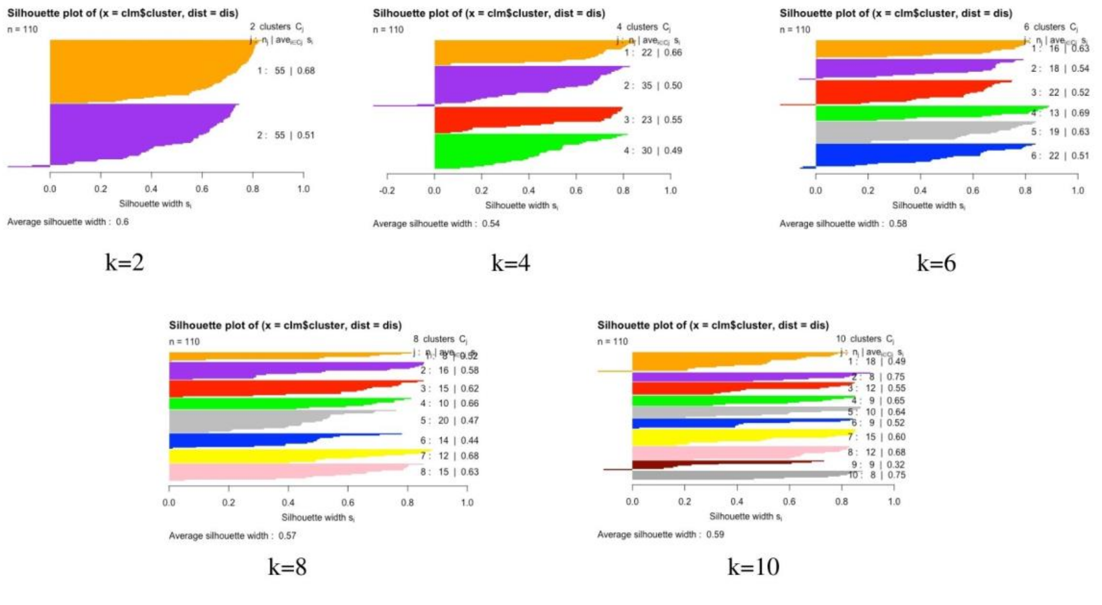

Fig. 4. Silhouette plot of the Euclidean Distance between each point in the second echelon.

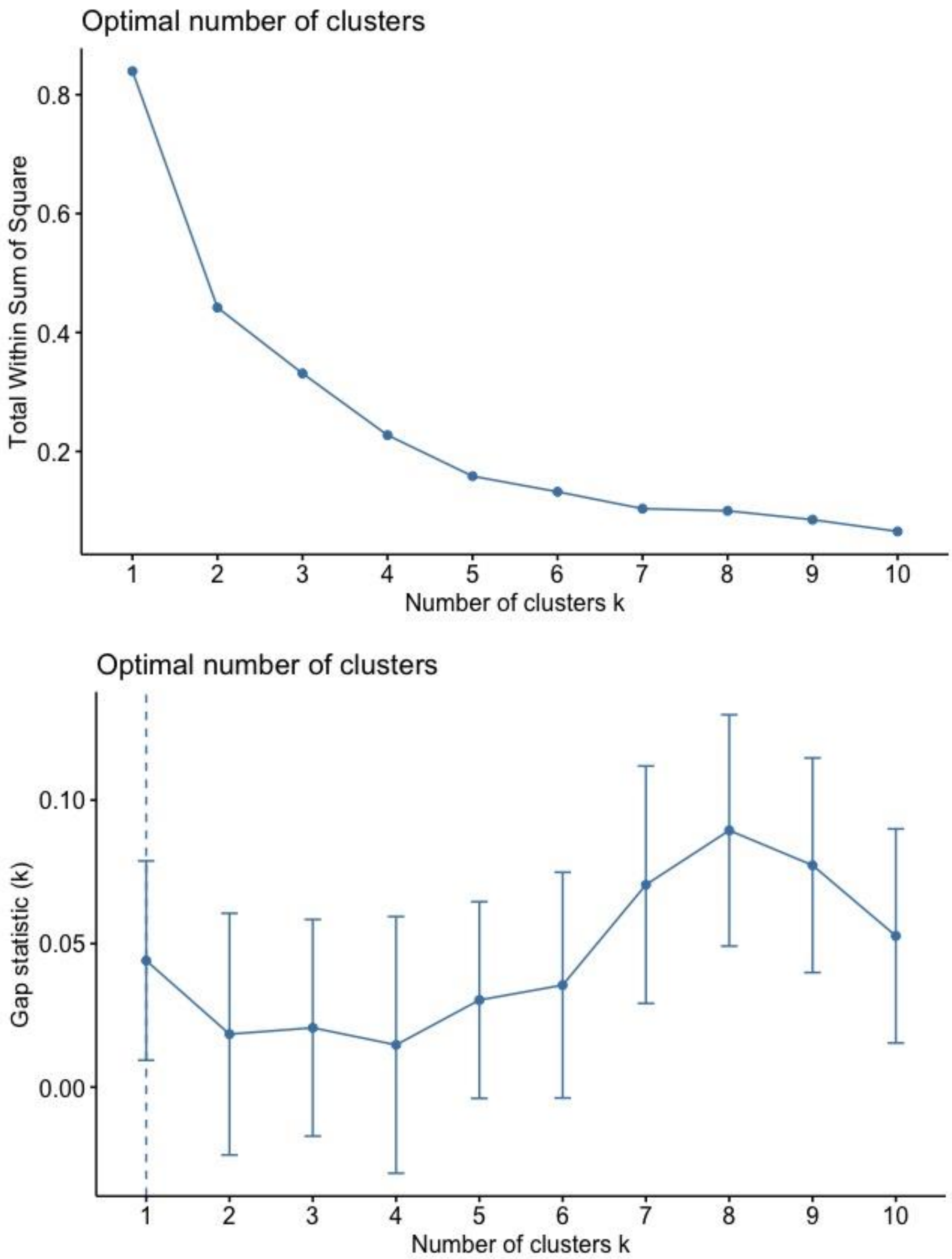

Fig. 5. (a) Elbow plot (b) Statistical gab plot

Based on Figure 4, it can be seen that the best average silhouette width value is k=2, then followed by k=10, k=6, k=8 and k=4. From the plots presented, it can be seen that there is a more natural clustering possibility at k=2, to ensure a good group homogeneity, it can also be seen in the analysis of the total within the sum of squares and the statistical gap presented in Figures 5(A) and 5(B). Based on Figure 5(a), the plot within the SSE has a very significant slope from k=1 to k=2. From the figure we can interpret that k=2 is more natural than other clusters, namely k=4, k=6, k=8, and k=10. However, in Figure 5(b), the statistical gab plot shows that the k=1 cluster has a better gab statistic. This paper will present a comparison of distance and cost based on the benchmark's test data as presented in Table 1.

After determining the optimal k clusters, the next step is to determine the routing using the 2 opt heuristic method. From the test results, the total distance in the second echelon can be seen in Table 2.

Table 1. Test of characteristic benchmark data

Instance	k	N_s	N_c	d_i	C_{ij}^{van}	C_{ij}^{mot}	ξ_{ij}	η_{ij}	UL_k
P01	2	10	100	100	2000	2250	2000	2000	1000
P02	4	10	100	100	2000	2250	2000	2000	1000
P03	6	10	100	100	2000	2250	2000	2000	1000
P04	8	10	100	100	2000	2250	2000	2000	1000
P05	10	10	100	100	2000	2250	2000	2000	1000

Table 2. Vehicle travels on the second echelon in kilometers.

Num. of Clust	1	2	3	4	5	6	7	8	9	10
k=2	101.37	115.40	-	-	-	-	-	-	-	-
k=4	51.00	52.70	59.87	43.32	-	-	-	-	-	-
k=6	36.98	36.18	30.53	35.55	38.49	37.38	-	-	-	-
k=8	31.77	36.58	31.74	25.67	28.90	33.33	20.89	25.29	-	-
k=10	17.60	20.02	18.32	33.50	14.51	22.84	18.34	19.30	25.77	22.35

Table 3. Total distance traveled by vehicles on the first and second echelon in kilometers and total costs.

Instance	Total Dist. in L1	Tot. Dist. in L2	Total Costs (IDR)
P01	46.63	216.77	948487
P02	63.01	206.88	988432.5
P03	68.54	215.11	1036625
P04	66.90	234.18	1086865
P05	74.87	212.54	1055817

Table 2 shows the total distance in each cluster. After calculating the total distance in the second echelon, the next step is to calculate the total distance in the first echelon using the 2-opt algorithm. Based on Table 3, we can see the total distance in L1 and L2. Table 3 also shows that the P01 instance with k=2 is superior in minimizing distance and costs.

CONCLUSION

This study provides a view of the logistics distribution network in e-commerce by combining van and motorcycle. We present the 2E-VRP model to minimize travel costs and fuel consumption. In the solution, we propose a combination of K-means clustering and 2-opt Algorithm to solve optimization problems and demonstrate the application of the model using numerical studies based on benchmark data testing. We look for solutions in two stages; the first stage is to look for solutions to problems in the first echelon, namely the problem of routing on the satellite to the customer. In the second stage, we solved the problem in the first echelon, namely the problem of routing between the depot and the satellite. In this paper, we cluster the second echelon using the K-means algorithm, a satellite, and a customer problem. We analyzed using the silhouette method, gap statistics , and calculated the SSE of the distance between points to provide an optimal cluster view. We adopt a solution with a 2-opt algorithm and analyze it with instances using k different clusters. The results of the study indicate that there is an influence in determining the number of clusters in minimizing the objective function, and the more the number of satellites, the higher the shipping costs. It can be explained because the distance traveled in the first echelon will increase because the number of satellites visited will increase, which will directly affect the cost of delivery. For future work, we will try to solve the model with the metaheuristic genetic algorithm method and compare it with the 2-opt heuristic method.

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ORIGINAL PAPER

THE SMART WAREHOUSE TREND: ACTUAL LEVEL OF TECHNOLOGY AVAILABILITY

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ABSTRACT. Background: Some phrases become common and contemporary without justification. One such term for business activities is the term smart. In the field of logistics, the trend toward "smart" warehousing is increasingly attracting attention. It is necessary to define it and the stage where intelligence can be achieved using available state-of-the-art technology, to follow the trend of the dehumanization of warehouse and in general manufacturing operations in the direction of Industry 4.0.

Methods: The article is based mainly on observational methods, literature review, and document analysis, based on data obtained during the implementation of consulting projects. The subject is limited to warehouses designated to process palletised goods.

Results: The available state-of-the-art solutions, like IoT, automation, robots, and communication standards, are close to smart warehouse implementation. But on the other hand, lack of full cooperation between various parties of supply chain and long-term return on investment stand in opposition to implementation.

Conclusions: Smart warehouse is the matter of the future. Technology is predominantly achievable, but standardization, universalization and trust are necessary to reach the level of real implementation. Smart solutions are within the reach of a single enterprise, but only in isolation from its microenvironment.

Keywords: smart warehouse, smart storage, smart logistics, smart technologies

INTRODUCTION

Smart is the expression that is becoming contemporary and common, in some areas without real technological justification. In the field of logistics, the term smart warehouse is becoming more and more popular, though the development of this technology is far from observation in the field of mobile communication. The definition of the solution and the determination of the stage at which it can be achieved through the use of state-of-the-art technologies are necessary. The literature review points to scientific gaps, whose completion initiated the survey.

The scientific objective of the paper is to determine the advancement of warehouse technologies toward achieving a solution defined as ‘smart’, which should initiate the discussion of smart warehouse implementation. In addition to filling the research gap, the aim of the article is to answer the question to what extent it is possible to implement in practice smart warehouses now and soon, confronting existing or emerging technologies with real needs. The trend of technology replacing humans, directing logistic to the 4.0 level, is accelerating and cannot be ignored, especially by science.

The methodological objective of the study is to determine the degree of applicability of available storage technologies against human labour in the context of creating a smart warehouse, taking into account the justification and limitations of its implementation. A missing attempt should be made to verify the applicability of the smart warehouse idea, which is the aim of the paper. Are there technologies that can be implemented to put intelligent warehouses into practice, technologies that will allow intelligent warehousing operations? If so, can synergies be obtained from their

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simultaneous functioning? Is the potential implementation consistent?

The results of the paper indicate areas of focus in order to implement realistic intelligent technologies that authorise the term smart warehouse use. These should be further researched and given special consideration by practitioners.

LITERATURE REVIEW

‘In recent years, several studies have proposed and discussed different types of smart warehouses, identified key challenges, and proposed several solutions to cope with these challenges. (…) However, very few studies exist on how smart warehouses are designed and the transition strategy and process to these new types of warehouses” [van Geesta et al. 2021]. It can be understood that there is not any publication with holistic look a smart warehouse solutions and along with the expected or possible advanced technology participation in the warehouse process. A review of the titles and content of some scientific services confirms that "smart warehouse" in literature is treated selectively, there are a few holistic approaches and evaluations of the applied solutions when eliminating unnecessary human work. Even the publication focused on ‘smart warehouse’ focus on a part of subject matter, for example software, warehouse organization, single technology, or case study (see Table 1). A technology implemented does not “make” warehouse smart, but is often is the main subject of a publication titled with “smart warehouse” phase.

Table 1. Number of publications with the phrase "smart warehouse"

Web service	Results	Holistic approach	Results in titles of articles, focused on:						
				IoT	warehouse technology	warehouse organization	software (AI, Big Data)	case study	others
Emerald	36	none	4	■	■			■	■
Science Direct	104	2	5	■		■		■	
Springer	243	none	11	■	■	■			
Taylor & Francis	14	none	1		■	■			
Elsevier (Scopus) [1]	67	none	2	■	■		■		■

Source: own work, data from March 2022

One of the holistic approaches [van Geesta and others 2020] answers the question: What is a proper reference architecture for smart warehouses, focusing mainly on warehouse software. Another approach [Zhong-Zhong 2021] indicates picking as a “smart” warehouse ground. Still, those are only elements of the whole idea in question.

It is not easy to define when warehouse can be called smart. Without all of those things, can the solution not be described as intelligent, or are only a few of them essential? The article tries to gather all aspects of smart warehouse and decide

[1] In the theme: Physical Sciences and Engineering journals only

which level (percentage of technology autonomy) can be reached using smart solutions.

MATERIALS AND METHODS

Of the research methods used, the most significant were observational methods and case studies based on many-annual experiences during research activities and information gathered from contacts with entrepreneurs. Slightly less important was the information obtained from a literature review. The quantitative techniques used included observation and document analysis, based on data obtained during the implementation of consulting projects.

Due to the strong relationship between process automation and standardization of handled units, solutions for goods palletized into cuboid units were used for analysis. Multiple types, parameters, and conditions of these units did not allow the assumption of complete standardization of flow objects.

RESULTS

The definition of ‘smart’ building depends on respective times - the ‘smart house’ of 1935 had an electric light in every room [Weiser 1996], later the determinants were TV sets or computers. The definition of smart warehouse from Internet of Things (IoT) perspective was proposed by the IoT Agenda [2019]: “A smart warehouse is a large building in which raw materials and manufactured goods are stored that uses machines and computers to complete the common warehouse operations previously performed by humans”. Although dimensions are a secondary matter, dehumanization is one of the most important factors of smart solutions.

Technology in place of manual work is not the deciding criterion. Interpretation of smart logistics definition narrows the area slightly by adding state-of-the-art to the specification of technology [Uckelmann 2008]: It enables people to focus on subjects that cannot be delegated, thus requiring more ‘smartness’.

Smart warehouse is a technology driven logistics solution, where subjects, which can be delegated, are performed by state-of-the-art software and equipment, smart technologies.

The spectrum of warehouse smart technologies is wide. First, it includes dedicated software: management systems – of warehouse (WMS, EWM), yard (YMS), forklift fleet (FFM), close related transport (TMS) and finally supply chain (SCM), resource planning – of enterprise (ERP) or manufacturing (MRP). Then the manipulation and storing technologies should be included [He et al. 2018], like automatic storage and retrieving systems (AS/RS), conveyors, automated guided vehicles, autonomous machines, robots (here conv+) and the whole spectrum of equipment supporting picking activities [Stoltz and others 2017]. Those are the ‘main’ technologies, which can be supplemented by further ones. Their "intelligence" is demonstrated by their technological sophistication. Simple solutions, which have existed for many years, are only characterized by reflecting the reality created by humans. Smart solutions themselves create this reality, within the framework defined by the human factor.

The Internet connection opens up an additional perspective, such as software-as-a-service (SaaS), cloud computing, cloud data storage, blockchain, and direct intertechnological communication - Internet of Things (IoT) [Čolaković and others 2020]. Communication protocols (such as EDI) or automatic identification (based on barcodes or RFID) cannot be omitted, nor the application of augmented reality (AR). The newest trend, planned to be fully implemented in 30 years, is Physical Internet. The last, but not least, and perhaps the most important, is artificial intelligence (AI), the perspective of developing any smart technology and its independence from the "human factor".

Table 2. Smart warehouse activities and related example technologies

Warehouse activities	Smart technologies														
	(EDI)	ERP	MRP	WMS	TMS	YMS	IoT	RFID	Bar codes	AS/RS	Conv+	Robots (incl. AGVs)	Dedicated equipment	FFM	CCTV, sensors, gates
Communication with business environment	■	■		■	■	■									
Internal communication		■		■		■	■								
Orders of goods (restock)		■	■												
Reloading organisation ("time windows")					■	■									
Road transport to/from warehouse					■										
Reloading organisation (availability of resources)				■	■	■									
Control of delivery compliance with the notification (warehouse access)						■									■
Control of compliance of the delivery with the orders (release for unloading)		■		■											
Unloading				■				■	■						
Preliminary quality and quantity control				■				■	■						
Detailed quality and quantity control			■	■				■	■						
Repacking, palletization and labelling of load units				■				■	■						
Manipulation – pallet load units				■						■	■	■			
Manipulation – boxes and pieces				■						■	■	■			
Picking zone replenishment				■						■	■				
Picking of pallet units				■						■	■				
Picking of boxes				■						■	■	■	■		
Picking of pieces				■							■	■	■		
Control of picking (may be skipped)				■									■		
Packing (items)				■								■	■		
Palletizing				■								■			
Loading				■									■		
Control of loading				■				■	■						
Inventorying			■	■											
Management of the distribution of goods in the warehouse				■				■	■						
Warehouse sequencing management				■				■							
Management of the directions of movement of forklifts / workers			■	■										■	
Administration - management			■	■				■							
Administration - activities				■											
Security						■									■

Source: own work

The set of technologies is ready to take over the work from warehousemen. Some of technologies can have different share in activity, for example, in case of standardized items picking manual work can be eliminated. More differentiated items lead to more sophisticated solutions. Sophistication is associated with higher expenditures and maintenance cost, which leads directly to the financial effectiveness issue. In case of complicated processes, the financial effectiveness can be lost much earlier. There is probably a technological solution for every warehouse activity, but the level of outlays and daily cost are still a barrier, growing in parallel with technological sophistication.

Activities that cannot be dehumanized, for example, road transport, can be identified. We can image autonomous trucks on the motorway, but on manoeuvre yard? We can imagine standardized load units, but standardized autonomous reloading systems for unstandardized units? Of course technologies are available but require pan-companies coordination and decades, not years, to universalize. Road transport and reloading are examples of activities that can be fully “smart” but with a long time horizon.

What are the opportunities for available (or soon to be available) technology to take over tasks for workers? An attempt of the answers is given in Table 2, indicating what the possibilities of technology are, abstracting from the level of outputs and the return on investment. The low value of the blue bar indicates the need to use the "human factor", here market with red.

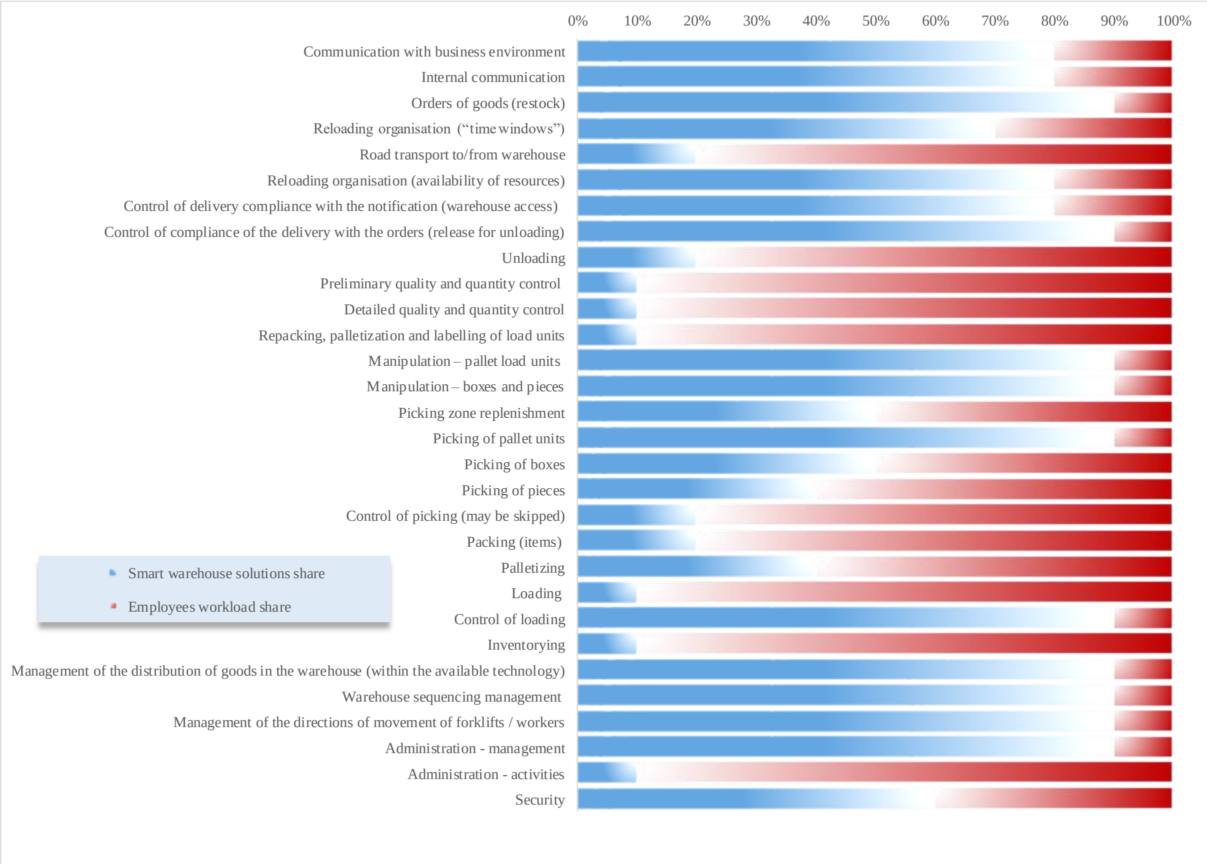
However, we as people, cannot trust artificial intelligence. A minimum of supervision is and, one must assume, will be necessary. The handling unusual situations will also be left to the human factor. The incorporation of artificial intelligence into warehouse every activity will theoretically be possible, but will it be financially effective? This assumption gives employees a minimum 10% share in all dehumanized activities.

The availability of technology has two minimum aspects. First, technological readiness, existence of proven technology. The second one is practice, when implementation is limited by other factors, like safety or lack of the standards. The example can be road transport, where theoretically technology offers solutions, especially in the case of cars. But autonomous trucks may cause threats, have to deal with congestion, different road conditions, or unpredictable humans, which practically eliminates implementation in the incoming decade.

The set of warehouse process activities with the share in estimated workload share for technology and humans is presented in the table. Additionally, there is a stated task for warehouse workers and technological solutions. And finally, technologies (software and equipment) tailored to individual tasks - this part should be treated as proposals or examples because there can be as many versions of the implementation as there are designers. But the technologies available now and in the near future are taken into consideration. The assumption is a possible usage of IoT in the whole process when the equipment and modular packages are adequately prepared. This will ensure the synergy effect.

The degree of applicability of available storage technologies against human labour is below the assumed 80% level, especially taking into account the limitations of its implementation. The justification for the implementation of smart warehouse technology is not general and requires a custom prior analysis, particularly in terms of profitability.

Table 3. Evaluation of currently available technologies compared to the requirements of the smart warehouse



Source: own work

DISCUSSION

There are technologies whose implementation makes it possible to apply the intelligent warehouse, and the synergistic effect of their implementation can be expected. Consideration should be given in determining the reasonableness of the overall implementation.

There are two main factors, indicating smart technologies. The first is the growing cost of labour, justifying proportionally larger investment outlays. The second one is the excellence of technologies in terms of accuracy, repeatability, consistent quality, and work continuity.

On the other hand, Kamali [2019] states the main disadvantages of smart warehouse, including high level of outlays related to several years to reach financial reimbursement, the need for specialised personnel, the risk of whole system stoppages, long-term dependence on particular spare parts, hardware and software providers. Two more important have to be added: the required standardization of turnover items and the fact that every complex technological system is a prototype, prone to faults in 'infancy age'. Technology is adaptable, but only within the framework agreed during the design process. The meaningful changes require additional investment, much higher than in the case of human workforce retraining. The reasonability of smart warehouse implementation has to be verified separately in every case, there is no clear indication of a universal answer.

The above comparison considers not only the available technologies but also the validity of their implementation. Theoretically, it is possible to automate or robotize all warehouse activities even for non-standard storage units. However, the return of investment period of such a system will be counted in tens of years, and for this reason it is a purely theoretical solution.

The share of human and technological factors throughout the scheme on average is equal. Today's state-of-the-art warehouse is not a smart warehouse when about 50% of activities have to be performed by workers. The assumed level is beyond the reach of differentiated supply chains. In the case of warehouses as part of an enterprise isolated from supply chain, when standardization of turnover objects is conducted, implementation opportunities are more likely.

Most publications with the phrase "smart warehouse" focus on one smart solution or a limited number of them, which does not allow the warehouse to "reach level 4.0". It is only the set of all or a significant number of solutions, possible and indicated for implementation in a given configuration, that allows a warehouse system to be called "smart". It is therefore difficult to agree with most of the authors of the mentioned publications that they touch upon a complete smart solution. However, it cannot be denied that they focus on the essential elements of a smart warehouse.

It should be emphasized that this paper is the first comprehensive approach to determine the degree of possibility of implementation of modern technologies in warehousing in the context of Industry 4.0, so there is no possibility to refer to other results of similar studies. This indicates a possible direction for further and more detailed studies.

CONCLUSIONS

The table does not give a straight answer, if the values are close enough to 100% to conclude, the set of presented technologies is a real smart warehouse, without clearly defined criteria. Even if we assume a level of 80%, this value will not be reached in many areas, which means that the smart warehouse in the holistic sense is currently unattainable. This also applies to the prospects for the next few years. However, this does not mean that we should not strive for it and make attempts, even in separate areas of warehouse logistics. It had to be underlined that the trend in the direction of dehumanization of main operation is strong.

What can be done to decrease the so-called human factor below assumed share values and reach the real smart warehouse-level value close to a minimum of 80% in every row? The first thing is standardization on a global scale. Standardization covers packages, including automatic identification means and communication protocols. Second, the automation and, in the case of road transport, standardization of road transport means. The third is trust, not only in automation effectiveness but in the honesty of cooperatives. These are very highly suspended requirements, it is hard to believe that they will be met in the next 10 to 20 years. The real smart warehouse is still far away, but some fields of storage can be “smart” now, as described, for example, by Žunić et al. [2018] or Bolu et al. [2019]. It is important to emphasize that smart warehouses can arise (and are arising) in isolation from the microenvironment. Little is in place to prevent the creation of smart solutions within the reach of an enterprise, but often in isolation from its suppliers and customers.

Despite the availability of a wide range of technological solutions, implementation constraints, including standardization, the need for close cooperation within the supply chain, and the unavoidable transfer of goods between facilities through public areas, with little control of the entrepreneur, are obstacles difficult to overcome by business practice.

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ORIGINAL PAPER

INTRA-HOSPITAL PATIENT TRANSPORTATION SYSTEM PLANNING USING BI-LEVEL DECISION MODEL

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ABSTRACT. Background: The intra-hospital patient transportation is an important aspect of patient care. It is about the transfer of patients between different healthcare units in the hospital. Many tasks are required for transferring the patients from one to another unit depending on available resources and the needs of the patients, such as types of supporting equipment, transfer routes, and supporters. Limited and unprepared resources for transferring the patients, such as lack of supporting equipment and available supporters, may impact the patient treatment and service quality. Therefore, these resources should be managed effectively in order to minimize these impacts. The case study hospital located in Chiang Mai province, northern Thailand is currently encountering the problem in managing and planning the intra-hospital transportation process. Therefore, this research aimed to propose a mathematical model for planning the intra-hospital transportation system in this case study hospital.

Methods: Our research proposed a bi-level mathematical model to tackle the intra-hospital transportation planning problems. The system is represented by a deterministic model using integer linear programming. The first level of the mathematical model is for identifying the locations and setting them as transportation depots. The second level of the model is to optimize the number of resources used for intra-hospital patient transportation. The model was then validated by using two sets of instances via LINGO solver.

Results: This research proposed a bi-level mathematical model that could help to manage the intra-hospital transportation challenges in the case study hospital. Furthermore, the outcomes from the test with two instances were depots positioned at a set of feasible locations. The model was used to designate resources to each depot for the instance, such as wheelchairs, stretchers, oxygen tanks, and employees. In each case, the outcomes are dependent on varying service timings and demands.

Conclusion: This research used the deterministic mathematical model for planning the intra-hospital transportation system consisting of the location assignment and resource allocation. The model, in addition, can solve with the exact method. Consequently, we can ensure that the presented model can apply to real situations in further study.

Keywords: Intra-hospital transportation, Patient transportation, Bi-level decision model, Hospital logistics, Optimization

INTRODUCTION

The hospital is where many complicated healthcare operations are performed. It has a direct meaning that refers to the hospital we are familiar with, as well as an implied meaning that refers to all medical treatment institutions where there are roles in supporting the population's health. Hospital care is administered in both the private and public sectors and can be used as a health-care alternative for the people. To deliver the greatest service to customers, numerous challenges must be carefully considered. The logistics perspective is one of those many concerning issues. The diversity of logistic flow in the healthcare system, such as food, medicine, waste, equipment, medical test samples, and patients, has important responsibilities to play in supporting medical activities for providing service to patients. Patient transportation, especially, has a significant impact on the performance of the healthcare system. The continuous flow of healthcare services in any hospital depends on these logistic activities under their own distinct rules and complexities. Generally, we can divide hospital transportation into two categories: 1) inter-hospital, which is related to transportation from outside to the hospital, and 2) intra-hospital, which is

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concerned with transportation between different services within the hospital. Intra-hospital transportation, which is the focus of this study, is a daily essential logistical activity that involves picking up and delivering patients between care units in the hospital. Transferring patients between healthcare units and service areas is the job of the transportation department in any hospital.

Intra-hospital transportation can be divided into two categories. First is the transferring of patients between departments, such as delivering a patient from an inpatient department to the medical diagnostic facility, returning a patient to the inpatient department, or transferring patients to another inpatient department. The second category of intra-hospital transportation is patient discharge, which refers to moving patients to locations unrelated to the medical treatment, such as pick-up and drop-off points. The patient transportation process starts when the medical personnel in the inpatient departments or clinics call the nearest patient transportation department when requiring transport. After someone makes a request, an employee at the transportation department requests information including the origin, destination, and type of vehicle. Next, they go with the equipment needed to pick up the patient at the requesting point then bring them to the destination. After ensuring that a patient arrives at their destination safely and is taken care of, the employee goes back to the original depot to prepare to receive the next job. Another situation is a service that is provided when a patient directly contacts the transportation department for assistance. An employee then transports the patient by the same method.

This case study hospital is a provincial hospital that provides healthcare services mainly for residents of Chiang Mai provinces, Thailand. There are complicated services for various types of patients arriving. Hence, there are a lot of transportation jobs daily that are determined by patient needs. The inpatient department is extremely busy because there are many patients awaiting admission. There are almost no empty beds in real-life situations. New patients are brought in as soon as a bed becomes available. Consequently, the speed of picking up a patient who is ready to be relocated has a high influence on the patient service system. The unavailability of patient transportation units due to issues such as taking too much time to reach a patient, lacking porters and equipment, or transport delay all lead to delayed treatment services, inconvenience, and dissatisfaction among the patients. It is critical to structure management efficiently so that the internal hospital transportation system is accessible with the least amount of difficulty. These concerns are often investigated to improve service quality.

Therefore, the objective of this study is to propose a model for planning intra-hospital transportation systems. It is in the field of internal healthcare logistics optimization. To specify the problem, we used mixed-integer programming. Appropriate models are the key to resolving the service quality issues that we are addressing. A bi-level mathematical decision model was developed to aid in making decisions in this planning problem. A numerical example was tested to validate the model via LINGO solver.

LITERATURE REVIEW

The application of Industrial Engineering (IE) tools in healthcare management studies has gotten a lot of attention for a long time. Boonmee and Kasemset [2019] surveyed the IE tools used to solve problems in the healthcare area, especially in Thailand. Operation research is one alternative approach by using a mathematical model to represent a real-life problem. One of the issues solved by this method was finding the best location to locate the facility. A location model is an underlying approach that has been applied to consideration on those. Daskin [2008] illustrates a taxonomy of those discrete location problems with the basic model formulation. The mixing of two goals into a single objective model that consisted of minimizing the number of facilities and minimizing the total distance of customers to facilities was applied to the facility location problem [Wayan Suletra et al. 2018]. A multi-level problem is another option used to solve multiple related problems within a study. There is a hierarchy of decisions in different stages in planning. Allocating depots to possible locations is considered in strategic level decisions [Fermín Cueto et al. 2021]. Application of the mixed-integer programming (MIP) model to integrating facility location problem on humanitarian logistics aspect was presented by Boonmee and Kasemset [2020]. It can be applied in healthcare logistic terms. Furthermore, resource management in the healthcare system is another critical concern. Boonmee et al. [2021a] use a MIP model to schedule patients served in the service using mathematical models. For the logistics aspect, fleet size or vehicle planning is considered along with installing depots. The decision on optimal fleet composition for a depot supplying customer demands is a concern that is formulated and solved with MIP [Etemadi and Beasley 1983]. A bi-level decision-making concept has been mentioned in multiple level hierarchy problem-solving. Numerous management and optimization issues in the real world can be addressed by using multilevel decision-making tools. Lu et al. [2016] examined current multilevel decision-making strategies and methodically clustered techniques developments.

There are some previous studies that have attempted to solve intra-hospital transportation problems. Those studies applied many approaches that can facilitate the determinants of hospital performance. To disrupt the traditional organization, Naesens and Gelders [2009] show the advantages of developing a decentralized structure to replace the centralized patient transportation system. The simulation technique was applied by Phongthiya et al. [2021] to evaluate the intra-hospital patient transportation strategies in their case study hospital. The strategies that they proposed could help to reduce the transportation time and, accordingly, increase the number of completed jobs per staff. The mathematical model technique is also widely adopted to solve the patient transportation problem, for example, Bouabdallah et al. [2013] used the MIP to determine the stretchers service in order to minimize the moves of empty stretchers. Kuchera and Rohleder [2011] and Gopal [2016] used a computerized tool to manage and optimize the use of staff in patient transportation to reduce patient waiting times and, in turn, improve service quality and customer satisfaction. The MIP model was also used in a study by Séguin et al. [2019] to solve the problem of assigning the employees to a specific route without disrupting the current staff schedules to solve transportation problems in a large hospital. Additionally, Turan et al. [2011] applied the routing planning models for non-ambulant patient transportation.

In the model development process, model validation is an important step. Testing the method with a small-size example is recommended before putting it into practice for the real problem. It is necessary to examine the adequacy of given constraints and satisfy the problem objective. Gass [1983] has recommended a technique about model validity in the paper. Model validation with the instance is recommended before practicing the model on the real problem [Turan et al. 2011]. Experiment numerical examples are generated based on real-world circumstances to verify and validate the developed mathematical model before approaching real-world application [Kasemset et al. 2020, Boonmee et al. 2021b]. Table 1 presents the previous studies on intra-hospital transportation that applied the mathematical models. Most research works applied a single-level mixed-integer model for optimizing a single variable either staff or transporters.

Table 1: Previous studies in the scope of intra-hospital transportation

Publication	Modelling method	Focused issue
Bouabdallah et.al. [2013]	Single-level mixed-integer model	Determining the stretcher usage planning.
Kuchera and Rohlwder [2011]	Single-level mixed-integer model	Optimizing staff schedules.
Gopal [2016]	Single-level mixed-integer model	Optimizing staff schedules and simulation.
Séguin et al. [2019]	Single-level mixed-integer model	Assigning specific employees to routes.
Turan et al. [2011]	Weighted sum approach model	Evaluating the optimal number of assigned porters.

As mentioned above, we proposed the bi-level formulation that includes more intra-hospital components (i.e., staff, supporting equipment, transporters, routes, and depots). Our formulation is different from those in other existing studies because our solution can cover the most required components in intra-hospital transportation. Other hospitals that provide intra-hospital transportation similar to the case study of this research can apply the formulation of this study.

PROBLEM DESCRIPTION

It is important to understand the current hospital situation before making decisions. The hospital needs to restructure its current operation due to the high volume of requests and inadequate response time. The concept is to distribute the internal patient transportation service points over the hospital's area to facilitate the requests comprehensively with the shortest access time. The considered locations, which are possible to become transportation service points, are empty areas or old transportation points in the hospital. The service departments which request transportation, known as demand nodes, can be a clinical point, different inpatient department, or discharge point. For discharge points, it is not only discharging a patient but can also be for admission. We assume those points are the same as the requesting department in this study. Furthermore, each transportation service point, or depot, needs the resources to serve patients' transportation requests adequately. The patient transportation process in this study operates with wheelchairs, stretchers, portable oxygen tanks, and employees—referred to as porters.

In practice, we divide the problem model into two levels of decisions because of the convenience of the management: structure-level and operation-level. The transportation depot determination is a structure-level decision because it should not be updated frequently to avoid personnel confusion. Quick recognition of personnel at depot locations influences in-hospital operation convenience. It is therefore an independent decision. For fast and convenient patient transportation, the hospital can have more than one service point. Operation-level decisions aim to allocate resources effectively to each depot to achieve high-quality service and patient satisfaction. To ensure that resources are used as efficiently as possible, the resources in each depot can trade-off independently when having a re-decision on the patient demand change. Modifications at this level can be made simply without affecting the operations of other departments since there is no significant impact on the overall system if the number of resources increases or decreases.

MATHEMATICAL MODEL

In the bi-level mathematical model formulation, we assume that the first level is a long-term decision to choose the optimized transportation depots for the patient transport from a list of possible depots. The second level is a short-term decision. It is about allocating the patient transportation resources to each depot obtained from the first level; they must be sufficient to meet the patient's requirements. Deterministic mixed-integer programming is used to represent the problem.

Transport Depots

The first level is to find suitable locations to install a transportation service depot that is able to offer service covering the maximal transportation requirements of patient service departments. At this level, we are interested in identifying the minimum number of depots that can provide the conditions that must cover the patients' demands. Therefore, the discrete location problem approach is applied in solving this level. We looked for various locations in the hospital areas which had the potential to become a transportation depot. Then, we chose the best locations considering the constraints. In the model, we are interested in customer satisfaction, so it is necessary to consider the restricted time to reach a patient. In the real situation, the service points are not only located on the same level of ground but also on the different floors which can be accessed by elevators. Thus, we did not use distance to restrict the model.

Sets:

I Sets of patient service departments (demand nodes)

J Sets of possible locations

Parameters:

d_i Patient transportation requests at node $i \in I$

t_{ij} Travel time between possible location $j \in J$ and node $i \in I$

t_{max} Maximum acceptable travel time to a patient

l Minimum number of required depots

Decision Variables:

$$x_j = \begin{cases} 1, \text{ if depot located at possible location } j \in J \\ 0, \text{ otherwise} \end{cases}$$

$$y_{ij} = \begin{cases} 1, \text{ if demand node } i \in I \text{ is assigned to depot located at } j \in J \\ 0, \text{ otherwise} \end{cases}$$

Objective:

$$minimize \sum_{j \in J} M x_j + \sum_{j \in J} \sum_{i \in I} d_i t_{ij} y_{ij} \quad (1)$$

Subject to:

$$\sum_{j \in J} y_{ij} = 1 \quad , \forall i \in I \quad (2)$$

$$y_{ij} - x_j \leq 0 \quad , \forall i \in I, j \in J \quad (3)$$

$$t_{ij} y_{ij} - t_{max} \leq 0 \quad , \forall i \in I, j \in J \quad (4)$$

$$l - \sum_{j \in J} x_j \leq 0 \quad (5)$$

$$x_j, y_{ij} \in \{0,1\} \quad , \forall i \in I, j \in J \quad (6)$$

The objective function uses the sum of two terms. The first term is to minimize the number of depots located at the possible locations. M is a large number used to prioritize the first term. The second term is to minimize the total demand-weights time. Equation (2) ensures the patient transportation requirement from each service department is assigned to only one depot. Equation (3) assumes that the service required department is assigned to only an open depot. Equation (4) ensures the travel time to the assigned department cannot exceed the maximum acceptable travel time determined by the hospital service quality policy. The restrictions ensure that patients do not have to wait for too long. Equation (5) is the lower bound of the number of depots determined by the hospital's requirements. Lastly, Equation (6) specifies the decision variables to be binary integers. In this study, the depot setting cost is the same everywhere in the hospital, so it is insignificant to consider in the model.

Resources Allocation

After obtaining the optimal depot at the first level, the next decision is allocating resources to each depot to ensure that the hospital can provide services available to satisfy overall demand. This level considers the optimal number of resources of each category for each depot. The hospital has two types of vehicles: wheelchairs and stretchers. The employee will choose the type of equipment, depending on the ability to self-support of patients. In very severe cases, it is necessary to use an oxygen tank to help the patient. The portable oxygen tank has to be installed on a stretcher. Hence in this study, we group an oxygen tank and the required installing stretcher into one vehicle type. Because of patient safety regulations, it is assumed that each trip can only carry one patient. Furthermore, each trip must begin and end at the same station. This study introduces a model providing the minimum number of allocated resources.

Sets:

- D Sets of depots from previous level decisions $D \subseteq J$
- K Sets of transportation requests for each depot
- V Sets of vehicle types

Parameters:

- d_{kj}^{v} The request $k \in K$ with vehicle type $v \in V$ of depot $j \in D$
- c^{v} Acquisition cost of each vehicle type $v \in V$
- q Daily wage of an employee
- q^{o} Overtime wage of an employee per minute
- L_j Minimum number of employees at depot $j \in D$
- A Length of work period a day in minutes
- t_{kj} Average travel time of request $k \in K$ of depot $j \in D$
- t_v Average service time of vehicle type $v \in V$

Average travel time, t_{kj} , begins when an employee walks with equipment from depot $j \in D$ to requesting department $i \in I$ following the request $k \in K$, leads the patient to the destination, then ends when the employee returning to the original depot. Each request $k \in K$ is travelling from $i \in I$ to each destination. According to the assignment supporting demand node i by the depot j in the first level, they must start from the depot j for travelling k implicitly. Average service time, t_v , is time to service a patient in transportation processes except for the time required for oxygen tank set up time or waiting time for the patient to lay down on a stretcher.

Decision Variables:

- n_j^{v} The number of vehicle types $v \in V$ are assigned to depot $j \in D$
- e_j Employees are assigned to depot $j \in D$
- h_j Overtime at depot $j \in D$

Objective:

$$minimize \sum_{v\in V}\sum_{j\in D} c^v n_j^v + \sum_{j\in D} q e_j + \sum_{j\in D} q^o h_j \quad (7)$$

Subject to:

$$\sum_{k\in K} d_{kj}^v (t_{kj} + t_v) - w_j A \le 0 \quad ,\forall j \in D, v \in V \quad (8)$$

$$\sum_{k\in K}\sum_{v\in V} d_{kj}^v (t_{kj} + t_v) - e_j A \le h_j \quad ,\forall j \in D \quad (9)$$

$$e_j - L_j \ge 0 \quad ,\forall j \in D \quad (10)$$

$$n_j^v, e_j \in \mathbb{Z}, h_j \in \mathbb{R}^+ \quad ,\forall j \in D, v \in V \quad (11)$$

With three terms, the goal function is to minimize the total operation cost. The total acquisition cost of each vehicle type is the first term. The second is the expense of recruiting an employee. The third term is the total overtime cost if there is a workload longer than the length of the work shift. Equation (8) determines the number of each vehicle type assigned to each depot to ensure it can support the sum of demands at each department under work time. It is a calculation of the goal number of resources based on possible round trips. Equation (9) ensures the demand can be met with the number of assigned employees. However, overtime is allowed. Equation (10) is the lower bound number of employees. Equation (11) forces the decision variables to be integers and positive numbers.

MODEL VALIDATION

This section explains how our model was validated. After we constructed the model and were satisfied, the next stage was to test the model's suitability for the physical system it represents. The model assumption, structure, parameters, and restrictions that are assigned in the model must undergo consistency testing to be able to ensure that the optimal solution can be found. The model testing was done by the LINGO solver. The two instances which were used to validate the model were generated. The size of the problem and the boundary instance used for testing are shown in Table 2.

Table 2: Testing instances

Situations	$\lvert I\rvert$	$\lvert J\rvert$	d_{kj}	d_{kj}^w	d_{kj}^s	d_{kj}^o	t_{ij}	t_{kj}	$\lvert K_j\rvert$
I	6	20	[6,28]	[0,10]	[0,7]	[0,3]	[7,15]	[13,33]	15
II	10	30	[10,40]	[0,13]	[0,8]	[0,2]	[3,16]	[7,39]	20

Results

All parameters were assigned a value to validate the model by using small numerical problem examples. The result of the first level selects located depot in 5 from 6 possible locations. In the first circumstance, one of the possible locations was not chosen to become the depot. For the second situation with changing demand and time, there is selecting located depot in 4 from 10 possible locations. According to a solution, those depots can cover demand in all demand nodes with those depots. The result of model testing using example data illustrate (e.g., see Tab.3). The obtained solution from the LINGO solver is a global optimal solution.

Table 3: Testing results

Situations	Depot (j)	Wheelchairs	Stretchers	Oxygen tanks	Employees	Overtime
I	1	4	4+1	1	12	0
	2	3	2+1	1	6	0
	3	1	1+1	1	3	0
	5	1	1+1	1	2	0
	6	1	1+1	1	2	0
II	3	3	3+1	1	8	0
	4	5	3+1	1	11	0
	6	6	4+1	1	13	0
	9	4	2+1	1	8	0

Both levels of the model were able to operate to discover solutions based on the assumptions and limitations that have been established. The solutions show the number of resources required by each depot to serve patients in each situation efficiently. In practice, the number of stretchers not only comes from the stretchers variable but also must include the number of oxygen tanks variable because of the previous determination of grouping two pieces of equipment into one variable. The solutions were examined with the assumption and constraints. It was concluded that our models can represent the problems and be used to find optimal solutions.

CONCLUSION AND RECOMMENDATIONS

In the healthcare logistics aspect, this study considers a location and resource allocation problem. There is the application of a bi-level deterministic mathematical model to represent the problem of the actual scenario and obtain optimal operation planning. The first level is to optimize the number of internal transportation depots in as many locations as possible. The second level is the assignment of the number of each type of resource to each determined depot. The LINGO solver was used to find the optimal solutions for both levels. The aim of choosing this basic model is to make it easy to apply in a variety of situations conveniently. However, the demand and service time is not close to real-life situations. Future research based on this area should extend the model to represent the problem of uncertain demand and travel time using the stochastic model. Emergency patients should be given the first priority to service. Thus, the order of urgency should be considered. The solutions may use other techniques that are efficient to implement in larger or more complex problems.

In hospitals, especially in some developing countries like Thailand, it is difficult to predict the number of patients because the patients can go to the hospitals anytime without appointments. This unpredictable situation leads to complications in providing healthcare services to the patients because there was an unbalance between the supply side that is limited (i.e., resources for intra-hospital transportations) and the demand side that are unplanned (i.e., number of patients). Therefore, it is crucial to find ways to manage and utilize the limited resources in order to service those unplanned number of patients. The mathematical model is thus often used for planning, managing, and optimizing the use of those resources. As discussed in this paper, our research has proposed the bi-level mathematical models that include as many as components/variables that should be considered to manage the intra-hospital patient transfer effectively – which is different from the existing studies that consider only one or two specific variables, as discussed in the literature review section.

Although our mathematical models could present many components/variables that need to be considered in order to manage the intra-hospital transfer process, we suggest that future studies that aim to apply or adapt our models or develop a new mathematical model based on our logic for the hospitals in other contexts, such as different sizes, wards, specialization, ownership, or even in different countries, should consider the components/variables that are related or have the impact on their intra-hospital transfer process.

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ORIGINAL PAPER

DEEP LEARNING FOR THE PREDICTION OF TRANS-BORDER LOGISTICS OF PATIENTS TO MEDICAL CENTERS

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ABSTRACT. Background: Covid 19 impacted many healthcare logistics systems. An enormous number of people suffer from the effect of a pandemic, infection diseases can spread rapidly within and between countries. People from the Kingdom of Cambodia and the Lao People's Democratic Republic are most likely to cross-border into Thailand for diagnosis and special treatment. In this situation, international referral cannot predict the volume of patients and their destination. Therefore, the aim of the research is to use deep learning to construct a model that predicts the travel demand of patients at the border.

Methods: Based on previous emergency medical services, the prediction demand used the gravity model or the regression model. The novelty element in this research paper uses the neural network technique. In this study, a two-stage survey is used to collect data. The first phase interviews experts from the strategic group level of The Public Health Office. The second phase examines the patient's behavior regarding route selection using a survey. The methodology uses deep learning training using the Sigmoid function and Identity function. The statistics of precision include the average percent relative error (APRE), the root mean square error (RMSE), the standard deviation (SD), and the correlation coefficient (R).

Results: Deep learning is suitable for complex problems as a network. The model allows the different data sets to forecast the demand for the cross-border patient for each hospital. Equations are applied to forecast demand, in which the different hospitals require a total of 58,000 patients per year to be diagnosed by the different hospitals. The predictor performs better than the RBF and regression model.

Conclusions: The novelty element of this research uses the deep learning technique as an efficient nonlinear model; moreover, it is suitable for dynamic prediction. The main advantage is to apply this model to predict the number of patients, which is the key to determining the supply chain of treatment; additionally, the ability to formulate guidelines with healthcare logistics effectively in the future.

Keywords: International Referral, Healthcare Logistics, Deep learning, Logistics model, Covid 19

INTRODUCTION

The Covid 19 has affected many healthcare logistics systems. An enormous number of people suffer from the effect of a pandemic. Infectious diseases can spread within and between countries. The government has policies to control the virus, such as lockdowns, social distancing, severely restricting travel, and many other activities globally. During the pandemic, travel behavior changed in four respects: demand for travel, the purpose for which travel was carried out, modes of travel, and the convenience of travel [Yang et al. 2021]. People from the Kingdom of Cambodia and the Lao People's Democratic Republic are most likely to cross the border into Thailand for diagnosis and special treatment. In this situation, there is unpredictability in the number of patients and

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their destinations. This outbreak has been significantly consequential and controlling the number of trans-border movements is of the utmost importance. Therefore, international health organizations are invited to assist in terms of management, sourcing, procuring, and distribution of aid in any type of humanitarian crisis [Alam et al. 2021]. Coordination of their efforts induces components of clinical treatment, especially the demand of a patient to cross the border, seeking better healthcare facilities, which causes referral back difficulties and challenges.

Logistics flow helps meet the growing demands of the public hospital network in the supply and distribution of products. Properly implemented logistics processes in the public hospital network can directly affect the quality of health services, reduce the risk of treatment, and increase satisfaction of health prosumers [Majchrzak & Bober 2016]. Healthcare supply chain management differs from other industries. It is a complex network consisting of many different parties at various stages of the value chain [Kritchanchai et al. 2019]. A significant number of logistical challenges have also been noted and are one of the six interrelated components of a healthcare system defined by WHO. These logistics and supply chain management issues include the relationship between access to equipment, medicines, and supplies [Babatunde 2020]. Additionally, the decision-making process presents strategies to improve efficiency along the healthcare value chain. [Sousa et al. 2019]. The management of medicines must be related to the appropriate level of the patient. Ensuring patient safety during hospitalization, as well as outside the hospital [Granillo 2020]. These data are crucial for the provision of proper medicinal products to the patient for whom they were prescribed. Information can pose a serious threat to the health and lives of patients [Gawrońska and Nowak 2017].

The northeastern region of Thailand borders two neighboring countries, the Kingdom of Cambodia and the Lao People's Democratic Republic (Lao PDR). The borders are located in the Provinces of Ubon Ratchathani, Sisaket and Surin. In terms of public health, Ubon Ratchathani Province accommodates a high-capacity level of the public health management system. It is a prominent health center and since it is a frontier city, it attracts a large number of patients.

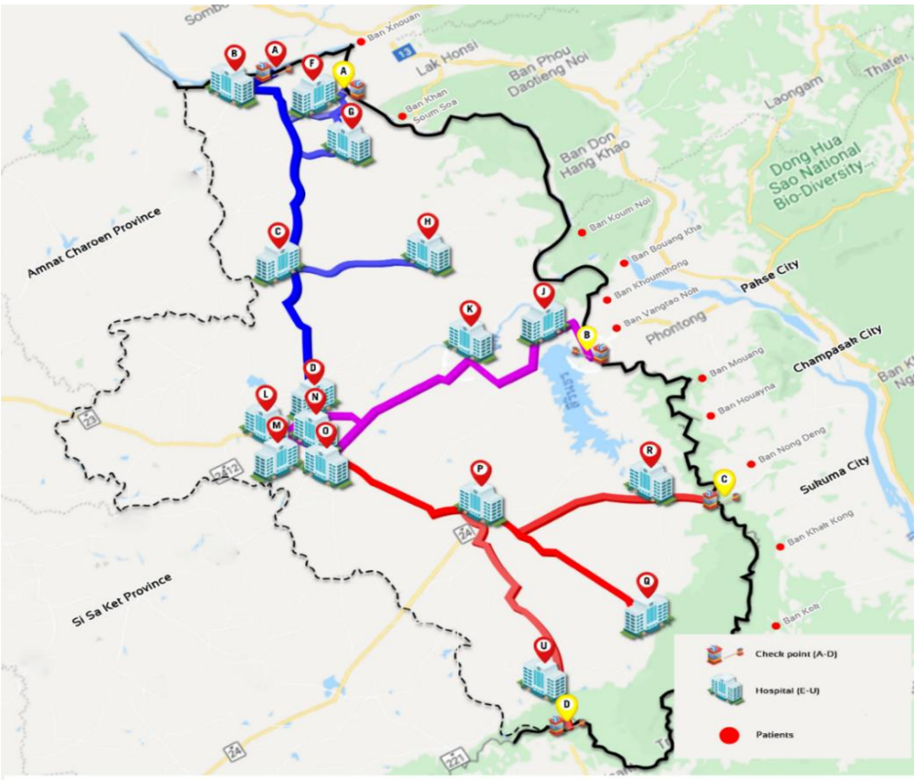

Fig.1. The health center and a frontier city

According to statistics, in 2018, more than 58,000 patients crossed the border for treatment in Thailand. Most of them are from the Lao People's Democratic Republic. They passed through the Chong Mek checkpoint to receive examination services (Figure 1). On average, approximately 60% of patients were treated at frontier hospitals, while approximately 40% were referred to the secondary hospital, due to the increasing trend of transboundary patient access. The Public Health Office must collect information to monitor, prevent, and control of disease and border disasters. Furthermore, the development of the cross-border referral system is similar to medical logistics. The health control officer or the personnel working in referral centers in cross-border locations should know the process of referral, repatriation, and consultation, including hospital hubs and local health service areas. Their priority is to select a hospital depending on the symptoms of the disease, service, and other information provided by the patient. They must show ingenuity in maintaining quality standards and putting the potential on full display. The covid 19 outbreak has been significant to the hospital. The hospital should improve the referral system, forecasting the travel demand of patients from international referral. Volume should be considered before preparing the service [Yang et al. 2019]. In terms of cross-border, the hospital must plan to manage resources and potential risks. Emergency rescuers should be prepared for both regular and disaster situations [Setzler 2007]. One of the performance indicators following hospital policy is that the operations of communication in the referral center are more convenient, fast and more efficient [Wajid and Unnikrishnan 2020]. Thailand, Laos, and Cambodia found different patterns of patients crossing the border; Laotians usually pass by personal vehicles or public vehicles, Cambodians like to pass by taxis or ambulances. Covid -19 is a major game changer in terms of travel patterns. Before the crisis, patients could travel by all modes of transport and directly from the health control centers to the hospitals. After the pandemic, the patient cannot cross the border, particularly in emergency cases characterized by their inherent uncertainty and the spatial distribution of the incoming demands. Delivery and distribution determine the criteria for using different channels. The heads of health control centers should monitor the volume of equipment as well as the inventory of medical material. Health care operations conducted in a warehouse are generally divided into reception, storage, order picking, sorting, and shipping. Treatment must consider reducing the gap between revenue and cost. In the Big Data era, analytical techniques such as data mining and deep learning are being used in inventory management to provide accurate and up-to-date information to make better decisions.

In recent years, the hospital has had a significant role in saving lives. One of the most widely used techniques for analyzing the actual problem is using the neural network model to predict the patient and the routing. In the future, this approach should be integrated with other approaches to better define the routing between hospitals and support a solution to the routing management problem [Kergosien et al. 2013]. In most research studies, the genetic process is preferred because it has better results than other methods [Inanç and Şenaras 2020]. Therefore, we propose a method to route vaccine distribution to hospitals. Sub-district health nurses using the bee colony method to determine the most optimal value for the fastest transit times. Von et al. [2019], suggests in-hospital management for referrals using mathematical equations under the conditions of workload, delivery time, patient symptoms, start and end time as mentioned above, in end-to-end patient care involved in all transportation, when the patient reaches the doctor, equipment and personnel must be sufficient and ready to accommodate the patient promptly. According to Lapierre and Ruiz [2007] gave a guideline for managing medical supply using a balanced schedules model and testing in real hospitals and the results showed that efficiency was improved. A review of the literature from 1990 to 2018 found that the model was divided into the supply chain model and the logistics model [Khanra et al. 2020]. The ability to discover new medical knowledge is constrained by prior knowledge that has high-dimensional time series data. They develop improved and more comprehensive approaches to studying interactions and correlations among multimodal clinical time series data [Belle, Ashwin 2015].

In this logistic model, emergency medical services include quantitative analysis, such as finding the lowest referral cost. Finding an emergency medical stop Vaccine management operating table of the emergency medical unit and qualitative analysis such as disaster planning. [Tlili et al. 2018]. The benchmark for emergency medicine efficacy in cross-border referral logistics is the starting point for having a service visitor or a customer. Medical expertise plays a role in deciding which hospital to choose. Analytic goals of medicine are prediction, modeling, and classification [Raghupathi and Raghupathi 2014]. Classification techniques include logistic regression, naive Bayesian methods, decision trees, neural networks, Bayesian networks, and support vector machines [Lee and Yoon 2017]. Therefore, the number of service users is the key to determining the support plan and the ability to formulate guidelines or methods to deal with problems effectively and performance indicators following the hospital policy province, health service area and ministry level. Based on the issues mentioned earlier, this research aims to develop a model to analyze the volume of border patients while also collecting spatial data location of hospitals near the border. The multilayer artificial neural network is one of deep learning, whose model differs from other mathematical methods and features due to the flexibility to obtain results in a nonlinear way. Ability to simulate datasets, training, learning, and improving weights close to results. The deep learning ability to adjust neural networks to learn a new environment and its forecasting capability can predict the amount of travel demand for patients across borders at each particular border. This study contributes to derived locations of the inter-reference that can handle all demand. The model allows the different data sets to predict the demand for the cross-border patient for each hospital that encompasses strategic and tactical planning decisions.

METHODOLOGY

This is a survey to study the demand for cross-border patients who wish to be admitted to network hospitals. With the outbreak of the covid 19 virus, these hospitals face huge risks in their day-to-day operations; moreover, take precautions against the virus. If border control and the hospitals use the deep learning model to predict the number of cross-border patients, they will be better prepared for planning and management.

In this study, a two-stage survey is conducted to collect data. The initial phase collects data on policy and planning. Interviews are conducted with 90 experts at the strategic group level of The Public Health Office, Commander of the Border Disease Control Division, The Hospital Director and the accident and emergency supervisor in Thailand's three northeastern frontier provinces. Next, observing patient travel behavior, route selection, vehicle type, cost by specifying a single starting point to the central hospital and finally choosing the best possible path. The areas outlined in this research were the Provincial Public Health Office, the hospitals near the border of the Lao People's Democratic Republic, a total of 28 hospitals. On the Cambodian border, a total of 28 hospitals were identified.

Study Area; Primary Hospital and Secondary Hospital.

The research team conducted this study with a list of hospitals in frontier cities; Ubon Ratchathani Province, Sisaket Province, Surin Province. Locations, as shown in Table 1. It consists of 1 permanent border crossing point, a total of 7 local, as shown in Table 2

Table 1. Researched Hospitals

No.	Name of Hospital	Frontier city	Nearby Country
1	Khemarat Hospital	Ubon Ratchathani	Laos
2	Natal Hospital	Ubon Ratchathani	Laos
3	Pho sai Hospital	Ubon Ratchathani	Laos
4	Sirinthorn Hospital	Ubon Ratchathani	Laos
5	Khong Chiam Hospital	Ubon Ratchathani	Laos
6	Buntharik Hospital	Ubon Ratchathani	Laos
7	Na Chaluay Hospital	Ubon Ratchathani	Laos
8	Nam Yuen Hospital	Ubon Ratchathani	Cambodia
9	Nam Khun Hospital	Ubon Ratchathani	Cambodia
10	Sapphasitthiprasong	Ubon Ratchathani	Medical hub
11	Kantharalak Hospital	Ubon Ratchathani	Cambodia
12	Khun Han Hospital	Ubon Ratchathani	Cambodia
13	Phu Sing Hospital	Si Sa Ket	Cambodia
14	Sisaket Hospital	Si Sa Ket	Medical hub
15	Buached Hospital	Surin	Cambodia
16	Sangkha Hospital	Surin	Cambodia
17	Kap Choeng Hospital	Surin	Cambodia
18	Surin Hospital	Surin	Cambodia

Table 2. Border Checkpoints Studied

No.	Border Checkpoints	Provinces	Border Crossing Areas
1	Trade relief point	Khemmarat district	Ban Tha Prachum, Lao PDR
2	Chong Ta U	Buntharik district	Champasak, Lao PDR
3	Trade relief point	Nam Yuen District	Phra Viharn, Cambodia
4	Permanent border	Natal District	Salavan Province, Lao PDR
5	Chong Mek	Sirindhorn District	Champasak,Lao PDR
6	Chong Sa Ngam	Phu Sing District	Udonmeechai, Cambodia
7	Chong Chom	Kap Choeng District	Udonmeechai, Cambodia

Deep learning for demand prediction

The decision system is an artificial intelligence-based problem solving tool designed to improve logistics in hospitals. The aim is to eliminate inconsistencies in hospital flows. [Dossou et al. 2021]. A Multilayer Perceptron Neural Network is a Neural Network of the feedforward type. This research is a forecasting model, deep learning techniques are adopted for diagnosing, classifying, and predicting [Ghaderzadeh and Asadi 2021]. Public datasets have training and testing datasets that are used to train and validate methods. Deep learning is suitable for complex problems as a network. The definition of an ideal model for healthcare logistics, case-based reasoning and generalization reasoning could be used [Galetsi and Katsaliaki 2020]. The MPL is an extremely powerful tool for solving various types of partial differential equations. The model includes three sets of layers: input layer, hidden layer(s) and output layer. The most commonly used multilayered network is backpropagation; MLP is trained based on that algorithm that follows a learning procedure based on error correction neurons that compute the data and undergo iterations [Arcos et al.,2018]. Then, the output layer predicts the output. The formulation of MLP output is as follows Eqs. (1):

$$a = f\left(X_{ij} + W_{ijk} + b\right) \qquad (1)$$

where a is the output, x is the input, w is the weight i to j hidden k, b is Biased. The research used multilayer perceptron algorithms to develop the MLP models, 70% (data sets) of the original data sets were randomly selected as the training set, and the remaining 20% (datasets) were used as the test set [Celikoglu 2011]. The random size is 1,000 pieces of data which never-before-learned. Radial basis functions are simple for implementing and solving high-dimensional partial (or ordinary) differential equations in complex domains. In most cases, such as the multiquadrics (MQ), inverse multiquadrics (IMQ) and Gaussian (GA), the accuracy of the RBF solution [Ilati and Dehghan 2015]

The MPL defines three data layers in this network: the input layer, two hidden layers, the output layer, and the data processing by the transfer function. The data are close to the real value used in batch training, Gradient Descent optimization. Covariates are used to control the differential influences between variables and their distribution, such as soft max function, Sigmoid function, Hyperbolic Tangent, Gaussian function [Ha et al. 2015]. For this research, the Sigmoid function is used for the hidden layer, and Identity is used for the hidden layer (Figure 2)

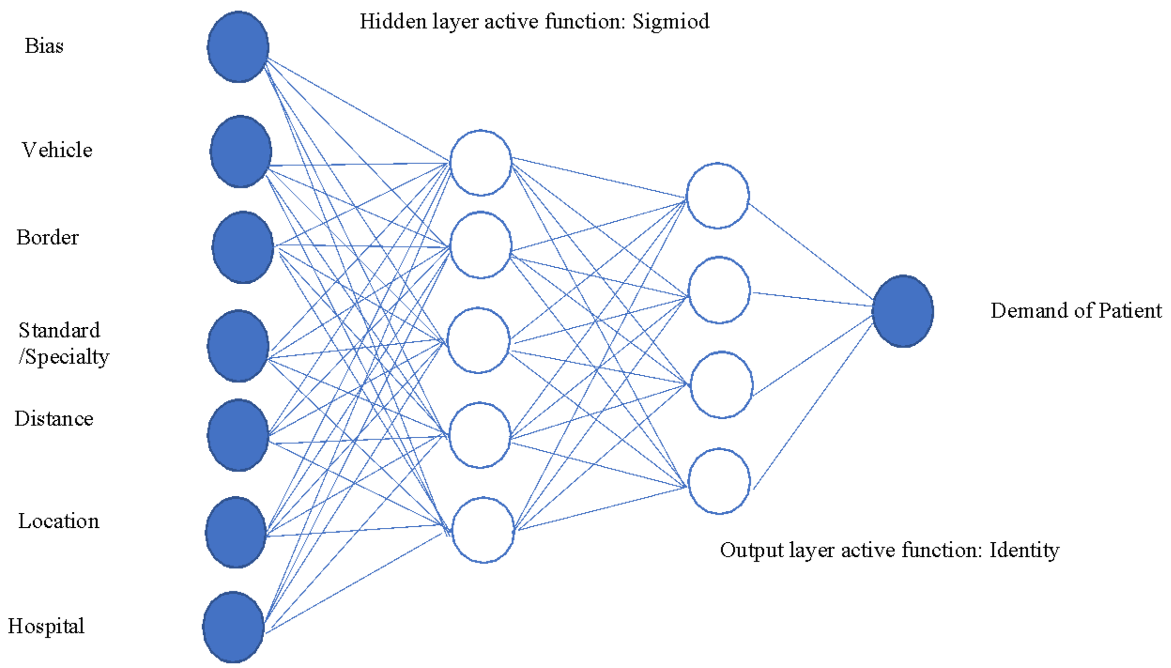

Fig.2. Multilayer Perceptron variables and active function.

Sigmoid functions are also useful for many machine learning applications in deep learning; they can be used as an activation function in an artificial neural network. The sigmoid function is defined as follows:

$$Sigmoid\ functions = \frac{e^x}{e^x+1} \tag{2}$$

An identity function is a function where each element in a set is multiplied and where the output is the same as the input. The identity function is defined as follows:

$$Identity\ function\ g(x) = x, for\ each\ x \in R, R\ is\ the\ real\ data \tag{3}$$

Determining the influential factors is considered one of the most fundamental steps in determining the international referral system. Therefore, the criteria used in the present research were adopted based on previous studies and the Ministry of Health requirements. The process resulted in 100 data. A set of variables, including information criteria of models, estimation information, formal statistical tests on residuals, and forecasting results. The parameter list is as follows;

$Demand_{patient}$: The volume of patients, Laotian or Cambodian, crossing the border from *i* to hospital *j*

Veh: This term refers to a type of vehicle for crossing point; ambulance or other.

Bor: The frontier border near Thailand.

Std: Standard hospital or specialist hospital.

Dis: This term refers to the distance from the origin *i* to the destination *hospital j*.

Loc: The location of the hospital to which the patient is willing to be referred.

Hos: This term refers to binary 1 hospital or binary 0 health center.

The accuracy of the validation proposed for this research instrument was carried out to verify the validity and accuracy of basic research instrument quality checks. The instrument was tested for accuracy, confidence, consensus or multiple choice of statements, questions, judging criteria, or evaluation, and the difficulty with different methods of operation by using statistical criteria such as analysis of the inner confidence of Pearson's Correlation Coefficient. The model validation of the goodness of fit compares the model's training and test traffic results with the actual survey values and explains the correctness. In this part of the paper, a comparative study was carried out to compare the performance and accuracy of the proposed MLP, RBF and R in order to a more comprehensive and better comparison, both statistical error analysis and graphical analysis approaches such as cross-plots and error distribution plots were used as criteria to evaluate the models. The essential statistical parameters used in this study include the average percent relative error (APRE), root mean square error (RMSE), standard deviation error mean, and correlation coefficient (R).

ANALYSIS AND RESULTS

Demand Forecasting: With regards to forecasting, this is conducted based on this model, the demand is a different original and different destination. The patient has a goal to travel to get diagnosed with professionals.

An effective model is forecasting demand from multi-location with appropriate location and standard hospital. The result of the nonlinear model was considered in Eqs. (4)

$$Demand_{\ patient} = \sum_{i:j} Veh\, w_j + \sum_{i:j} Bor\, w_j \sum_{i:j} Std\, w_j + \sum_{i:j} Dis\, w_j \sum_{i:j} Loc\, w_j + \sum_{i:j} hos\, w_j + bias \qquad (4)$$

Weight output layer, w_i*=(0.453, 4.986,-1.182, -0.944), bias=-0.054*

Forecasting performance comparison

The MLP network structure has two hidden layers as displayed and six variables. Variables include distance, a type of vehicle, border near Thailand, hospital or health control, stand of the hospital stand, or specialist hospital and location. In the summary of the MPL model, there were fewer errors in training than in testing and holding samples. Average percentage relative error (APRE) 4.031, root mean square error (RMSE) 269.8, standard deviation error means 460.4, and correlation coefficient (R) 0.877

For the RBF, the average percent relative error (APRE) 8.196, root mean square error (RMSE) 431.2, standard deviation error means 534.2, and correlation coefficient (R) 0.888

For Regression analysis coefficients of all six predictors as given correlation coefficient (R) 0.859

Table 3 Statistical parameters of the developed MLP

Statistical parameter	Value		
	MLP	RBF	R
The average percent relative error	4.031	8.196	
Root mean square error	269.8	431.2	431.2
Std. Error mean	460.4	534.2	512.1
R	0.877	0.888	0.859

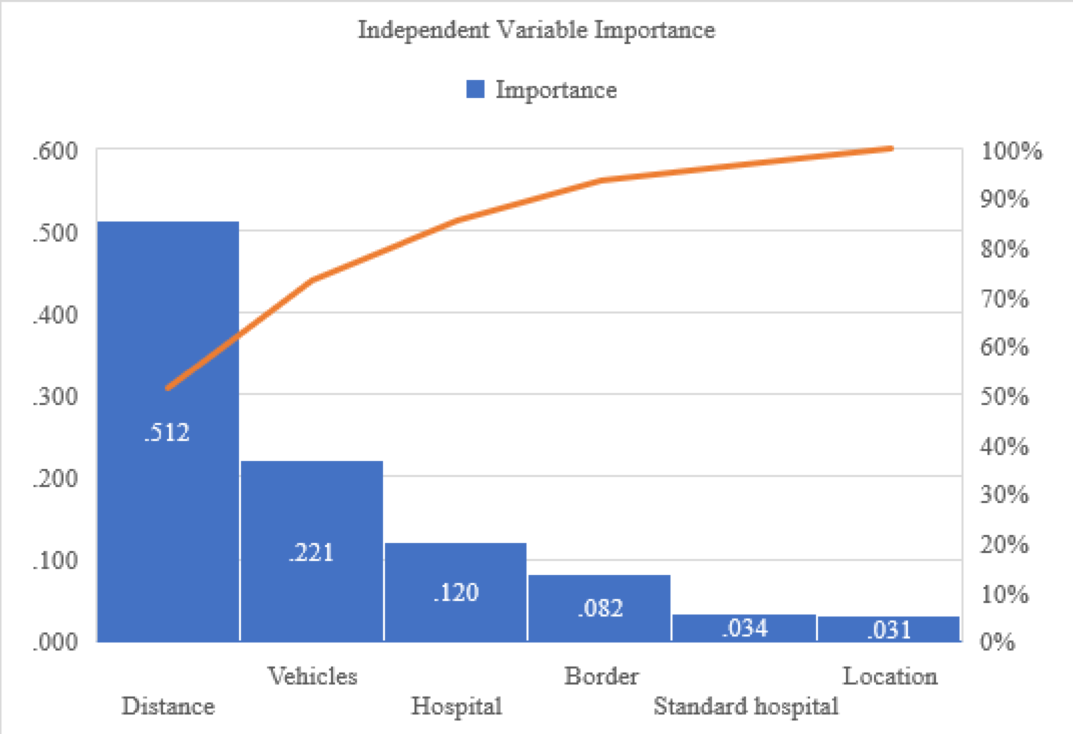

Fig. 3. Multilayer Perceptron variables and active function.

The result shows that MLP performs better than ordinary regression in terms of the amount of variation in the dependent variable explained by the model. The prediction is due to the fact that the MLP model can be used in the future with high consistency. Finally, the most important model is the distance 0.512, vehicle 0.221, hospitals 0.120, border 0.082 and standard hospital location 0.31 (Figure 3)

Both Cambodia and Lao People's Democratic Republic have an international referral policy of referral for patients to receive further treatment abroad. Regarding the referral of patients from the Lao People's Democratic Republic to Thailand, patients from there must coordinate with the border control offices. The immigration police must know the process of referring in and out and referring of any return details. The healthcare center's main activities are as follows:

Customer Service: There is an ambulance service which transports only Cambodian permanent border crossings for emergency hospital treatment in Thailand. Cambodian patients must coordinate with the immigration police to inform The Eastern Economic Corridor (EEC), Accident and the Emergency Department and ambulance staff of hospitals to have available ambulances to transport Cambodian patients. Some patients may contact the EEC directly to request an ambulance service. Most of the patients were found to have accidents injuries, followed next by antenatal and childbirth, then patients with cerebrovascular disease accounted for the final numbers. In addition, the hospital has patients suffering from chronic diseases such as anemia, diabetes, high blood pressure, plus patients requiring follow-up treatment.

Order Processing: For patients who wish to change hospitals to continue their medical treatment at the initial destination hospital. If the patient has symptoms that are not critical the doctor will assess the patient's condition and issue a referral to the patient for further examination or treatment, including being referred out.

Transport: According to the operating levels of the specific units, emergency response kits can be divided into four main categories as follows:

The first response unit (FR) is responsible for assessing and providing primary care to emergency patients, such as lifting and moving the injured, as well as providing basic resuscitation.

The basic life support unit (BLS) serves as a more capable operation than a basic life support unit, such as administering oxygen, performing basic procedures, and providing care for the injured other than proactive support.

The Advanced Life Support Unit (ALS) provides an elevated level of emergency care similar to the care of patients in a hospital emergency department, such as fluid administration, intravenous administration, and intramuscular defibrillation, airway care, and other proactive assistance.

Reverse Logistics: Reverse logistics or repatriation. There is an ambulance service for referred patients. The deceased are sent to the communicable disease control unit checkpoint at the border crossing, but there is no ambulance service to refer the deceased back across the border.

CONCLUSIONS

One of the major problems of international referrals is demand forecasting. Many healthcare organizations forecast using the gravity model and the regression model. The parameters include spatial data and nonlinear data. Therefore, this paper presents deep learning which is suitable for complex problems as a network. The findings of this research suggest that the deep learning model performs better than RBF and regression models. The model allows the different data sets to forecast the demand for each hospital. Based on the identification of the knowledge gap, this approach could be recommended for healthcare logistics to determine the treatment supply chain and the future ability to formulate guidelines effectively with healthcare logistics effectively.

In addition, this study tried to train multiple data sources to build model bases that could be used for predictive analysis. The field of healthcare logistics must utilize the best available supply chain system to provide the best treatment possible to its patients. The impact and responsibilities of the destination countries are relative to the political risk. The main activity must be to coordinate with the immigration police before crossing the border. The border office must know the process of referring in and out ;additionally, referring any return details. Furthermore, opportunities or challenges can interface with applications in medicine and clinical decision support. The deep learning approaches could benefit the healthcare field, such as applications related to these methods when used in the context of precision medicine, Diagnosis classification, Prediction of Disease, and so on. However, we also note limitations and need for improved methods development and applications, especially in terms of simplicity of use and accuracy.

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ORIGINAL PAPER

OPTIMISATION OF THE STOCK STRUCTURE OF A SINGLE STOCK ITEM TAKING INTO ACCOUNT STOCK QUANTITY CONSTRAINTS, USING A LAGRANGE MULTIPLIER

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ABSTRACT. Background: Optimisation in the area of stock management is most often performed in relation to cycle stock. The classic example here is the Harris-Wilson formula for calculating the economic order quantity. Often these models are not subject to any constraints imposed on the optimised quantities. However, in practice, taking such constraints into account is important. The application of the so-called Lagrange multiplier is helpful here, but the examples of its application usually refer to the multi-position sets of stock items (e.g. the search for the optimum structure of stock of material groups in the case of capital constraints). This paper attempts to optimise the structure of the stock (cycle stock vs. safety stock) for a single stock item.

Methods: To achieve the objective of determining the optimum stock structure for the various conditions under which stock replenishment is implemented, a general model has been built, a component of which is a Lagrange function containing the constraint conditions for the solution. Next, this model has been implemented in the form of an EXCEL spreadsheet application.

Results: The result of solving the optimization task based on the proposed model is a system of equations, the solution of which (with the help of the EXCEL application) allows to determine the optimum value of the Lagrange multiplier, on the basis of which the components of the inventory structure and other related quantities (service level indicators and costs, such as stock replenishment, stock maintenance and stock deficit costs) are calculated. This has been illustrated using a fictitious example, which at the same time made it possible to observe certain general relationships between the adopted constraints and the recorded quantities.

Conclusions: Two types of conclusions can be presented. The first type concerns the approach itself. The possibility of determining the optimum structure of the stock (cycle stock vs. safety stock) depending on various values characterising the adopted stock replenishment system as well as the adopted limitations has been demonstrated. The second type of conclusions results from the presented example of application of the method for the assumed ranges of changes of selected quantities.

Keywords: stock optimization, Lagrange multiplier, service level, stock related costs

INTRODUCTION

Commonly applied models of costs related to stock cover their three groups: stock replenishment, stock maintenance, and stock deficit costs [e.g., Korponai et al., 2017]. It allows optimising the value of parameters controlling stock replenishment [e.g., Samak-Kulkarnia, Rajhansb, 2013]. The objective function adopted in the considerations is the total cost including the above-mentioned cost groups. The cost of stock maintenance and replenishment has been limited to variable costs since all fixed costs, even if included in the model, would disappear after differentiation, as independent of the assumed independent variables. These variables are two quantities that impact both the components considered in the stock of a given stock item: the quantity of order (delivery) quantity q (which affects the cycle part) and the safety factor ω determining the quantity of the safety stock. The optimization of delivery quantity is often applied, and its classic example is the commonly used formula for the so-called economic order size, first presented by F.W.

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Harris [Harris 1913] (despite significant limitations in its application) . The case is different when it comes to optimising the level of service and, more generally, the safety coefficient. Usually these values are determined arbitrarily, on the basis of experience, customers' requirements or by comparison with competitors. Meanwhile, if the costs accompanying the occurrence of stock deficit are known (both related to the occurrence itself and to the deficit quantity), it is possible to determine the optimum value of the safety coefficient, ensuring minimisation of the sum of the expected annual cost of occurrence of stock deficit and the annual cost of maintaining the safety stock.

Figure 1 shows a synthesis of the research problem presented in this paper. For comparison, it shows the problem in the case of no constraints and the situation where some constraints related to the allowable stock size are imposed on the objective function.

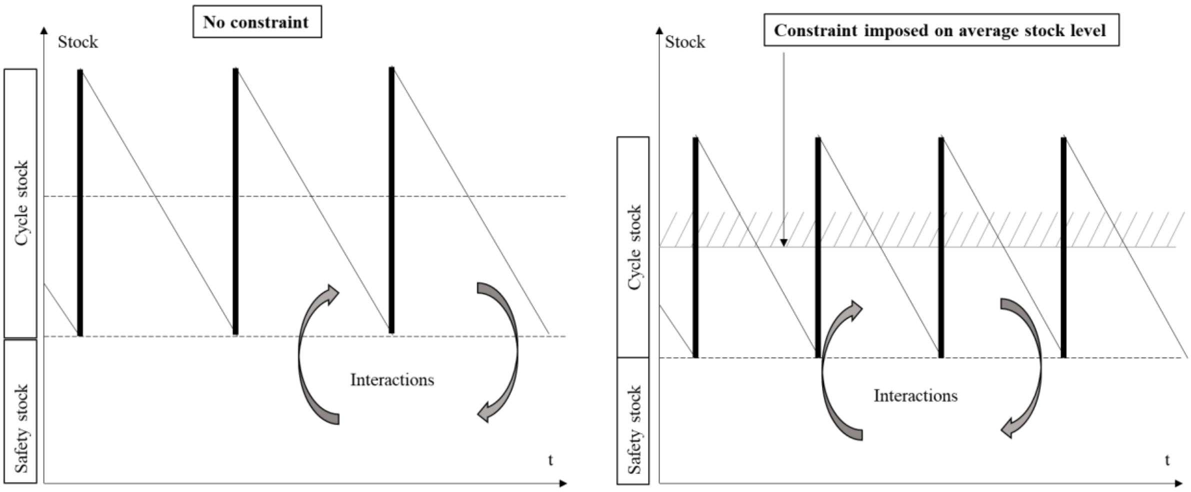

Fig. 1 Synthesis of the research problem - optimization of cycle and safety stock in the absence of constraints and in the situation of imposition of constraints (here - the maximum level of average stock size).

Source: own study.

It is worth noting that there are interactions between the optimal size of cyclic stock (optimization of delivery quantity q) and the optimum level of the safety stock (optimization of safety coefficient ω). For example, decreasing the cycle stock (by decreasing the delivery quantity) results in the need to increase the number of orders, and this increases the expected cost of stock deficit, resulting in the need to increase the safety stock. On the other hand, decreasing the safety stock increases the risk of shortage in the replenishment cycle and forces an increase in the volume of deliveries and consequently in the cycle stock.

TOTAL STOCK COST MODEL WITH CONSIDERATION OF CONSTRAINTS

It has been assumed that the stock is replenished in the Reorder Point system, with a fixed order (delivery) quantity. This system, in the terminology of the European Logistics Association, is denoted as BQ [European Logistics Association 1994].

The model applies the following designations related to demand, costs, and service level:

D – demand in a time unit (e.g., daily/weekly demand),

σ_D – standard deviation of demand in an adopted time unit,

σ_{DLT} – standard deviation of demand in a stock replenishment cycle of mean LT,

D_a – annual total demand,

cc_a – annual stock-carrying cost coefficient,

ω – safety coefficient – directly influencing service level:

αSL – service level (probability of a non-occurrence of stock deficit in its replenishment period, probability to serve demand in a cycle), corresponding to safety coefficient ω treated as an independent variable,

FR (fill rate) - as a percentage realization of demand in a quantitative approach

q – order/delivery quantity – independent variable,

c_r – unit cost of stock replenishment (cost of order, organisation, and execution of a single delivery),

cd_1 cost related to stock deficit occurrence during the stock replenishment cycle,

cd_2 – cost related to stock deficit occurrence in relation to one missing piece of the stock item,

p_u – purchase price (variable production cost) of a unit of the discussed stock item,

nd_a – number of orders (delivery) per year.

The considerations concern stock replenishment on the basis of reorder level, with a fixed delivery quantity. A cost model covering the stock replenishment, stock carrying, and stock deficit of stock will be the starting point.

$TC =$	$\frac{D_a}{q} \cdot c_r +$	$\frac{1}{2} q \cdot p_u \cdot cc_a +$	$\omega \cdot \sigma_{DLT} \cdot p_u \cdot cc_a +$
Overall cost	Annual replenishment cost	Average cost of carrying cycle stock	Periodical (e.g., annual) cost of carrying safety stock

$+cd_1 \cdot [1 - F(\omega)] \cdot \frac{D_a}{q}$	$+cd_2 \cdot I(\omega) \cdot \sigma_{D,LT} \cdot \frac{D_a}{q}$	(1)
Stock deficit cost resulting from stock deficit occurrence probability in a replenishment cycle	Stock deficit cost resulting from deficit volume	

This formula should now be extended by adding one more component:

$$+\lambda \cdot \left(\frac{1}{2} \cdot q \cdot c + \omega \cdot \sigma_{DLT} \cdot c - C\right) \quad (2)$$

The product of the Lagrange multiplier λ by the assumed constraint.

There are many examples of an application of Lagrange multiplier for stock optimization. Yassa R. I, Ikatrinasari Z.F. (2019) used it for calculations of multi-item Economic Order Quantity. Fergany H. A., Gomaa M. A (2018) applied a Lagrange multiplier based model to analyse how to deduce the optimal order quantity and the optimal reorder point to reach a minimal expected total cost. Lukitosari V. et al. (2019) used the Lagrange multiplier method to solve inventory model for spare parts. Examples of application of Lagrange multiplier for stock optimisation can be also found in a review paper by Hoswari S. et al (2020).

The product (2) is always equal to zero, which follows from the definition of the Lagrange multiplier [e.g., Kowiger 2012]; in the discussed case:

$$\lambda = 0 \quad if \quad \left(\frac{1}{2} \cdot q \cdot c + \omega \cdot \sigma_{DLT} \cdot c - C\right) \neq 0$$

$$\lambda \neq 0 \quad if \quad \left(\frac{1}{2} \cdot q \cdot c + \omega \cdot \sigma_{DLT} \cdot c - C\right) = 0$$

C – constraint

c - the unit quantity of the assumed constraint:

c = p_u (unit price if the stock holding cost is a constraint: C = SHC)

c = v (volume of the stock unit, if the stock volume V is a constraint: C = V)

c = m (mass of the stock unit, if the stock mass M is a constraint: C = M)

c = 1 (when the constraint is the stock quantity in natural units)

After adding the constraint component together with the Lagrange multiplier, the model becomes a Lagrange function and will be further denoted by L.

$$L = \frac{D_a}{q} \cdot c_r + \frac{1}{2} \cdot q \cdot p_u \cdot cc_a + \omega \cdot \sigma_{DLT} \cdot p_u \cdot cc_a +$$

$$+cd_1 \cdot [1 - F(\omega)] \cdot \frac{D_a}{q} + cd_2 \cdot I(\omega) \cdot \sigma_{DLT} \cdot \frac{D_a}{q}$$

$$+\lambda \cdot \left(\frac{1}{2} \cdot q \cdot c + \omega \cdot \sigma_{DLT} \cdot c - C\right) \qquad (3)$$

Coefficient ω occurring in the part of formulas (1) and (3), related to the carrying of safety stock, is called here the safety coefficient, and it depends on the adopted service level understood as the probability of serving the entire demand in a replenishment cycle αSL [Tempelmeier, 2000], as well as on the type of demand distribution.

The standard deviation in a stock replenishment cycle σ_{DLT} is generally calculated using the following formula:

$$\sigma_{DLT} = \sqrt{\sigma_D^2 \cdot LT + \sigma_{LT}^2 \cdot D^2} \qquad (2)$$

where:

σ_D – standard deviation of demand in an adopted time unit,

LT – mean stock replenishment cycle time,

σ_{LT} – standard deviation of the replenishment lead time.

Amounts F(ω) and I(ω) present in formula (1) and used to calculate the stock deficit cost are as follows:

F(ω) – distribution function related to the distribution of demand observed in a stock replenishment cycle, equal to service level αSL; thus [1- F(ω)] is a probability (risk) of going out of stock during a replenishment lead time.

I(ω) – standardised number of deficits; expected volume of deficits in a cycle is calculated with the following formula: $I(\omega) \cdot \sigma_{D,LT}$.

The standardized number of deficits can be calculated as follows [e.g. Krzyżaniak 2017]:

$$I(\omega) = f(\omega) - \omega \cdot [1 - F(\omega)] \qquad (3)$$

where f(ω) is the function of the density distribution.

A prerequisite for the existence of a minimum of the L-function is the zeroing of the first derivatives of the L-function with respect to both independent variables: q and ω.

The derivatives with respect to the assumed independent variables are calculated as follows:

$$\frac{\delta L}{\delta q} = -\frac{D_a \cdot c_r}{q^2} + \frac{p_u \cdot cc_a + \lambda \cdot c}{2} - \frac{D_a \cdot \{cd_1 \cdot [1-F(\omega)] + cd_2 \cdot I(\omega) \cdot \sigma_{DLT}\}}{q^2} \quad (4)$$

$$\frac{\delta L}{\delta \omega} = \sigma_{DLT} \cdot p_u \cdot cc_a - cd_1 \cdot \frac{D_a}{q} \cdot \frac{dF(\omega)}{d\omega} + cd_2 \cdot \sigma_{DLT} \cdot \frac{D_a}{q} \cdot \frac{dI(\omega)}{d\omega} + \lambda \cdot \sigma_{DLT} \cdot c \quad (5)$$

It should be noted that $\frac{dF(\omega_i)}{d\omega_i} = f(\omega_i)$, which is the density function of the distribution under consideration.

It can be demonstrated [e.g. Krzyżaniak 2017] that:

$$\frac{dI(\omega)}{d\omega} = \frac{df(\omega)}{d\omega} + \omega \cdot f(\omega) + F(\omega) - 1$$

and in the case of a normal distribution, which is assumed in the solution, there is

$$\frac{dI(\omega)}{d\omega} = F(\omega) - 1$$

In addition, the derivative with respect to the Lagrange multiplier is calculated:

$$\frac{\delta L}{\delta \lambda} = \frac{1}{2} \cdot q \cdot c + \omega \cdot \sigma_{DLT} \cdot c - C = 0 \quad (6)$$

From condition $\frac{\delta L}{\delta q} = 0$ we obtain:

$$q = \sqrt{\frac{2 \cdot D_a \cdot \{c_r + cd_1 \cdot [1-F(\omega)] + cd_2 \cdot I(\omega) \cdot \sigma_{DLT}\}}{p_u \cdot cc_a + \lambda \cdot c}} \quad (7)$$

From formula (5), assuming that $\frac{\delta L}{\delta \omega} = 0$, and considering that $\frac{dF(\omega_i)}{d\omega_i} = f(\omega_i)$ we obtain:

$$q = \frac{D_a \cdot [cd_1 \cdot f(\omega) + \cdot cd_2 \cdot \sigma_{DLT}(1-F(\omega))]}{\sigma_{DLT} \cdot (p_u \cdot cc_a + \lambda \cdot c)} \quad (8)$$

When comparing the delivery quantity q from equations (7) and (8), we obtain the following equation:

$$\sqrt{\frac{2 \cdot D_a \cdot \{c_r + cd_1 \cdot [1-F(\omega)] + cd_2 \cdot [f(\omega) - \omega \cdot [1-F(\omega)]] \cdot \sigma_{DLT}\}}{p_u \cdot cc_a + \lambda \cdot c}} = \frac{D_a \cdot [cd_1 \cdot f(\omega) + \cdot cd_2 \cdot \sigma_{DLT}(1-F(\omega))]}{\sigma_{DLT} \cdot (p_u \cdot cc_a + \lambda \cdot c)} \quad (9)$$

Figure 2 shows a simplified algorithm to determine the optimum value of the Lagrange multiplier λ_{opt}, allowing the calculation of the optimal pair of independent variables $\{q; \omega\}_{opt}$.

TOTAL STOCK COST MODEL - WITHOUT CONSTRAINTS

The solution to the problem of optimizing the order quantity and safety coefficient in the case of no constraints can be found using the above equation, functions and relations, assuming the Lagrange multiplier λ=0 (as indicated above, this applies to the case when $\left(\frac{1}{2} \cdot q \cdot c + \omega \cdot \sigma_{DLT} \cdot c - C\right) \neq 0$, i.e., when no constraint C applies. Equation (3) will then take the following form:

$$TC = \frac{D_a}{q} \cdot c_r + \frac{1}{2} \cdot q \cdot p_u \cdot cc_a + \omega \cdot \sigma_{DLT} \cdot p_u \cdot cc_a + + cd_1 \cdot [1 - F(\omega)] \cdot \frac{D_a}{q} + cd_2 \cdot I(\omega) \cdot \sigma_{DLT} \cdot \frac{D_a}{q} \quad (14)$$

Formulas (4), (5),)7), (8) and (9) can be transformed in a similar way (that is, by removing the Lagrange multiplier λ from them) and then using the idea of the algorithm shown in Figure 2.

In the case of unconstrained optimization, in order for the pair $\{q, \omega\}_{opt}$ to correspond to the local minimum of the TC function, in addition to the conditions of zeroing of the first derivatives of the TC function with respect to q and ω, the conditions associated with the second derivatives of the TC function must be satisfied:

$$\partial = \left[\frac{\delta^2 TC}{\delta q\ \delta\omega}\right]^2 - \frac{\delta^2 TC}{\delta q^2} \cdot \frac{\delta^2 TC}{\delta \omega^2} < 0 \qquad (10)$$

$$\text{and } \frac{\delta^2 TC}{\delta q^2} > 0 \text{ and } \frac{\delta^2 TC}{\delta \omega^2} > 0 \qquad (11)$$

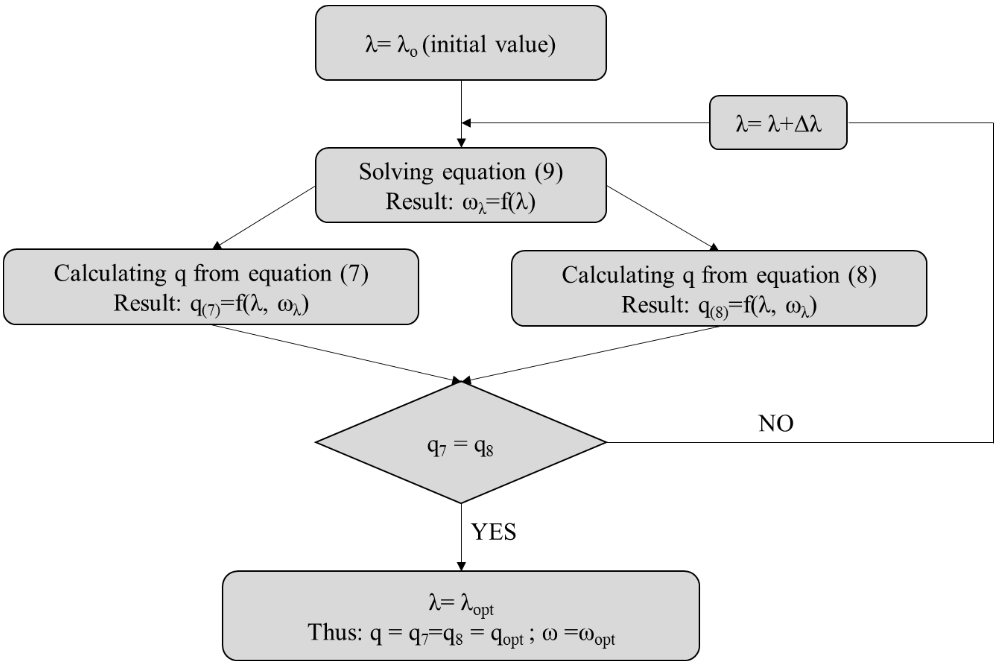

Fig. 2. The algorithm for determining the optimum delivery quantity (q_{opt}) and safety coefficient (ω_{opt})

Source: own study.

Table 1 Data adopted in the presented example

D = 50 units per week
σ_D = 10 unit standard deviation of weekly demand,
LT = 4 weeks (replenishment lead time), with no delays ($\sigma_{DLT} = 0$)
$\boldsymbol{\sigma_{DLT} = \sigma_D \cdot \sqrt{LT} = 20\ units}$
D_a =2,600 units,
cc_a – 0.1,
c_r = 300 €,
cd_1 = 500 €, 1,000 €
cd_2= 50 €
p_u = 500 €
Constraint – C = maximum admissible average stock level: 70, 80, 90, 100, 110, 120 units.

Source: own study.

AN EXAMPLE OF MODEL APPLICATION

The above considerations will be illustrated using the example of hypothetical material item X. The following data have been assumed (according to the previous designations):

The calculation algorithm shown in Figure 2 has been implemented in the EXCEL spreadsheet application. This tool has been used to determine the optimum stock structure and other accompanying indicators for the quantities assumed in the example.

In addition - as an example - the impact of changes in one of the assumed cost quantities (cost related to stock deficit occurrence during the stock replenishment cycle) on the optimal stock structure in the case of optimisation without constraints and for the chosen constraint value (maximum admissible average stock level C=70 units) has been examined. The results are presented in Fig. 4.

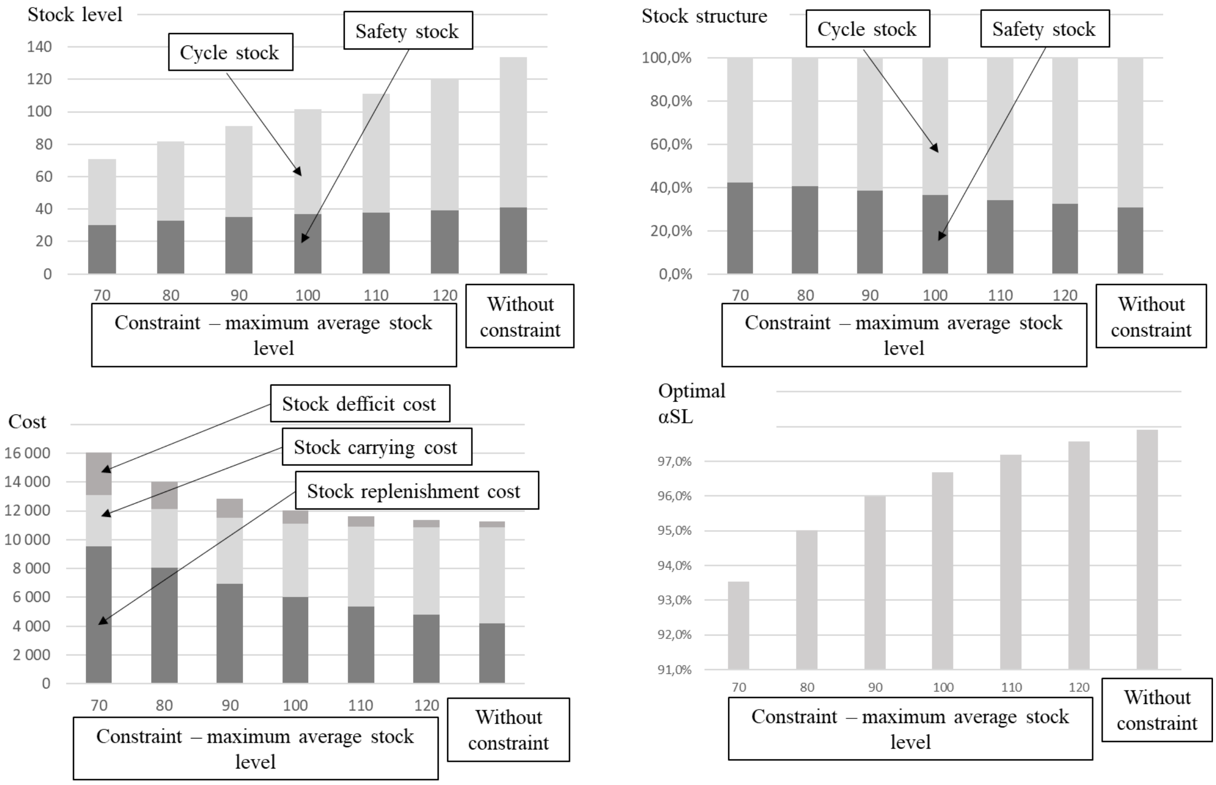

Fig. 3 Results of optimization calculations: stock level, stock structure, stock costs (replenishment, maintenance and deficit) and optimum service level αSL under selected constrain levels in given conditions (maximum acceptable average stock level) and for the case where no constraint has been introduced.
Source: own study.

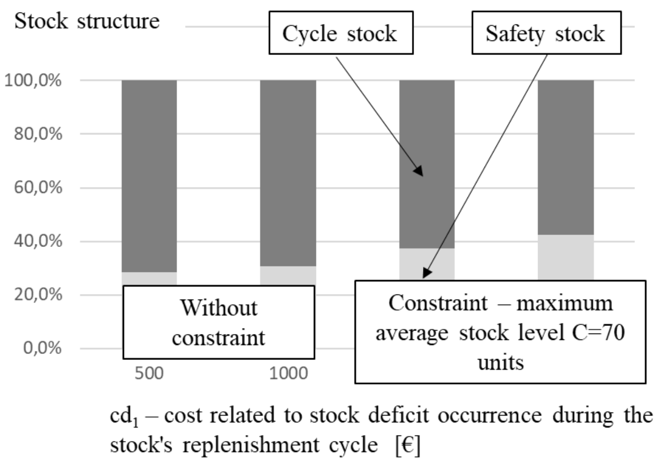

Fig. 4. The impact of changes on one of the assumed cost quantities (cost related to stock deficit occurrence during the stock replenishment cycle) on the optimum stock structure in the case of optimisation without constraints and for the chosen constraint value has been examined.

Source: own study.

CONCLUSIVE REMARKS

The use of the Lagrange multiplier is a well-known way to determine the optimum values of independent variables in the presence of constraints (ties) imposed on the quantities occurring in optimisation models. In the area of inventory management, the application of this method usually concerns sets of stock items, where, e.g. capital constraints (total stock outlays) or spatial constraints (total stock volume) are introduced. The paper demonstrates the possibility of applying the Lagrange multiplier for a single stock item, assuming the total cost of: replenishment, maintenance and deficit to be the objective function. Two types of deficit costs were taken into account: those resulting from the very occurrence and from quantitative shortages. The independent optimised variables have been the order quantity and the so-called safety coefficient, which translates into service level (measured by two indicators). Both of these quantities determine the two main components of the stock structure: the cycle stock and the safety stock. When we impose constraints (related to quantity, value, or space) on the stock, which means that the average total stock cannot exceed a certain level of constraint, we obtain the optimum stock structure under given conditions, i.e. the percentage share of each stock component in the total stock. Optimisation models, taking into account the restrictions imposed on the size of the stock, have been presented under the assumed conditions (stock replenishment in the Reorder Point system, distribution of the demand frequency occurrence in accordance with the normal distribution) and the method of solving this optimisation task has been indicated.

The proposed algorithm using the developed models has been implemented in an EXCEL spreadsheet application and calculations have been carried out for an example data set. Although the purpose of this has been mainly to illustrate the possibility of carrying out optimisation with imposed constraints, the presented results can also be in themselves a source of interesting information about the impact of selected values (mainly the level of constraints) on changes in the optimum stock structure. This example can be an inspiration for more complex research on the impact of various factors on optimisation results.

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ORIGINAL PAPER

INITIATORS AND MOTIVES FOR COOPERATION IN HUMANITARIAN SUPPLY CHAINS

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ABSTRACT. Background: The concept of humanitarian supply chain management is based on theoretical and methodological assumptions of the idea of cooperation between industry and trade. The overarching goal of humanitarian aid is to save or improve people's quality of life, which makes the problem of economic efficiency a secondary issue. The subjective structure of supply chains is also different, which determines the division of roles and motives in the process of cooperation between their participants. The publication aims to identify differences and controversies related to the transformation of the business concept of supply chain management into the cooperation of entities as part of humanitarian aid actions. Consequently, the second objective tends to identify factors of logistic cooperation among humanitarian organizations.

Methods: To achieve both goals, the article was divided into a theoretical part on the idea of logistics cooperation in supply chains (methods: logical analysis and critical analysis of the subject literature) and a presentation of the results of an anonymous questionnaire survey diagnosing initiators and determinants of logistics cooperation in humanitarian supply chains in Poland (methods: questionnaire survey and descriptive statistics).

Results: Humanitarian and business supply chains differ in terms of the purpose of functioning, the main entity that coordinates material, information, financial, human and reverse flows, stakeholders of the activities carried out, the location of the idea of cooperation in the supply chain management system and the impact of external conditions on efficiency of functioning. Regularities are diagnosed with respect to the initiators and factors of logistic cooperation in humanitarian supply chains: (1) the main initiators of logistic cooperation in humanitarian supply chains are humanitarian organizations who (2) underestimate the important factors and opportunities to achieve synergistic effects, there is a (3) requirement for greater involvement of national government institutions and international humanitarian organizations, and (4) the type of a humanitarian crisis has an impact on logistic cooperation.

Conclusions: A random sample of 100 humanitarian NGOs based on a survey requires a more complete diagnosis of the initiators and the correctness of logistic cooperation in humanitarian supply chains from the perspective of other actors and beneficiaries of aid actions, as well as in the context of competition of cooperating entities, i.e., coopetition. Survey responses obtained should be confronted with an in-depth analysis of a case study of logistic cooperation in humanitarian supply chains to war refugees from Ukraine.

Keywords: cooperation, humanitarian supply chain, humanitarian crises, logistics cooperation

INTRODUCTION

Crises related to hostilities, natural disasters, technical disasters, or terrorist attacks require aid activities to be carried out as part of humanitarian supply chains. Although the awareness of the importance of logistics support in warfare and rescue operations has been developing since ancient times, the theoretical foundations of the so-called humanitarian supply chains have only recently crystallized. The authors who attempted to define and describe their essence start primarily from the professionalization of tasks related to safety and providing assistance in saving human health and lives and then point to their role in counteracting, minimizing, and even eliminating the negative effects of random events [Thomas 2004; Thomas and Mizushima 2005; Thomas and Kopczak 2005]. Nowadays, there are also views that indicate the need to include in the management of humanitarian aid actions the category of efficiency of flows of people, goods, and services. An example is a proposal for a definition of J. Marcinkowski [2019], who

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understands humanitarian logistics as "*coordinating the processes of flows of goods, people and services with accompanying information in connection with the difficult situation of society..., to provide assistance and reduce and/or eliminate the effects of events in an efficient and effective way*". Although it can be agreed that the professionalization of flows of people, goods, and services during humanitarian operations should take into account the possibilities of reducing the associated costs, the assumption of striving to achieve the effectiveness of these flows in the situation of saving people's lives and health becomes a secondary goal. Therefore, based on the subjective interpretation of supply chains [Witkowski and Baraniecka 2018], the essence of **humanitarian supply chains are cooperating government organizations, local governments, non-profit institutions, enterprises, and individuals whose common goal is to obtain, move and distribute material and financial aid and related information to prevent or reduce the negative effects of crises on residents in the affected areas**. The humanitarian supply chain ideogram is presented in Figure 1.

The discussion of the humanitarian supply chain is getting more and more attention among researchers in recent years. The potential for cross-learning between the humanitarian and private sectors in the context of cooperation has been discussed by L. van Wassenhove [2006]. The author suggested the need for agility, adaptability, and alignment for humanitarian organizations and for wide cooperation of humanitarian actors in disaster relief to make humanitarian supply chains more effective. The infancy of humanitarian relief chain coordination has been discussed by B. Balcik et al. [2010]. The topic is all the more justified due to the variety of humanitarian actors involved with different logistics expertise. Therefore, there is a question on how to measure performance in humanitarian supply chains. This topic has been already discussed by B. Beamon and B. Balcik [2008], who compared performance measurements of humanitarian and business supply chains and proposed new performance metrics. The authors have underlined, among others, the role and impact of cooperation and coordination of relief chains. However, the discussion among academicians on the role of particular humanitarian actors is visible in the literature. R. Tomasini and L. van Wassenhove [2009] diagnosed the role of the private sector, while A. Leiras et al. [2014] suggested the need for a closer relationship between humanitarian organizations and academia. The cooperation of humanitarian actors is varied; however, the composition of the entire network imposes the necessity of effective and purposeful cooperation [Marcinkowski 2022]. However, the subject literature on cooperation in humanitarian supply chains faces a lack of publications referring to the factors of logistics cooperation and its initiators.

Thus, the main objective of the article is composed of two parts. The first objective is to identify the differences between logistics cooperation in business and humanitarian supply chains. Consequently, the second objective tends to identify factors of logistic cooperation among humanitarian organizations. To achieve both goals, the publication was divided into a theoretical part concerning the idea of logistics cooperation in supply chains and a presentation of the results of a questionnaire survey diagnosing initiators and determinants of logistics cooperation in humanitarian supply chains in Poland. The adopted research procedure is presented in Figure 2. It consists of three interrelated parts, in which there are separate steps with their own goals and the research methods used. A broader explanation of the methods from the second part will be presented in the following parts of the publication.

The article consists of four sections. The first part is an introduction to the issue under study, in which the motives for taking up a given topic have been presented. The second part presents the idea of cooperation in humanitarian supply chains in theoretical terms. The third part is the results of the questionnaire survey, so the empirical part, in which the initiators and factors of development of logistics cooperation in humanitarian supply chains are identified. In the last part, the most important conclusions and the resulting prospects for further research are formulated.

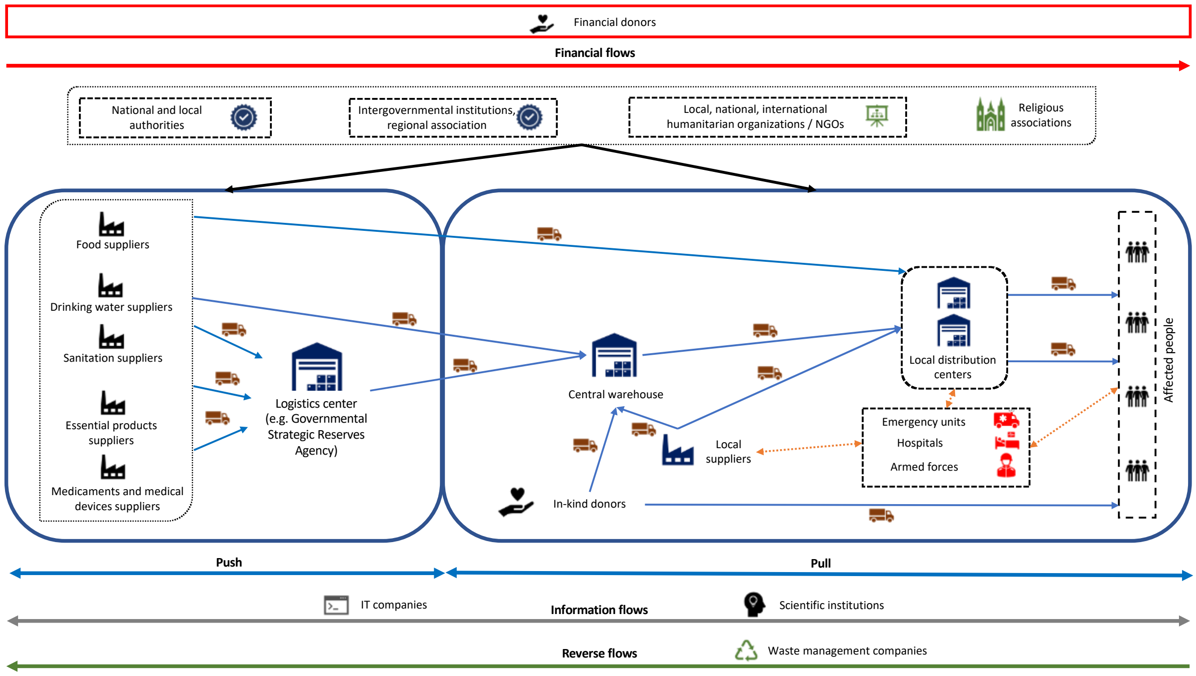

Fig. 1. Subject structure of the humanitarian supply chain. Source: own elaboration.

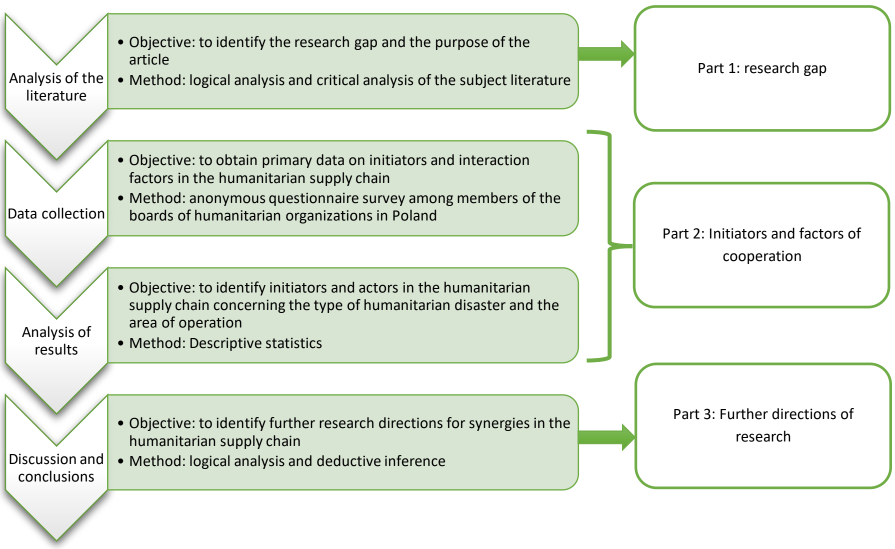

Fig. 2. Research procedure. Source: own elaboration.

THE IDEA OF COOPERATION IN HUMANITARIAN SUPPLY CHAINS

According to T. Kotarbiński, who was one of the creators and propagators of the praxeological theory of efficient cooperation, **the concept of positive cooperation means organized cooperation, in which all participants are united by a common goal superior to various individual goals** [Kotarbiński 1972]. The main benefit of cooperation is synergy, i.e. additional effects that are greater than the sum of the effects of activities carried out individually. To achieve additional synergistic effects of interaction in supply chains, it is necessary to shape the relationship between its links based on trust and proportional sharing of risks and benefits between them. The literature on the importance, participants, conditions, and types of partnership relations between suppliers and customers in business supply chains for achieving synergistic interaction effects and sustainable competitive advantage has been developing since the mid-90s of the twentieth century [Lambert, Emmelhainz and Gardner 1996]. From the perspective of the study of business relationships in supply chains, a special place is given to the theory of transaction costs to justify outsourcing [Williamson 2008] and explain the sources of efficiency [Kekokivi and Mahoney 2020]. However, there is a cognitive gap on the correctness of cooperation between participants in humanitarian supply chains, where rational motivations and effective goals of cooperation are of secondary importance to saving the lives and health of victims.

Regardless of the chronic nature of some emergencies (e.g., a long-term pandemic), in most cases, humanitarian supply chains arise as a response to sudden and unpredictable events that require a range of tactical and operational decisions and actions. Decisions to evacuate or leave the population in vulnerable areas are the responsibility of governments or local authorities. On the other hand, the basic decisions and logistic actions were taken by humanitarian organizations after the occurrence of a crisis include purchase of aid products, choice of means of transport and route of transport from the supplier to the place of the disaster, the location of temporary storage facilities, and the provision of aid to those in need (Witkowski, 2020).

In addition to the pressure of time and costs, an additional difficulty in making these decisions and actions is the diversity of stakeholders of aid actions (so-called humanitarian actors), which, apart from humanitarian organizations (local, national, and international), include: other nongovernmental organizations, religious associations, sponsors (individual and collective donors), intergovernmental organizations, authorities (local, national, and international), logistics service providers, suppliers (food manufacturers, drinking water suppliers, sanitation suppliers, suppliers of medicines and medical devices, suppliers of other necessities), emergency units, hospitals, armed forces, fuel companies, IT and telecommunications companies, waste management companies, scientific institutions, and communities affected by humanitarian crisis. Due to the low participation, and often even omissions, of these entities in strategic preventive activities, the greatest problems with the coordination of their activities occur immediately after the disaster and are gradually alleviated in the reconstruction phase. The requirements for humanitarian supply chains in different phases of crises are presented in Table 1, while the main differences between logistics interoperability in business and humanitarian supply chains are systematized in Table 2.

Due to the time pressure and *ad hoc* nature of humanitarian supply chains, their functioning is disrupted by the lack of professionalization of decisions and actions taken by volunteers from humanitarian aid organizations. This is mainly due to the lack of properly prepared management staff, but also to the lack of developed organizational structures, procedures, and modern ICT technologies for information transparency of humanitarian supply chains (see [Baumgarten 2010]). The advantage of the intuitive method of making operational logistics decisions and operating in difficult infrastructure conditions in areas affected by disasters often results in a lack of effectiveness and high costs of aid actions.

Table 1. Challenges for humanitarian supply chains in different phases of emergencies

Challenges \ Disaster phase	**Prevention**	**Emergency aid**	**Reconstruction**
Duration	Long and continuous	Days, weeks, months	Months, years
The scale of transport activity	Low	High	Moderate
Types of supplied aid	Reserves of standard aid products	Food, medical products, sanitation, water, tents, etc.	Wide range of different products
Source of purchase	Local	International	Local and international
Time pressure	Low	High	Moderate
Stakeholders pressure	Low	High	Moderate

Source: own elaborations based on [Kessler 2013].

Table 2. Differences between logistics cooperation in business and humanitarian operations

Features \ Type of chain	**Business supply chain**	**Humanitarian supply chain**
Aim	Effective and efficient flow of products, information, and financial resources to increase the added value	Preventing or limiting the effects of crises (hunger, epidemics, homelessness, mortality, etc.) under the pressure of time-domination over costs
The main link in the supply chain	Consumer as a source of demand and the end link in the supply chain	Humanitarian organizations and, if necessary, local and national government institutions as initiators and central coordinators of aid operations
Key participants/stakeholders	Clients, production and trading companies, logistics companies, transaction brokers	Humanitarian organizations, victims, sponsors, national and local authorities, uniformed services, media, logistics companies
Place in the management system	Integration in strategies, organizational structures, and IT systems	The dominance of intuitive decisions and non-integrated operational activities
External conditions	Stable infrastructural, technological, and legal conditions	Underdeveloped or destroyed logistics infrastructure and frequent political and legal instability

Source: [Witkowski 2015].

INITIATORS AND FACTORS OF DEVELOPMENT OF LOGISTICS COOPERATION IN HUMANITARIAN SUPPLY CHAINS – SURVEY RESULTS

The empirical part of the article focuses on the diagnosis of initiators and factors of logistics cooperation in humanitarian supply chains. These factors determine *implicitly* the undertaking of joint transport and storage ventures, the final effect of which is to save or improve the quality of life of people affected during humanitarian crises.

The identification of the initiators and the assessment of the factors of logistics cooperation were carried out using an anonymous questionnaire addressed to members of boards of humanitarian organizations operating in Poland. The structure of the questionnaire consisted of three parts, and only a fragment of the questionnaire was taken for analysis in this article. The survey was conducted between November 2021 and January 2022 among humanitarian organizations in Poland that provide aid in-kind and/or technical assistance. This means that organizations that are exclusively engaged in the provision of financial assistance have been excluded from the population. The completion of the questionnaire survey in January 2022 also eliminated the possible disruption of the concentration of humanitarian organizations' activities mostly (or exclusively) on helping people affected by the war in Ukraine from 24.02.2022.

The research sample consisted of 100 humanitarian organizations, that is, 10-15% of all organizations operating in Poland dealing with humanitarian aid. At this point, it should be emphasized that it was impossible to indicate the total population of humanitarian organizations. The report of the Central Statistical Office in Poland from 2019 indicates that there were 88,000 nongovernmental organizations in Poland, of which 6,600 dealt with social and humanitarian assistance according to the reported statutory activities [GUS 2019]. The combined treatment of social and humanitarian assistance and the inclusion in this number of organizations providing only financial assistance has significantly hampered the identification of the population of humanitarian organizations providing aid in-kind and/or technical aid. During the questionnaire survey, contact was made with 1216 nongovernmental organizations, among which 100 humanitarian organizations provided the will to participate in the survey and meet the criteria, which *a posteriori* is the final research sample (8%). These organizations actively participate in relief efforts during humanitarian crises that may occur in various areas of the world. The structure of these crises and the areas served are presented in Table 3.

Table 3. Humanitarian crises and areas of activity of humanitarian organizations in Poland in a research sample

Type of the humanitarian crises	Percentage share	Area of activity	Percentage share
Food insecurity (hunger, malnutrition)	71%	European Union	59%
Drought, desertification	11%	Eastern Europe	31%
Shortage of drinking water, no access to water	17%	Middle East	12%
Diseases, epidemics	24%	Caucasus	5%
Natural disasters with long-term community effects (e.g. earthquake, tsunami)	13%	Central Asia	6%
Healthcare deficit	35%	South Asia	4%
Armed conflicts (military operations, civil wars, acts of terrorism, genocide)	17%	Far East	3%
Refugees and external migrations	18%	North Africa	3%
Internal migrations (Internally Displaced Persons)	8%	West Africa	5%
Another chronic disaster/humanitarian crisis	2%	Central Africa	12%
		East Africa	10%
		South Africa	3%
		Another region	4%

Source: own elaboration.

Distribution activities in the form of aid in-kind and technical aid require extensive logistics cooperation, which is crucial to the efficiency of humanitarian actors. This cooperation is usually unstructured and informal, and such a phenomenon creates challenges for the coordination and synchronization of activities. Almost every project during a humanitarian crisis aimed at logistics cooperation begins on the initiative of the investigated humanitarian organization. This belief is the foundation for initiating joint humanitarian activities in the area of transport and storage (95% of respondents), and at the same time informs about autarkic tendencies to decision-making independence in the context of cooperation. Only 11% of humanitarian organizations note that the logistics cooperation initiative is undertaken by other national NGOs. This declarative state of focus on one's own logistics needs results from the passivity of national government institutions and international humanitarian organizations, which, having the greatest access to up-to-date information on supply and demand streams for aid goods, could play the role of initiator and central coordinator of flows in humanitarian supply chains. According to the research, international non-profit organizations that monitor humanitarian crises around the world and have the resources to address them are responsible for only 3% of logistics cooperation initiatives. Such low participation of this group of humanitarian actors is one of the reasons for the lack of cooperation among humanitarian organizations (local, national and international), which is mentioned in the subject literature [Chen, Liu and Appolloni 2020; Wankmüller and Reiner 2021]. Another of the initiators of logistics cooperation is religious associations, which have help to those in need defined in the axiology of the religion represented, and take the initiative in 8% of humanitarian crises.

National public administration bodies (national government, local authorities, crisis management centers, etc.) account for 6% of logistics cooperation initiatives. These organizations have direct solutions and mechanisms in place to involve a variety of humanitarian actors in all humanitarian activities. A humanitarian crisis is a situation in which the local community demands external support for the deficit of basic human needs. This support goes beyond the available capacity of communities and public administrations to overcome the negative effects of the humanitarian crisis. The scope of involvement in the area of logistics cooperation is lower in the case of government and local authorities bodies in areas affected by the humanitarian crisis. Normally, these organizations cannot deal with the crisis using their resources, so they need the support of other humanitarian actors. However, knowledge of the area affected by the humanitarian crisis, which is an inherent feature of local public administration units, is not used to coordinate logistics activities; only 3% of these bodies (according to the declarations of humanitarian organizations in Poland) initiate the coordination of logistics processes in the area of transport and storage. A similar phenomenon occurs in the case of regional associations (e.g., the European Union, the African Union, the League of Arab States) or other supranational bodies. Rather, these intergovernmental and transnational organizations focus on supporting humanitarian organizations and public administrations in providing logistics support to aid bodies. Furthermore, the initiation of logistics cooperation is rare with respect to the coordination centers of rescue units (2%), whose main task is to support joint operations. The same applies to private logistics operators (e.g. transport companies, logistics centers, 2%), which cooperate extensively with humanitarian organizations, but according to the reported demand [Bealt, Barrera, and Mansouri 2016]. The last of the initiators of logistic cooperation are the armed forces and allied forces, which initiate actions in this field in the event of a 1% humanitarian crisis. An example is peacekeeping missions carried out, e.g., by the UN or NATO [Dobrowolska-Polak 2008].

Logistics cooperation in the humanitarian supply chain is motivated by a variety of factors that directly and indirectly influence the initiatives taken by individual humanitarian actors. It should be noted that humanitarian practice and literature highlight that it is still humanitarian organizations that are most active in humanitarian aid operations in the area of humanitarian crisis [Ryfman 2007; Alexander 2015]. The authors of the article examined twelve factors of logistic cooperation among humanitarian organizations in Poland, and the results are presented in Figure 3.

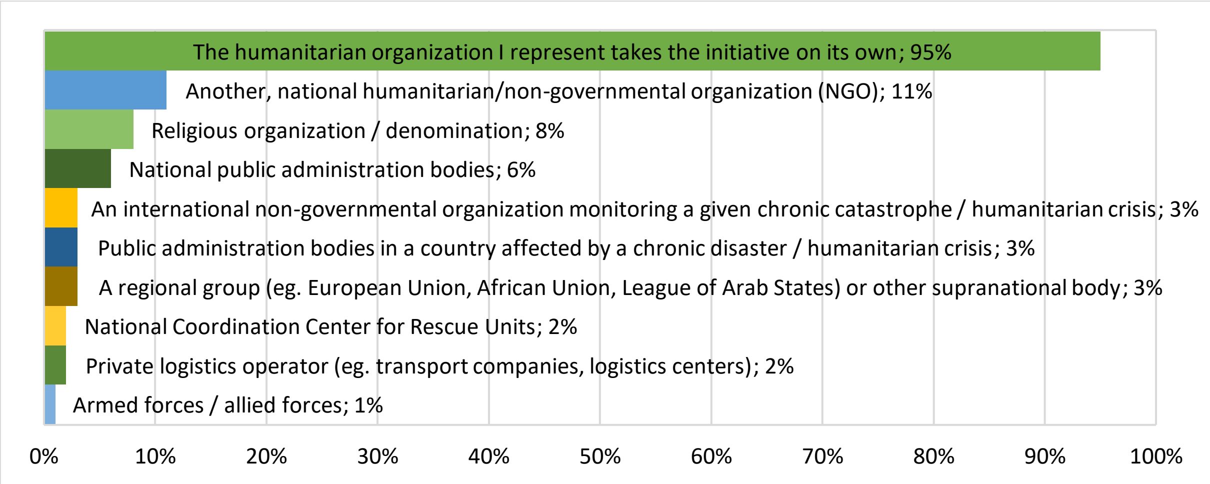

Fig. 3. Initiators of logistic cooperation during humanitarian crises from the perspective of humanitarian organizations in Poland.

Source: own elaboration.

A survey of humanitarian organizations in Poland identified factors of key importance for making decisions about logistics cooperation during a humanitarian crisis. The predominant is the urgency of aid activities, which is of great or key importance for 55% of humanitarian organizations. This speaks in favor of a strong focus on the statutory objectives of humanitarian organizations and the main principles of humanitarianism (the so-called Seven Principles of Humanitarian Aid [ICRC 2015]). The mere fact that immediate assistance is necessary to those in need is sufficient for a humanitarian organization to cooperate logistically with another humanitarian actor. It is interesting to note that 50% of humanitarian organizations recognize the importance of lower operating costs and the use of economies of scale. Although, as indicated in the introduction to the article, efficiency plays a secondary role in the humanitarian supply chains, it is a matter of concern for humanitarian organizations. It is not without reason that it is treated as one of the challenges in the area of humanitarian logistics, which determines the quality of assistance provided to people in need [Polman 2010; Scott 2014]. For 45% of humanitarian organizations in Poland, the type of aid goods and their suitability for the affected community are an important factor in establishing joint logistics activities. Such participation should not come as a surprise, especially since inappropriate types of aid goods are one of the key challenges in the first phase of providing humanitarian aid, the so-called mass aid [Polman 2010].

In the case of food insecurity, 55% of humanitarian organizations in Poland noted that the urgency of aid activities and lower operating costs, and the use of economies of scale are the most important factors in logistic cooperation. The other ten factors have much smaller percentage shares and, de facto, less importance. The situation is analogous to the case of healthcare deficits, diseases, and epidemics. In the first case, 63% of humanitarian organizations in Poland are in favor of the urgency of aid activities and 54% of lower operating costs and the use of economies of scale. In the case of diseases and epidemics, this is 67% for both identified factors of logistic interaction. It follows that humanitarian crises related to food shortages and health aspects are conditioned by urgency and the use of economies of scale. It should be noted that the three types of humanitarian crises indicated above usually affect more people (just look at the Covid-19 pandemic), determining the dominance of the two factors of logistics cooperation discussed.

The situation is different for the other three humanitarian crises presented in Table 4, i.e., refugees and external migration, armed conflicts, and drinking water shortages. While the urgency of aid activities and lower operating costs are still important factors of logistics cooperation, four other factors are also beginning to lead the way, i.e. the political and legal situation, the type of aid goods, and their adequacy for the affected community, infrastructure conditions, and previously signed cooperation agreements. The greater importance of these factors should not be questioned with regard to identified humanitarian disasters (83%, 82%, and 65%, respectively). Refugees, external migrations, or armed conflicts are usually a posteriori provoked by the political and legal situation of a given area or state. Therefore, the more difficult this situation is, the more legitimate the logistic cooperation of humanitarian actors is. The situation is similar in the case of the shortage of drinking water, which is also a humanitarian disaster that is also a frequent cause of armed conflicts (for example, the conflict in Darfur [Bromwich 2015]). These three types of humanitarian disasters require completely different categories of aid goods, which makes this factor more important than in the case of other humanitarian disasters (65-67%).

CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

The difference between logistic cooperation in business and humanitarian operations is very visible. Humanitarian and business supply chains differ in terms of the purpose of functioning, the main entity that coordinates material, information, financial, human and reverse flows, stakeholders of the activities carried out, the location of the idea of cooperation in the supply chain management system and the impact of external conditions on efficiency of functioning. On the basis of the literature studies and empirical research, the following conclusions can be formulated:

the main initiators of logistic cooperation during aid actions are non-governmental humanitarian organizations, most of which take spontaneous actions guided by the immediate need to meet aid needs while declaring awareness of the importance of operating costs and taking advantage of economic effects,

the humanitarian organizations surveyed underestimate the important factors and opportunities for achieving synergistic effects of logistics cooperation in humanitarian supply chains, which are manifested in greater efficiency, lower operating costs and improved efficiency,

striving to improve the efficiency of flows in humanitarian supply chains before and after a crisis requires greater involvement of national government institutions and international humanitarian organizations, which, through access to information, are best placed to act as initiators and central coordinators of logistics cooperation between all humanitarian actors,

the type of humanitarian crisis has an impact on differences in perception of the importance of the factors of logistics cooperation, and in particular, the more long-term the crisis, the logistics cooperation in humanitarian supply chains requires the professionalization of management focused not only on emergency aid, but also on appropriate preventive and stabilization decisions and actions adapted to the political and legal situation, the type of aid goods, infrastructure conditions, and regulatory in a given region.

Table 4. Factors of high-importance logistics cooperation in selected humanitarian crises

Factor / Type of humanitarian crises	Food insecurity (hunger, malnutrition)	Healthcare deficit	Diseases, epidemics	Refugees and external migrations	Armed conflicts (military operations, civil wars, acts of terrorism, genocide)	Shortage of drinking water, no access to water
The urgency of aid activities	55%	63%	67%	100%	53%	76%
A common source of supply of aid goods	30%	31%	17%	33%	12%	29%
Type of aid goods and their relevance to the affected community	46%	46%	29%	67%	65%	65%
Maintaining a high level of stocks of aid goods	15%	14%	17%	28%	18%	29%
A high degree of complexity of transport tasks (numerous transshipments, requiring means of transport, etc.).	13%	11%	21%	33%	35%	29%
Infrastructure conditions in a given country/area (poor quality of transport infrastructure, shortage of storage infrastructure, etc.)	30%	29%	46%	61%	47%	59%
The political and legal situation of the country/region (eg. war, authoritarian governments, imposed economic sanctions)	35%	31%	38%	83%	82%	65%
Pre-signed cooperation agreements with other humanitarian, non-governmental, or intergovernmental organizations, both national and transnational	38%	29%	38%	61%	65%	53%
Mass delivery of humanitarian aid (the number of aid goods exceeding the current needs of the affected communities)	32%	29%	29%	33%	35%	35%
Low mobility level of humanitarian workers of the humanitarian organization	24%	20%	25%	39%	35%	29%
Willingness to avoid supplying aid goods to unauthorized persons/groups	24%	20%	21%	28%	35%	29%
Lower operating costs and use of economies of scale	55%	54%	67%	61%	65%	65%
The total share of humanitarian organizations in the research sample	**71%**	**35%**	**24%**	**18%**	**17%**	**17%**

Source: own elaboration.

The authors are aware of the limitations of inferring from a random sample of 100 humanitarian NGOs based on a survey. For a more complete diagnosis of the initiators and the correctness of logistic cooperation in humanitarian supply chains, it would be advisable to examine this issue from the perspective of other actors and beneficiaries of aid actions, as well as in the context of competition of cooperating entities, i.e., cooperation. Additionally, to verify the diagnosed regularities, the authors plan to confront the survey responses with an in-depth analysis of a case study of logistics cooperation in humanitarian supply chains for war refugees from Ukraine.

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ORIGINAL PAPER

THE USE OF DRONES IN MOUNTAIN SEARCH AND RESCUE (GOPR) IN POLAND – POSSIBILITIES AND LIMITATIONS

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ABSTRACT. Background: Distribution using drones is treated as a developmental and promising form of transport in the future – an innovative way of moving about. The literature review showed a lack of a comprehensive and holistic assessment of the phenomenon of the use of drones in mountain search and rescue in Poland, a research gap. The aim of the article is to perform a quantitative and qualitative assessment of this issue, acquiring new knowledge about the basics of phenomena and observable facts (cognitive aspect).
Methods: The subject of the study are drones. The scope of the study covers only the mountain search and rescue in Poland. The entities under study are central branches of Mountain Volunteer Search and Rescue (GOPR). The study used the method of an in-depth direct interview carried out with mountain rescuers – drone pilots in GOPR.
Results: The result of the analysis of the material from interviews is an assessment of the use of drones in search and rescue in Polish mountains: what drones are already used, in which mountain groups, how many are, how often they are used, what rescue tasks they perform, how many drone pilots there are, what competences they have, what opportunities and problems are associated with the operation of drones in mountainous terrain.
Conclusions: Drones are already used in mountain search and rescue by GOPR – mainly for searching for people and monitoring avalanches. At the moment, the scale of the phenomenon is not very impressive. However, drones are treated as a developmental issue in GOPR. In addition to plans to increase the number of drones, GOPR is also considering the introduction of drones into other categories of rescue tasks as well as providing the current fleet with new additional equipment. The main barriers to further proliferation of drones in GOPR are legal, insurance, financial, and behavioral issues.

Keywords: drones, unmanned aerial vehicle (UAV), rescue, mountains, Poland, Mountain Volunteer Search and Rescue (GOPR)

INTRODUCTION

Observing the spectacular use of drones in high mountains (the Himalayas, the Alps), it is only a matter of time before mountain rescuers are equipped with such devices in lower mountains, including the Polish Sudety and Karpaty Mountains. Increasingly better technical parameters of drones coupled with increasingly lower costs of their production and operation are favourable conditions for their further development and proliferation, even in such an extreme environment as mountains. In situations where difficult mountain terrain poses threat to human life and health, drones feature key advantages such as their mobility in space (flexibility of movement) and objectification (possibility of even risking the destruction of a device to save a human being). As can be seen from the long history of mountain accidents, the abilities of mountain rescuers and equipment they use have their limitations. In certain situations, the risk of responding to emergencies is too high. This opens up an option to use drones.

Distribution with the use of drones is seen as a promising form of transport in the future and is part of economic development framework programmes where transport is one of the priorities. Supporting mountain rescuers with drones will contribute to shortening the time of providing help to people injured in the mountains. In some situations, when weather conditions temporarily prevent rescuers from reaching the site where an accident happened, it

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may be the only option to provide search and rescue services (transport of medicines, video monitoring of a casualty).

The current introduction of drones in mountain search and rescue in Poland (Internet sources search) takes the form of local pilot programs implemented by individual groups of Mountain Volunteer Search and Rescue (GOPR). According to the author of this article, so far no systematic and thorough scientific research has been carried out on the functioning of rescue drones in the Polish mountains - a research gap. Therefore, the aim of the article is to perform a quantitative and qualitative assessment of this issue – acquiring new knowledge about the basics of phenomena and observable facts (cognitive aspect).

THEORETICAL BACKGROUND

A systematic literature review was carried out in September 2022 on the basis of the Scopus abstract and citation database. The analysis of the literature consisted in searching for selected characteristic words and phrases in three places: title, abstract, and keywords.

In relation to the subject of drones, one selected:

- a total of 80,861 publications (entry "unmanned aerial vehicle" or "uav"),
- of which only 2,161 relate to rescue operations in general,
- including mountain rescue operations – only 52 positions,
- of which only 4 publications concern the territory of Poland.
- The results of the alternative selection are presented as follows:
- a total of 26,813 publications (entry "drone"),
- of which only 881 relate to rescue operations in general,
- including mountain services – only 26 positions,
- with no publication concerning the territory of Poland.

As part of the literature review, only the first result set was considered (higher number of sources, better selection accuracy). In the context of the Polish mountains, the first publication concerns a new method for detecting a person captured in aerial images acquired by an unmanned aerial vehicle (UAV). The UAV images were acquired during the field campaign carried out in the Izerskie Mountains (SW Poland). The method is used in a newly built system that supports search and rescue (SAR) activities [Niedzielski et al., 2017]. The second publication concerns the investigation of the role of clouds in the effectiveness of automated human detection in aerial imagery acquired by unmanned aerial vehicles (UAVs). Data were acquired during a field experiment carried out in the Izerskie Mountains (southwestern Poland). Sensitivity analysis, carried out on the basis of artificially blurred imagery, confirms that reduced image clarity may improve automated human detection [Niedzielski & Jurecka, 2018]. The third publication concerns the investigation of a potential impact of boosting saturation of aerial imagery on the performance of unsupervised human detection algorithms. The study is empirical since it is based on processing photographs taken during a full-year experiment in the Izerskie Mountains (southwestern Poland). We found that saturation boost is an image pre-processing method that may potentially improve the performance of human detection [Jurecka et al., 2019]. The fourth publication presents a report of a search and rescue mission carried out by the Bieszczady Mountain Rescue Service near the village of Cergowa in SE Poland, where a 65-year-old man (who suffered from Alzheimer's disease) was rescued after being detected using the use of SARUAV software. This software uses convolutional neural networks to automatically locate people in close-range nadir aerial images. The presented case study proves that the use of an UAV assisted by SARUAV software can accelerate the search mission [Niedzielski et al., 2021].

In conclusion, the subject of interest of all four publications is the search for lost individuals. The authors of these articles focus mainly on the issues of image processing, including the analysis of external (weather) conditions affecting it. Individual reports should be treated in the category of selective case studies from the area of the Izerskie Mountains and the Bieszczady Mountains – lack of a holistic publication synthesizing the state of facts regarding the functioning of drones in search and rescue operations in the entire Polish mountains.

As part of the extended treatment of the analysis of the issue-related literature, it was decided to determine what subject matter is addressed in publications concerning mountain search and rescue operations outside Poland. Of the 52 publications, only articles from scientific journals were analyzed (maintaining consistency of source type) – 22 positions. Individual authors undertake the following research points:

- simulation environment for offline path planning of unmanned aerial vehicles on three-dimensional terrains – search and rescue assisting operations over mountains [Oz et al. 2013],
- novel work on autonomously identifying Safe Landing Zones (SLZs) which can be utilised upon occurrence of a safety critical event – mountain search-and-rescue [Patterson, 2014],
- design and verification of a Conflict Detection and Resolution (CD&R) system for manned/unmanned aerial vehicle (UAV) – useful to additional applications to mountain hikers for emergency search and rescue [Lin & Lai, 2015],
- evaluation of the concept and feasibility of using a Remotely Piloted Aircraft (RPA) system to support remote sensing in simulated major incident exercises - simulated exercise: mountain rescue [Abrahamsen, 2015],
- the flight path optimization algorithm, to search and locate lost persons in mountains [Xiang et al., 2018],
- using a drone to locate a mountaineer after he and his climbing partner were separated while summiting Broad Peak in the Karakoram Mountains – drones may become an invaluable tool in search and rescue operations, helping to reduce response time and maintain the safety of responders in many other types of difficult terrain [McRae et al., 2019],
- a novel approach to person detection in UAV aerial images for search and rescue tasks in Mediterranean and Sub-Mediterranean landscapes – better effectiveness than the system currently used by Croatian Mountain Search and Rescue Teams (IPSAR) [Božić-Štulić et al., 2019],
- a dynamic track planning algorithm for disaster detection UAVs – the model was constructed for different terrains in the environment, and the corresponding function model was designed for obstacles such as mountains and peaks [Qin et al., 2019],
- mission planning method of fire fighting and rescue of multi-UAV for multiple fires –
- by dropping fire extinguishing bombs by multiple UAVs [Zhang et al., 2020],
- the optimal allocation of drone base stations in a given geographical region – reducing the time span between sudden cardiac arrest (SCA) and early defibrillation by automated external defibrillators (AED) [Wankmüller et al., 2020],
- several image processing algorithms – important resource in search-and-rescue (SAR) missions - have been used by the Croatian Mountain Search and Rescue (CMRS) [Gotovac et al., 2020],
- the reliability of existing state-of-the-art detectors to simulate rescue scenes – proposing a model that can be used in SAR operations [Sambolek & Ivasic-Kos, 2021],
- the determinants that drive the behavioral intention of mountain rescuers to adopt drones in rescue missions – the relevance of personal and environmental factors for the acceptance of drones [Holzmann et al., 2021],
- evaluation of feasibility of using a rotor-wing unmanned aerial vehicle to support situation assessment in search and rescue operations in the mountains (avalanches) in the mountains of Setesdalen (Hovden) in Norway – a UAV is an effective tool carrier and saves time in rough terrain, it is a safe supplement to human resources in high-risk work environments, like an avalanche [Abrahamsen, 2021],
- a method of search and rescue location based on acoustic wave communication in the blind zone of communication – the search and rescue positioning system has been designed in detail [Yunfeng et al., 2021],

- investigation of the viability of using an aerial drone-repeater system configuration to restore and maintain radio communications between incident command (IC) and deployed rescuers in Southern Utah – this method of restoring radio communication among SAR personnel could drastically improve the ability to assist victims and help mitigate the risks faced by rescuers [McRae et al., 2021],
- the application using a solar powered unmanned aerial vehicle (UAV) to inspect mountain sites for the purpose of safety and rescue – with the maintenance of positive residual energy [Huang & Savkin, 2021],
- a new image segmentation algorithm using the RGB component difference clustering (RGBCDC) - the proposed algorithm shows a better potential for use in uncommon situations, especially for rapid emergency rescue after serious mountain hazards [Liu et al., 2021],
- an overview of the developing epidemiological situation related to the COVID-19 pandemic in mountainous areas - the use of technologies, such as drones, could contribute to an effective and timely emergency response in mountainous and remote settings [Van Veelen et al., 2021],
- widespread practical implementation of a drone still not taking place – rescuers benefit from drone usage, especially in urgent missions such as search and rescue and emergency items delivery, as the technology reduces response times while simultaneously minimizing risk exposure [Wankmüller et al., 2021],
- a convolutional neural network-based model for the detection of humans in aerial images of mountain landscapes acquired by unmanned aerial vehicles (UAVs) used in search and rescue operations – the detection of humans in aerial images based on the EfficientDET architecture and ensemble learning [Dousai & Lonearic, 2022],
- proposal of a three-dimensional path planning algorithm for multi-UAVs based on LSTM-DPPO (long short-term memory-distributed proximal policy optimization) framework – the proposed method can plan the optimal detection path with the minimum energy consumption [Zhang et al., 2022].

In summary, the thematic spectrum of the points is very diverse, although here also the topic of searching the terrain – mainly searching for people - prevails. Individual publications focus on narrow, detailed threads that can be divided into two clear categories: technical issues and organizational issues of working with drones. From the point of view of the complexity of the analysis of the phenomenon (similarity of the subject treatment to this article), two articles are worth noting: the experience of Croatian Mountain Search and Rescue Teams [Božić-Štulić et al., 2019] and the systemic design of the drone network [Wankmüller et al., 2020].

RESEARCH RESULTS

The subject of the study are drones, treated as an innovative way of distribution. The scope of the study covers only the realm of mountain search and rescue, limited only to the mountains in Poland. The entities under study are central branches of Mountain Volunteer Search and Rescue (GOPR). There are only 7 such branches: Karkonosze Group (Jelenia Góra), Sudety Group (Wałbrzych), Beskidy Group (Szczyrk), Podhale Group (Rabka Zdrój), Krynica Group (Krynica Zdrój), Jura Group (Podlesice), Bieszczady Group (Sanok). As part of the study, business trips (delegations) were made to each branch. The study was conducted in the form of an in-depth direct interview with mountain rescuers. The form of direct study was chosen as it primarily enables one to obtain very accurate and reliable information. The approach based on numbers and narratives was adopted: a synergistic co-relationship between quantitative components (hard statistical data) and qualitative components (soft verbal information).

As part of the study, 3 business trips were made (for the sake of organization and time and cost reduction, nearby locations were combined): 1. Szczyrk, Krynica Zdrój and Rabka Zdrój (20-24 June 2022), 2. Sanok and Podlesice (11-15 July 2022), 3. Jelenia Góra and Wałbrzych (18-21 July 2022). A day was planned to be spent in each location to gather data.

13 mountain rescuers, drone pilots - were interviewed. From 1 to 3 mountain rescuers participated in an interview in a given branch, 2 per interview on average. These were only men aged 25 to 55 (average age 44.5 years, median 46 years, mode 50 years).

All GOPR Groups are equipped with drones. Table 1 presents basic quantitative and qualitative data related to drones.

Table 1. Drones in GOPR – basic data

	Beskidy	Krynica	Podhale	Bieszczady	Jura	Karkonosze	Sudety
number of drones	2	2	3	6	3	2	1
drone model	DJI Mavic 2 Enterprise Dual, Autel Evo II Pro	DJI Mavic 2 Enterprise Advanced, Autel Evo II Pro	DJI Phantom 4, DJI Mavic 2 Enterprise Dual, Autel Evo II Pro	DJI Mavic 2 (Zoom, Enterprise Dual, Enterprise Advanced) (3 units), DJI Matrice 300 RTK (2 units), Autel Evo II Pro (1 unit)	DJI Phantom 4, DJI Mavic 2 Enterprise Dual, Autel Evo II Pro	DJI Mavic 2 Enterprise Dual, Autel Evo II Pro	Autel Evo II Pro
since when in the Group	2020, 2021	2020, 2021	2016, 2019, 2021	2020, 2021, 2022	2019, 2020, 2021	2020, 2021	2021
area of the Group (km2)	2,160	2,000	4,200	3,800	2,615	3,020	2,400

Source: Author's own compilation.

Based on Table 1, it can be concluded that drones in GOPR are a new and developing topic, tracing its beginning to 2019 (interesting fact: historically drones appeared in the Podhale Group already in 2016). GOPR possesses a total of 19 drones. On average, the majority of GOPR Groups have 2-3 drones at their disposal, with the highest number of drones being in the Bieszczady Group, and the lowest number in the Sudety Group. There are 4 drone models in GOPR: DJI Mavic (8 units), DJI Matrice (2 units), DJI Phantom (2 units), Autel Evo II Pro (the last one in each group, 7 units – the result of a sponsorship scheme in 2021). Most of the drones used by GOPR are light drones (weighing about 1 kilogram), which can reach a maximum service ceiling of about 1,000 meters (in practice, the drones in GOPR fly at heights of 50-100 meters). Under normal stable weather conditions, a GOPR drone flies 20-30 minutes on one charge, covering a distance of 2.5-3.5 kilometers (a need for direct "visibility" of the operator – drone). All GOPR drones are equipped with an ordinary camera and the vast majority of them also have a thermal imaging camera. Additional equipment that drones in GOPR feature (depending on the needs of a given Group) includes: a reflector, a loudspeaker, a strobe diode, and a drop kit. In addition (no longer directly on the drone), there are: spare batteries and software supporting image processing, e.g. SARUAV (https://www.saruav.pl/).

Table 2 presents the possibilities of using drones by GOPR.

Table 2. Drones in GOPR – possibilities of their use

	Beskidy	Krynica	Podhale	Bieszczady	Jura	Karkonosze	Sudety
kind of operation	searching for people	searching for people	searching for people	searching for people evaluation and monitoring of avalanches, delivery of cargo	searching for people records of dangerous places	searching for people avalanche danger monitoring	searching for people
frequency of use (per year)	6-10	1-5	6-10	10-15	30-40	6-10	1

Source: Author's own compilation.

Based on Table 2, it can be concluded that at the moment drones in GOPR are used primarily to search for people (in each group) - the task of searching the area. The second significant group of tasks comprises monitoring and searching through avalanches, as well as making records of dangerous places (only in certain Groups). Only the Bieszczady Group used drones to transport cargo. Drones were used the most frequently in the Jura and Bieszczady Groups, the least frequently in the Sudety Group. On average, in a given year, a given GOPR Group used drones in operations from 6 to 10 times. Unfortunately, it is impossible to determine the most frequent and least frequent places of use of drones by GOPR due to the fact that accidents are random, they can happen everywhere. Due to the specific character of drones, the preferred areas of their work are open and unforested areas.

Table 3 applies to pilots – mountain rescuers operating drones.

Based on Table 3, it can be concluded that in total in the structures of GOPR there are 58 drone pilots, who are mainly able to fly each drone in their group. The largest number of drone pilots can be found in the Karkonosze and Bieszczady Groups and the lowest in the Podhale and Sudety Groups. The number of pilots (Table 3) is greater than the number of drones (Table 1), indicating the possibility of their effective use at all times. To pilot a drone, one must have appropriate qualifications. It takes a few days (up to a week) to obtain them. It is a cost of PLN 5,000-6,000. However, as in the case of a driving licence, skills are further refined by each pilot in practice.

The cost of purchasing one drone with basic equipment is in the order of PLN 10,000-15,000 (recently there has been a significant increase in the cost of these devices in connection with the war in Ukraine). Additional optional equipment is an expense of PLN 100,000-150,000 thousand (the better the equipment parameters, the higher the price). The main operating costs of a drone include: charging a battery and replacing propellers (low, several hundred zlotys a year) and insurance – both of a drone and pilot (significant, several thousand zlotys per year for one package of a drone plus a pilot).

Table 3. Drones in GOPR – drone pilots and their qualifications

	Beskidy	Krynica	Podhale	Bieszczady	Jura	Karkonosze	Sudety
number of drone pilots	8	5	3	16	5	18	3
substitutability (ability to pilot each drone in a Group)	full	full	full	full	full	partial	partial
number of mountain rescuers in a Group (total)	350	100	200	200	130	160	120
number of professional rescuers in a Group (in the above-mentioned total)	22	15	22	20	15	19	16

Source: Author's own compilation.

The further development (chances) of drone exploration in GOPR rescue operations in the Polish mountains will depend on the following:

- creating an internal systemic program of drone operation as a dedicated section within the framework of GOPR,
- the possibility of obtaining rights for internal certification of drone pilots within the framework of GOPR (a pilot's qualifications should be updated periodically – it is quite expensive), which would allow one to reduce the costs of a license,
- simplifying legal regulations and preferential insurance regulations dedicated to mountain search and rescue (GOPR) using drones,
- spending more time training drone skills as part of the search and rescue service in GOPR,
- the number of accidents in the mountains related, on the one hand, to an increase in the number of tourists, on the other hand, to a variety of activities undertaken (hiking, skiing, cycling, paragliding) – a strong upward trend in recent years,
- technological development of drones with regard to greater speed and accuracy as well as extending the time of using devices (power supply issue),
- changes in the attitude of rescuers and those rescued toward the issue of drones – statistics show that this solution works, so it should be trusted,
- providing financing for the development (new purchases) and maintenance (additional equipment) of the drone fleet in the structures of GOPR.

In rescuers' opinion, in a mountain operation with the use of a drone, the most difficult problematic aspects (limitations) include the following:

- adverse weather conditions (strong wind, high precipitation, dense fog/cloudiness, low temperatures – risk of drone icing),
- inacquaintance with the terrain in which an accident occurred,

- the planning stage of a rescue mission and then its implementation stage (drone and pilot logistics),
- the issue of electric power backing – the need to replace and charge a battery during a rescue operation,
- an element of time pressure and focus – working under stress (pilot's concentration, risk of drone failure),
- aviation law provisions that GOPR must comply with (risk of flight delays pending approval by air traffic controllers),
- exchange of information and data (different standards) between GOPR and other services, e.g., the police if they also participate in a rescue operation.

CONCLUSION, LIMITATIONS AND FURTHER RESEARCH

The study result is a comprehensive and exhaustive quantitative and qualitative assessment of the fleet of rescue drones in the Polish mountains in a geographical cross section (individual mountain groups): what drones are already used, in which mountain groups, how many there are, how often they are used, for what rescue operations, what tasks they perform, how many drone pilots there are, what competences they have, what opportunities and problems are associated with the operation of drones in the mountainous terrain. The results of the study allow identification of similarities and differences between individual GOPR groups. The study results should be treated as pilot categories.

Drones are already used in mountain search and rescue operations by all GOPR Groups, mainly for searching for people and monitoring avalanches. At the moment, the scale of the phenomenon is not very impressive: frequency: most often several times a year. Within a given GOPR Group, there are definitely more drone pilots than devices (flexibility of work), and in most cases, each pilot can operate any drone (mutual substitutability). The issue of drones is treated as a development issue in GOPR. In addition to plans to increase the number of drones, GOPR is also considering the introduction of drones into other categories of rescue tasks as well as providing the current fleet with new additional equipment.

Knowledge about drones in mountain search and rescue operations is much broader than presented in this article – limited only to the Scopus base. From the point of view of up-to-date information, popular science articles in the press and on the Internet are at the forefront. It is planned to review other sources of knowledge in the future in order to obtain a more complete theoretical picture of the phenomenon. In the future, in a few years, it would be advisable to conduct an identical empirical study again to compare the scale of the changes. The entity under study was only GOPR. In the future, it is planned to also extend the research to the Tatra Volunteer Search and Rescue (TOPR), which provides assistance in the highest mountains in Poland.

The author hopes that these study results contribute to the development of science, originality and novelty. The advantages of this article are the following: it relates to developmental, future distribution technology (drone transport), it is considered in the context of a specific, niche research area (mountain search and rescue), it is a socially important topic from the point of view of protecting human health and life (alternative ways of providing help).

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ORIGINAL PAPER

ANALYZING NEW WAYS TO ADAPT THE TRIPLE-A SUPPLY CHAIN MODEL AND ITS EXTENSIONS IN AGRI-FOOD SUPPLY CHAINS

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ABSTRACT. Background: With the emergence of supply chain management as a key strategic function in the agri-food sector, a lot of research has been conducted to find ways to improve the performance and sustainability of agri-food supply chains. The Triple-A Supply Chain concept, which refers to the agility, adaptability, and alignment of the supply chains, has been a field of study for various researchers aiming at shaping meaningful and sustainable competitive advantages for businesses and organizations in various sectors. Over the years, alternative, complementary, or upgraded versions of this approach have been proposed, such as the "New AAA Supply Chain", which describes the renewed Triple-A Supply Chain model based on Super-Agility, Architectural Adaptability, and Ecosystem Alignment, and the "Triple A & R" framework, which refers to Agility for Robustness, Adaptability, and Resilience, and Re-Alignment.

Methods: This paper presents the results of a selective study of the bibliography considering the Triple-A Supply Chain model, the "New AAA Supply Chain" model and the "Triple A & R" framework. These frameworks are analyzed and compared with each other considering their principles, and their implementation in the agri-food sector is researched. The scope of this study is to analyze the potential of the application and suitability of these frameworks in agri-food supply chains, having considered the particularities of the sector.

Results: Examining the models concerning the evolution of the Triple-A Supply Chain paradigm, it is evident that they differ from each other, as they approach supply chain management from different viewpoints.

Conclusions: The potential of application of various models originating from the Triple-A Supply Chain paradigm was examined in the case of the agri-food sector considering product nature, sustainability, and investment cost as the factors affecting it. These frameworks could partially find application in the agri-food sector, as some of their guidelines promote the increase of the agri-food supply chain effectiveness.

Keywords: agri-food supply chain, agility, adaptability, alignment, sustainability

INTRODUCTION

In the era of globalization, supply chain systems are highly involved in material flow procedures worldwide [Manning, 2018]. The interconnection of supply chains across the world shapes a new kind of supply chain network, enhancing the need of applying new supply chain management practices. Supply chains have been affected by the recent economic, environmental and social crisis, having altered the supply chain management approaches, which are currently focused on the adoption of sustainable practices as a means to form resilient supply chain systems. Especially in the case of agri-food supply chains, which are complicated systems consisting of different internal and external stakeholders, there is a high need for the application of up-to-date supply chain management systems that take into consideration the particularities of the products involved and the different circumstances of each region [Tsai et al., 2021]. There are global attempts to overcome these barriers and move towards a sustainable world, such as the Sustainable Development Goals (SDGs) 2030 Agenda, which includes 17 ambitious objectives with 169 targets on all dimensions of sustainable development [UN General Assembly, 2015]. The agri-food supply chains are highly engaged in the achievement of the SDGs, as FAO has published a strategic framework to promote the principles established by the United Nations in the agri-food sector [FAO, 2016].

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Sustainability has been considered a pillar of the current proposed frameworks of supply chain management. In terms of sustainable supply chain management, there have been efforts of shaping models to include specific targets of the supply chains in order to achieve higher performance in a sustainable means. The Triple-A Supply Chain concept [Lee, 2004] which refers to the agility, adaptability, and alignment of the supply chains has been a field of study for various researchers aiming at shaping sustainable competitive advantages for businesses and organizations in various sectors. An updated version of this framework, the "New AAA Supply Chain", which describes the renewed Triple-A Supply Chain model based on Super-Agility, Architectural Adaptability and Ecosystem Alignment has been recently presented by Lee himself as a modification and evolution of the original Triple-A Supply Chain model in order for supply chains to gain a competitive advantage focusing on the new aspect of the Triple-A supply chain framework principles [Lee, 2021]. The "Triple A & R" framework, which refers to Agility for Robustness, Adaptability, and Resilience, and Re-Alignment, has also been proposed as an updated alternative based on the original Triple-A Supply Chain model approaching sustainable supply chain management and managing uncertainties [Cohen & Kouvelis, 2021].

The scope of this study is to analyze the potential of the application and suitability of these frameworks in agri-food supply chains, having considered the particularities of the sector.

SUPPLY CHAIN PARADIGMS

This paper presents the results of a selective study of the bibliography considering the Triple-A Supply Chain model, the "New AAA Supply Chain" model and the "Triple A & R" framework. These frameworks are analyzed and compared with each other considering their principles, and their implementation in the agri-food sector is researched.

The Triple-A Supply Chain model

The Triple-A Supply Chain model indicates that supply chains should be agile, adaptable, and aligned in order to achieve a competitive advantage and high efficiency [Lee, 2004]. This means that supply chains should respond to short- and long-term changes occurring through all stages, providing all stakeholders with a competitive advantage related to the supply chain performance [Alfalla-Luque et al., 2018; Leończuk, 2021]. This model is also proposed as a means of achieving at the same time higher performance for both supply chain systems and all stakeholders in both developed and developing countries [A. Attia, 2015; Kontopanou et al., 2021].

The first pillar of the Triple-A Supply Chain model is agility. Agility refers to the ability of the supply chain to rapidly adapt to short-term changes that occur considering market demand and manage any external upheavals [Lee, 2004]. The ability to adapt the volume and range to meet the demands under short-term changes is also a dimension of agility [Marin-Garcia et al., 2018]. Agility is proposed as a means to manage the complexity and uncertainties of supply chains [A. M. Attia, 2016] such as in the case of the recent COVID-19 pandemic that tested the supply chains systems' agility [Jindal et al., 2021]. For example, in the case of meat supply chains, it is shown that agility is essential for firms to survive sudden changes in the market and still retain a competitive advantage [Hobbs, 2021].

Adaptability is the second component of the Triple-A Supply Chain model. Adaptability refers to the ability of supply chains to respond in long-term changes, driven by market trends, economic changes, customer habits, and internal changes caused by the updating of production processes and technological equipment [A. M. Attia, 2016; Marin-Garcia et al., 2018]. Proper forecasting and monitoring of trends in the supply chain can reinforce risk management and become the source of a sustainable competitive advantage.

The Triple-A Supply Chain model indicates that supply chains should also be aligned. Alignment involves the promotion of common interests between the stakeholders involved in a supply chain, minimizing the differences between the individual targets and setting common goals for all of them which are related to the total productivity and effectiveness of the supply chain. This indicates a holistic approach to supply chain management in which all stakeholders are treated with respect to their goals, but also as a part of an interdependent supply chain system [Gölgeci & Kuivalainen, 2020].

All three pillars of the Triple-A Supply Chain management are treated as components of one system, even though each of them has been investigated separately [Engelseth, 2016; Geyi et al., 2020]. Achievement of competitive advantage and performance targets of the supply chains depends to all three dimensions, as it is shown that all should be achieved [Marin-Garcia et al., 2018]. The connection of this model to the sustainability of supply chains is also a matter of discussion between scholars [Erhun et al., 2021]. Even if achieving agility, adaptability, and alignment of a supply chain could reinforce the achievement of higher performance and competitive advantage, the SDGs are not necessarily achieved [Gligor et al., 2020].

The research on the application of the Triple-A supply chain framework in supply chain networks has been expanded recently, focusing on different aspects of supply chain systems and producing various results. Implementing the Triple-A paradigm in the sectors of automotive components, electronics, and machinery as a means of enhancing the competitive advantage gives mixed results [Alfalla-Luque et al., 2018]. When considering the Triple-A concept in its core ingredients, it is observed that agility has a slightly positive impact on the total competitive advantage, in contrast to adaptability and alignment, which seem to enhance the competitive advantage of supply chains. In the case of the textile industry, the application of the main principles of the Triple-A paradigm positively affects the overall performance of the supply chain [A. M. Attia, 2016]. In the case of the agri-food sector, agility, adaptability, and alignment are proposed as a means of forming more sustainable agri-food supply chain networks [Erhun et al., 2021].

The “New AAA Supply Chain” model

In 2021 Lee presented the “New AAA Supply Chain” model, aiming to replace agility, adaptability, and alignment terms with more contemporary ones, aiming to focus on recent supply chains as formed by the global changes that have taken place [Lee, 2021]. In order to enrich the existing Triple-A Supply Chain paradigm, he proposed Super-Agility, Architectural Adaptability, and Ecosystem Alignment as the new pillars of an effective and resilient supply chain system.

Super-Agility refers to the response to the short-term changes in the digitalization era, where information can be rapidly spread and easily accessed. As a result, the upcoming changes are rapid, and the response of supply chains to them should be accelerated. New technologies implemented in the supply chain sector, such as Internet of Things (IoT), Big Data, and sensor technologies, are used as a means for stakeholders to predict changes and gives them information in order to facilitate decision making and achieve competitive advantage [W. Ali et al., 2022]. Despite the advantage given by technological development during the recent COVID-19 pandemic, there are cases where firms revealed lack of responding to the new conditions [Patrucco & Kähkönen, 2021].

Architectural adaptation refers to an extended term of the response to long-term changes which includes more dimensions, focusing more on the production and supply management. The adoption of new technologies, the forecasting of demand, and the design of supply chains according to the market needs also drive architectural adaptability. Continuous changes in the rules of commerce and the nature of products, especially in the case of the agri-food sector, lead to the shape of a different structure of the supply chain in order to ensure long-term adaptability.

The original alignment term included the relation of interests between stakeholders that constitute the supply chain. In this renewed model, ecosystem alignment encloses all internal and external stakeholders, such as nongovernmental organizations (NGOs), governments and communities which are involved in the supply chain from environmental and social aspect. By including external stakeholders in the equation, Lee aims to improve information sharing between the different parties in order to facilitate decision-making in the supply chains in a way that promotes the total productivity of the supply chain as a common goal for the groups involved by being approached from different aspects.

The "New AAA Supply Chain" model is recently presented, and the literature on this subject is limited. Especially in the case of the agri-food supply chains, the different impact of the new version of the Triple-A Supply Chain paradigm is slightly explored. However, there have been some attempts to improve the original Triple-A model by setting new components, such as the "Triple A&R" paradigm [Cohen & Kouvelis, 2021] that is analyzed in the following section.

The "Triple A&R" model

The "Triple A&R" model has been proposed as an alternative approach to the Triple-A Supply Chain model by adapting its main pillars to contemporary supply chain systems. According to this proposal, Agility for Robustness, Adaptability, Resilience and Re-Alignment are the three characteristics that determine a functioning and effective supply chain system.

Robustness refers to the ability of a supply chain network to respond to internal and external pressures or failures without losing its original structure [Monostori, 2021]. A robust supply chain system is planned to be resistant to sudden changes, such as pandemics and extreme weather conditions [Gölgeci & Kuivalainen, 2020]. A robust system is based on the creation of a stock of products and the acquisition of backup suppliers in order to be functional during disruptions [Cohen & Kouvelis, 2021]. In the case of the agri-food supply chains, supplier selection is a very important issue, as the nature of the products involved gives stakeholders limited choices [Verdecho et al., 2021]. In this case, robust optimization systems have started to be applied in order to reduce risk, manage uncertainties, and facilitate the decision-making processes [Banasik et al., 2019]. Robust strategies are mostly applied in a preventive way; thus agile strategies are referred to the actions taken during and after a crisis. Agility for Robustness encompasses all the actions planned to smoothly survive and recover from sudden changes in the supply chain environment [Chowdhury & Quaddus, 2017].

Resilience is a holistic term that refers to the ability of an organization, supply chain, or system to respond to disruptions and uncertainties. The ability to recognize, avoid, and adjust to disturbances and changes characterizes a resilient organization. Resilience focuses not only on the tolerance on a supply chain system to shocks but also on the ways it can recover and adopt innovative practices in order to resist to similar interruptions [Coopmans et al., 2021; Ramdan et al., 2021]. Gligor et al. [2019] extensively analyzed agility and resilience and came up with six major traits for each of them that are partially overlapping. Aslam et al. [2020] claim that supply chain ambidexterity leads to supply chain resilience and suggest that supply chain agility plays a mediating role in the relationship between ambidexterity and resilience. Adaptability is related to resilience, as they both refer to the adoption of strategic planning in order to be prepared to withstand and recover from unexpected events and, at the objectives of same time maintain the supply chains [Lohmer et al., 2020]. Resilience has been a field of study for the agri-food sector, especially after the COVID-19 crisis, when agri-food supply chains where particularly stressed due to the limitations of transportations worldwide [W. Ali et al., 2022; Coopmans et al., 2021; Hobbs, 2021; Rejeb et al., 2020]. Especially in the case of cold and perishable products, the formulation of a resilient strategy is very important to survive the sudden changes and decrease their impact on total performance [I. Ali et al., 2018]. Most agri-food systems were afflicted by this crisis, showing that resource management is also important to achieve resilient and adaptable agri-food supply chain systems.

Re-alignment promotes the enhancement of coordination between stakeholders in a different way. In recent months, alternative supply chain contracting designs have been implemented by various sectors and government bodies. After-sales service supply networks in a variety of industries have embraced the Performance Based Logistics model, in which suppliers' profit is based on supply chain performance. This framework suggests that the alignment of profits leads to alignment of interests, and thus to the increase of the supply chain efficiency. In the case of agrifood supply chains alignment is mostly as a way to set common goals, mostly focusing mainly on achieving higher sustainable performance of the agri-food supply chain system [Chen et al., 2017].

AN ANALYSIS OF SUPPLY CHAIN MODELS IN THE CASE OF AGRI-FOOD SUPPLY CHAINS

The contemporary agri-food supply chain systems

Agricultural products are vital for human life. Food availability is an emerging problem that has arisen, as food production should increase by 70% by 2050 to cover the world's food demand [Alexandratos & Bruinsma, 2012]. For this reason, the agri-food supply chain management practices followed in the agri-food domain are very important in order to ensure product availability worldwide.

The agri-food supply chains present many particularities compared to other supply chain systems. Products involved in agri-food supply chain procedures are characterized by various properties referring to their safety and quality [Jouzdani & Govindan, 2020]. The seasonality and perishability of agricultural products indicates that the stages of production, transportation, processing distribution, and retailing operate under a strictly controlled environment to ensure product integrity [Esteso et al., 2021]. Managing uncertainties that occur in the agri-food sector is challenging [Feyissa & Sharma, 2016]. The production of agri-food products depends on environmental conditions and the demand is modified depending on the economic and social circumstances.

Modern agri-food supply chain systems consist of different stakeholders, from various fields and regions, linked to each other "from farm to fork". As a result, there is a need for cooperation between all parties in order to achieve a competitive advantage through the agri-food supply chain [Moreno-Miranda & Dries, 2022]. In the case of agri-food supply chains, sustainable performance is positively linked to total efficiency [Pearce et al., 2018]. For this reason, the models and frameworks proposed as appropriate for agri-food supply chain systems take into account the sustainability factor.

Results and discussion

Examining the models concerning the evolution of the Triple-A Supply Chain paradigm, we observe that they differ from each other, as they approach supply chain management from different viewpoints. In Table 1 there is a categorization of the principles proposed by each of the proposed frameworks.

Table 1. The evolution of the Triple-A Supply Chain model

Models	**Triple-A Supply Chain [Lee, 2004]**	**"New AAA Supply Chain" [Lee, 2021]**	**"Triple A&R" [Cohen & Kouvelis, 2021]**
Principles	Agility	Super-Agility	Agility for Robustness
	Adaptability	Architectural Adaptability	Adaptability for Resilience
	Alignment	Ecosystem Alignment	Re-Alignment

Source: own work.

The two new proposed frameworks have retained the basis of the original Triple-A Supply Chain model and explore new ways to implement the Triple-A paradigm in supply chain management. To analyze the potential of these new frameworks to be adopted by agri-food supply chain systems, the assessment of critical factors is necessary.

The preservation of food safety and quality is one of the primary objectives in the formation of a framework for an agri-food supply chain system. In many cases products are characterized by a short shelf life, such as in the case of fresh fish, meat, and vegetables. Most food products demand specific environmental conditions while transported and stored. The right temperature and humidity should be ensured through all stages [Dora et al., 2021]. As a result, decisions should be made by taking into account the products' nature.

The aspect of sustainability is strongly related to the performance of agri-food supply chain systems. Most recently, the practices followed by stakeholders have started to be modified in order to achieve the environmental, economic, and social targets set in the agri-food supply chains. Some of the most emerging goals for the agri-food supply chains are food waste, energy, and gas emission reduction [Jouzdani & Govindan, 2020; Matzembacher et al., 2021; Samotyja, 2021]. Contemporary agri-food supply chain management frameworks must include sustainability as a factor affecting the total outcome of agri-food supply chain systems.

In examining the adoption of a new agri-food supply chain management model, the investment cost is a matter of discussion. Especially in the case of small-scale firms, a big investment negatively affects the short-term profit and discourages them [Cupertino et al., 2020]. Even for firms that have already invested in new technologies, the adoption of a new framework is easier when it is proposed as a smooth transition towards more efficient agri-food supply chain systems. Therefore, the cost of investment for the implementation of the new framework is also important in the decision-making process.

Considering the nature of product, sustainability and investment cost as three of the main axes affecting the adoption of these frameworks, the level of the potential application is analyzed.

The "New AAA Supply Chain" model promotes Super-Agility, Architectural Adaptability, and Ecosystem Alignment. Super-agility is necessary for the agri-food supply chains due to the quick shifts on the product demand, depending on consumer needs and availability of products. The quick response is necessary due to the short shelf life of the product. To achieve an accurate forecasting of demand information sharing, using technologies such as blockchain, through all stages, has proved to be helpful [Lohmer et al., 2020] but not easily adopted by medium and small-scale firms. Another strategy proposed to achieve Super-Agility is delayed differentiation, which demands the creation of a stock before the demand evolves [Mak & Max Shen, 2021]. In the case of perishable agri-food products this strategy cannot easily be applied. Architectural adaptability as proposed in the "New AAA Supply Chain" model includes the product quality factor in the equation, in contrast to the original framework. The quality and innovation have been taken into account in the long-term strategic planning of the agri-food supply chain, which is very important for food products. Long-term planning in the agri-food supply chain sector meets difficulties due to the existing uncertainties. As a result, the adoption of such a model can lead to the framework of more successful long-term strategic planning, facilitating uncertainty management, and thus increasing the efficiency of the agri-food supply chain. Ecosystem alignment refers to the involvement of both internal and external stakeholders' interests in a holistic framework for agri-food supply chains. This requires cooperation and coordination between all parties involved in the agri-food supply chain management, not only "from farm to fork" but even beyond the consumption stage to those actions which will lead to a closed-looped agri-food supply chain system that strengthens its sustainable performance. Taking into account the relationship of the agri-food supply chains with external stakeholders, such as the government, the achievement of the SDGs considering the agri-food supply chains could be enhanced in the form of a holistic strategic plan. The application of an advanced AAA supply chain model in the agri-food sector can enrich agri-food supply chains with new capabilities, especially in the post-pandemic world [Patrucco & Kähkönen, 2021].

The "Triple A&R" framework promotes Agility for Robustness, Adaptability and Resilience and Re-Alignment as its basic pillars. For robust agri-food supply chain systems a stock of products is necessary. In the case of the agri-food supply chain systems something like this is not possible due to the nature of the products as it can lead to food waste, affecting its sustainable performance. On the other hand, agri-food supply chains could use robust optimization systems in order to strongly resist sudden changes that occur. Resilience is strongly linked to the survival of the agri-food supply chains through the changes, as it includes an integrated plan to predict changes, facing difficulties and recover. Re-Alignment as proposed in this framework focuses on the economic motives in order to align interests between stakeholders. Re-Alignment should be expanded and include not only the economic, but also the sustainable coordination between the stakeholders. If the goals of all stakeholders are aligned and achieved in common efforts the agri-food supply chain systems have greater chances to a long-term survival, evolution and profitability. The adoption of the "Triple A&R" framework could promote the form of resilient agri-food supply chains, proposing a solution to problems caused by sudden disruptions. The form of a resilient agri-food supply chain system can have a strong impact on the sustainable performance of agri-food supply chains.

CONCLUSIVE REMARKS

Thousands of research conducted in order to find ways to improve the performance and sustainability of agri-food supply chains. The shape of various frameworks towards more effective supply chains reinforces the improvement of the agri-food supply chain performance. The Triple-A Supply Chain model, as proposed by Lee in 2004 is promoted as an effective way to endorse agri-food supply chain management. After the recent COVID-19 pandemic, the need for more evolved frameworks led to the proposal of the "New AAA Supply Chain" model by Lee and "Triple A&R" framework from Cohen and Kouvelis [2021]. These frameworks aim to adapt the original model to new circumstances by proposing more holistic approaches to each of its three components. The agri-food supply chain systems have their own discrete characteristics compared to other supply chains. The potential of application of these models was examined considering product nature, sustainability, and investment cost as the factors affecting it. These new frameworks could find application in the agri-food sector, as some of their guidelines promote increased agri-food supply chain effectiveness. There is still room for improvement in the ways in which these frameworks. However, the shape of a framework adapted to the particularities of the sector could lead to the shape of more sustainable and efficient supply chain networks. This research focused on the exploration of these two frameworks as an update of the original Triple-A Supply Chain system. The exploration of suitable supply chain management models for the agri-food supply chains is ongoing research aiming to shape a holistic framework for sustainable agri-food supply chain management.

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ORIGINAL PAPER

THE INFLUENCE OF KEY FACTORS OF VISUAL MERCHANDISING ON IMPULSIVE BUYING

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ABSTRACT. Background: Modern retail is experiencing an accelerated transformation with online sales growth, further accelerated by the COVID-19 pandemic. Nevertheless, physical stores, especially grocery stores, are still the key to retail business and are likely to remain so for the foreseeable future. Competition among retailers is becoming more pronounced and aggressive, and the expectations of modern consumers from retailers are stronger and more precise - they require the creativity of retailers in attracting and motivating them to enter their stores and return. Once consumers are in the store, the goal of retailers is to make them buy as much as possible. In modern retail, visual merchandising has become one of the crucial factors on the supply side by achieving a comfortable in-store environment and directing customers toward targeted shopping behaviour. The aim of this paper is to investigate which factors of visual merchandising are successful in encouraging impulsive consumer buying.

Methods: The article conducted an extensive review of the previous literature, while the primary research was conducted on 226 respondents, people who participated in purchases in large retail grocery stores (primarily hypermarkets), to conclude the factors influencing visual merchandising on impulsive consumer buying.

Results: The results of the regression analysis indicate that there is a statistically significant positive impact of secondary displays, price promotional labels, and in-store music on impulsive purchases, while the availability of prices over the Internet and weekly promotional catalogs have a negative impact on impulsive purchases.

Conclusions: This research provides clear instructions to grocery retailers, and their suppliers (manufacturers and distributors) who place their products in their stores about elements of visual merchandising that can significantly affect consumers' impulsive buying and generate additional revenue. Although retailers receive direct positive feedback, it is also of equal importance for manufacturers (manufacturing brands), as they often participate in in-store visual merchandising processes.

Key words: grocery retailing, visual merchandising, impulsive buying, secondary exhibitions, price promotional labels, store atmosphere

INTRODUCTION

While consumer habits are changing, physical stores are still the dominant buying channel, especially in grocery retailing (predominantly food products) retailing. With fierce competition and the need for adaptability to new consumer demand expectations (e.g., omnichannel consumers), the physical store remains the place where retailers have the strongest influence on consumer buying, especially on their impulsive part. In that sense, retailers primarily use visual merchandising and store environment tools to increase impulsive buying. According to Berman and Evans [2018], visual merchandising includes the in-store layout, the type of fixtures, the display windows of the store and aisle width, but also the way in which the merchandise is visually organized, the types of lighting, in-store signage, the choice of background music, the paint on the walls and graphics, the type of flooring, and the use of videos on in-store screens. All of these factors are designed to increase consumers' stay in the store and consequently the overall spending in the store. Due to the vast choice of different visual merchandising tools and limited budget, on the other hand, retailers need to be aware of the effectiveness of each of them and understand the principles of its use in the store.

The aim of this paper is to investigate which factors in the store environment (and especially

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visual merchandising) are successful in encouraging impulsive consumer buying. Therefore, two research questions were stated.

RQ1: Are all visual merchandising tools statistically influencing impulsive consumer buying in grocery stores?

RQ2: Which visual merchandising tools influence impulsive consumer buying positively and which negatively in grocery stores?

The paper contains an extensive literature review on the elements included in the model, namely *impulsive buying* as the dependent variable and *store layout, store design and cleanliness, regular promotional signage, in-store product displays, in-store price promotional labels, out-of-store price promotions, in-store colours, in-store music*, and *store employees* as independent variables. Furthermore, the research methodology was given, followed by the results, discussion, and conclusion.

LITERATURE REVIEW

Beatty and Ferrel [1998] usually associate **impulsive buying** with a feeling of pleasure, excitement, or a strong desire. Bayley and Nancarrow [1998] describe impulsive buying as a sudden but appealing, hedonistically complex purchase in which the speed of the decision-making process precludes a deliberate intention to consider alternative information and choices. Pirion [1991] states that the phenomenon of impulsive buying includes four criteria: impulsive buying is always unplanned, and such an instinctive decision is always made "on the spot", arises from a reaction to a stimulus, and involves a cognitive and/or emotional reaction. Therefore, it can expect that in-store elements, including visual merchandising, are designed to enhance impulsive buying. Including all possible elements of visual merchandising in this paper would require a much more theoretical background and a larger research sample. Therefore, some of the major chosen elements of visual merchandising that create a specific store-buying atmosphere will be analysed below. Gelsomino [2018] highlights several significant factors in merchandising within the store that further influence the emphasis on customer desire and the transformation of the "browser" into a customer. He includes the store's front identity and first impressions, the store's layout, and promotional activities among the more important aspects.

Store layout refers to the way departments and aisles are organized in a store, with the basic goal of gaining customers, retaining customers, and promoting sales [Davies and Tilley 2004]. According to the American Marketing Association [2018], store layout or arrangement of departments or groupings of merchandise has to be organized to provide for ease of customer movement through the store and to provide maximum exposure and attractive display of merchandise. Previous research has recorded different outcomes. A significant positive correlation between layout and impulsive buying was found by Saad et al. [2015], while Nishanov et al. [2016] did not find a positive relationship between layout and impulsive buying.

Store design and cleanliness should make consumers feel comfortable in the store. Cleanliness of the sales area can be considered one of the most important elements of the store's appearance. According to Yun and Good [2007], store cleanliness creates an impression of luxury that attracts customers, contributes to a cozy atmosphere and keeps customers in the store longer. Bell and Ternus [2002] argue that lighting is a key driver of impulsive buying behaviour. It creates an efficient atmosphere, makes products more attractive, and encourages customers to buy more. Lighting attracts customers within the store and influences the creation of perceptions of the product and/or store value by customers [Bell and Ternus 2012].

Regular promotional signage from brands and regular offers have the role of enhancing the recognition of products among many other products at the point of sale, improving communication with customers, and also the visual appearance that attracts the attention of consumers. The role of promotional labels is to highlight certain products within the store, with an emphasis on creating a visual impression of the store [Štulec and Petljak 2016]. With the help of promotional labels, Mehta et al. [2013] claim that customers can buy the product fully informed without the help of sales staff. In the retail industry, promotional labels are aimed at stock-up shoppers (the ones who spend more time in the store), and less at customers who aim to make a purchase as quickly as possible [Sorensen 2016]. Many previous research indicate the influence of promotional labels in the store on the purchase decision and impulsive buying [Anić and Radas 2007, Sarma 2014, Syahrivar 2016, Pawar et al. 2016]. On the other hand, the results of research by Hubrechts and Kokturk [2012] indicate that, despite the correlation, promotional labels in the store do not affect impulsive buying.

In-store product displays have become a powerful tool to attract consumers' attention in the store. Their cost is usually carried by manufacturers, since they represent additional exposure of products. They are used to maximize valuable retail space [Goworek and McGoldrick 2015] and to design and deliver offers that stand out [Grewal et al. 2017]. Their main role is to challenge and persuade the consumer to impulse buying [Ramandeep et al. 2015]. Previous research suggests that 50 % of total purchases made in grocery stores are influenced by product displays [Davies and Tilley's 2004]. Other researchers [Tumundo et al. 2022, Sarma 2014, Hubrechts and Kokturk 2012] have also found a significant positive influence of product displays on impulsive buying.

In-store price promotional labels are certainly considered one of the most common sales tools in contemporary retail. Lichtenstein et al. [1993] define consumer awareness of price promotions as 'the degree to which a consumer focuses solely on paying a low price'. However, price awareness varies from individual to individual, so different segments of consumers may differ on whether they find the price high or low [Sinha and Batra 1999]. Therefore, the influence of price promotional activities on impulsive buying depends largely on the personal characteristics of the consumer and the current situation in the environment [Zhou and Gu 2015]. Faced with a reduced price, the consumer reacts impulsively and his intention to buy increases significantly [Zhou and Wong 2004]. Although price has always been considered a significant factor in impulsive buying [Tendai et al. 2009], there are several different conclusions about the influence of price promotions. Using the eye-tracking method, Huddleston et al. [2015] found that providing promotional labels with product information, but without the indicated price of the product, increases the probability of purchase compared to labels with the indicated price. At the same time, a positive relationship was established between customer attention to visual cues that show the price and the likelihood of purchasing these products. On the other hand, a negative relationship was found between attention to promoted information and the likelihood of purchasing that product. Weerathung and Pathmini [2015] recorded a high level of significant influence of tools of price promotional tools (price discounts, free samples, 1 + 1 free and loyalty program) on the consumers' impulsive purchases by consumers. The sales and price discounts had the strongest influence and Omid [2016] confirmed the same.

Out-of-store price promotions are very common to inform consumers about special prices. Thereby, various information channels are used, such as the Internet, promotional catalogues or TV ads. Voss and Seiders [2003] state that when an ad is based on price, it is primarily in the service of attracting consumers by temporary price promotions. Retailers are counting on the fact that most consumers will also buy other products during their visit to the store, but many consumers can expect to plan their shopping trip based on temporary low prices. That planning can lower the tendency to impulsive buying. In support of this, there is the development of specialized websites and applications that serve as a tool for consumers, making it easier for consumers to compare prices and buy at the lowest prices [Ziliani and Ieva 2015].

In-store colours play an important role in creating the atmosphere in the store. Colours stimulate sales, and Bellizi and Hite [1992] state that colour within the store plays a vital role in the process of impulsive buying behaviour and represents the first thing customers notice before entering the store. Babin et al. [2003] claim in their research that colours affect mood swings, perception, shopping time, and satisfaction. Therefore, colour is important in all areas of retail, especially visual merchandising, lighting, and display positioning [Bhalla and Anuraag 2010].

In-store music relaxes or excites customers, and therefore affects how customers shop in the store. Milliman [1982] in his research studied the influence of the tempo of background music in a store on sales volume. The research findings indicate that a slower pace is most often associated with high sales volume, while a faster pace is associated with lower sales volumes. Furthermore, louder, faster-paced music that does not match the consumer's musical taste will affect the feeling of spending significantly more time in the store than it really is [Berkhout 2016]. Yalch and Spangenberg [2000] researched the effects of familiar or unfamiliar music. They concluded that when the background music is less familiar to the consumers, the time spent in the store and research of the offer is longer, communication is better, and shopping satisfaction is higher. It is possible to conclude that music affects the emotions of consumers and their purchasing decisions depending on the tempo, choice of music, and volume. On the other hand, music also affects the efficiency of employees themselves. Berkhout [2016] indicated how music affects employee efficiency, i.e., how faster music leads to higher employee productivity.

The importance of **store employees** stems from the interactive effects [Gwinner and Bitner 2005] that result in customer service, thereby directly influencing the encouragement of purchase readiness and ultimately purchase decisions [Baker et al. 1992]. Research by Mattila and Wirtz [2008] indicates that employee accessibility, employee education, and training to be more customer-oriented during the most frequent customer visits will influence consumer impulsive behaviour. Mihić and Kursan [2010] concluded that the kindness and skill of sales personnel motivate customers to make an impulsive purchase, while direct assistance or support by sales staff in shopping can partially influence their impulsive buying behaviour. Saad and Metawie [2015] did not indicate a possible prediction of impulsive buying based on the consideration of the role of store employees. However, the findings of their research indicate that customers who develop positive interactive relationships with store employees express a higher level of a tendency toward impulsive buying and, therefore, a higher number of impulsively purchased products.

RESEARCH METHODOLOGY

The primary research was focused on supermarkets and hypermarkets, that is, large retail formats in the Croatian retail context. Using a highly structured questionnaire as a research instrument, both paper-based and online version through the Google Forms template, a convenient sample of 226 respondents was included. All respondents met the basic criterion: They are involved (main or occasional buyer) in purchasing for their household. To facilitate the completion of the questionnaire, the respondents had to nominate one retailer in whose store they buy most often and base their further responses on that retailer's store. Statistical software package IBM SPSS 23.0. was used to analyze the obtained data using the regression analysis method. Table 1 shows the main characteristics of the sample.

The model consists of impulsive buying as the dependent variable and store layout, store design and cleanliness, regular promotional signage, in-store product displays, in-store price promotional labels, out-of-store price promotions, in-store colours, in-store music, and store employees as independent variables. Variables were measured by scales consisting of statements presented in 5-point Likert scales. Commonly acceptable reliability, according to Nunnally [1978], is the value of Cronbach's Alpha (CA) above 0.7. All the constructs included in the model have CA higher than 0.7. The lowest reliability has the construct for store design and cleanliness (0.712). Reliability analysis and descriptive statistics of the constructs are shown in Table 2.

RESEARCH RESULTS

Regression analysis was conducted to investigate the explanation for impulsive buying through the existence of a statistically significant influence of key factors of visual merchandising on it. Table 3. shows the proportion of the variance in the (impulsive buying) dependent variable that is explained by the given model of visual merchandising elements. R Square of .271 means that this model explains 27.1 % of the variance in consumers' impulsive buying.

Table 1. Sample description

		N	%
Gender	**Total**	**226**	**100**
	Male	83	36,7
	Female	143	63,3
Age	Total	226	100
	18-24	86	38,1
	25-30	69	30,5
	31-40	34	15,0
	41-50	17	7,5
	51-60	13	5,8
	61-70	7	3,1
Education	**Total**	**226**	**100**
	Primary school	7	3,1
	High school	82	36,3
	Higher education	41	18,1
	Faculty	59	26,1
	Scientific masters or doctoral degree	37	16,4
Employment status	**Total**	**226**	**100**
	Student	80	35,4
	Employed	102	45,1
	Unemployed	35	15,5
	Retired	9	4,0
Members of household	**Total**	**226**	**100**
	1	9	4,0
	2	42	18,6
	3	66	29,2
	4	65	28,8
	5 and more	44	19,5
Household monthly income	**Total**	**226**	**100**
	not answered	1	0,4
	less than 400.00 €	24	10,6
	400.00 – 800.00 €	52	23,0
	800.00 -1,200.00 €	64	28,3
	1,200.00-1,500.00 €	34	15,0
	1,500.00 -1,800.00 €	19	8,4
	1,800.00 € and more	32	14,2

Source: own work.

Table 2. Reliability analysis and descriptive statistics of the constructs

Scale	N of items	Cronbach Alpha	Mean	Variance	Std. deviation	Scale source
Impulsive buying (IB)	6	0.833	15.66	26.562	5.154	Hubrechts and Kokturk (2012); Mehta and Chugan (2013)
Store layout (SL)	8	0.780	27.77	29.953	5.473	Hubrechts and Kokturk (2012); Henry (2014)
Store design and cleanliness (SDC)	4	0.712	13.73	9.238	3.039	Grewal and Baker (1994); Bouzaabia et al. (2013)
In-store product displays (IPD)	6	0.894	18.48	28.429	5.332	Hubrechts and Kokturk (2012); Henry (2014)
Regular promotional signage (RPS)	5	0.863	15.68	22.140	4.705	Hubrechts and Kokturk (2012)
In-store price promotional signage (IPP)	7	0.917	25.95	34.611	5.889	Hubrechts and Kokturk (2012); own
Out-of-store price promotion (OPP)	3	0,755	11.18	7.482	2.735	Hubrechts and Kokturk (2012); own
In-store colours (IC)	4	0.783	13.63	9.763	3.125	Henry (2014); Jamnani (2015)
In-store music (IM)	4	0.888	9.83	15.216	3.901	Henry (2014.), Jamnani (2015)
Employees staff (ES)	4	0.890	15.12	9.960	3.156	Baker et al. (1994); Ngobo and Coutelle (2014)

Source: authors' work

Table 3. Model summary

Model Summary[b]				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,521[a]	,271	,241	6,99161
a. Predictors: (Constant), Total_IC, Total_OPP, Total_ES, Total_RPS, Total_SL, Total_IM, Total_SDC, Total_IPD, Total_IPP				
b. Dependent Variable: IB				

Source: own work

The ANOVA results are shown in Table 4. Taking into account that Sig = .000, i.e. p<0005, this indicates the statistical significance of the result in the model summary table.

Table 4. ANOVA

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3931,584	9	436,843	8,937	,000[b]
	Residual	10558,651	216	48,883		
	Total	14490,235	225			
a. Dependent Variable: IB						
b. Predictors: (Constant), Total_IC, Total_OPP, Total_ES, Total_RPS, Total_SL, Total_IM, Total_SDC, Total_IPD, Total_IPP						

Source: own work

The following Table 5 shows which variable contributes to the prediction of the impulsive buying. The significance column indicates that in-store product displays, in-store price promotion labels, out-of-store price promotions, and in-store music statistically significantly (p<0.05) influence impulsive buying.

Table 5. Regression coefficient

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	24,353	3,290		7,403	,000
	Total_IPD	,362	,107	,275	3,367	,001
	Total_SL	,066	,111	,045	,592	,554
	Total_RPS	,023	,133	,013	,171	,864
	Total_IPP	,233	,104	,208	2,249	,026
	Total_OPP	-,470	,215	-,160	-2,184	,030
	Total_ES	-,059	,166	-,023	-,358	,721
	Total_IM	,447	,156	,217	2,859	,005
	Total_SDC	-,072	,210	-,027	-,346	,730
	Total_IC	-,026	,211	-,010	-,125	,900

Source: own work

While in-store product displays (β= 0.275), in-store price promotion labels (β= 0.208) and in-store music (β= 0.217) influence impulsive buying positively, out-of-store price promotions negatively influence impulsive buying (β= -0.160). The obtained results are discussed in the following section.

DISCUSSION AND CONCLUSION

In times when online retailing gains considerable and rising attention, impulsive consumer buying is one of the last advantages of in-store business for retailers. Therefore, retailers invest considerable time and funds into promotional activities, especially merchandising, in their retail stores to increase impulsive buying. Although there are many directions to canalize in-store visual merchandising investments, contemporary retailers seek the right combination of investment in merchandising tools to get the best overall blend of atmosphere, incentives, and products displayed, and finally the highest return on investment. Previous research has shown differences when it comes to existing of the significant influence of certain merchandising variables on impulsive in-store buying, and there are no general conclusions. Our research has tested the most used retailing tools for increasing impulsive buying: store layout, store design and cleanliness, regular promotional signage, in-store product displays, in-store price promotional labels, out-of-store price promotions, in-store colours, in-store music, and store employees. Obviously, the influence of merchandising on impulsive buying in retail stores is a multidimensional phenomenon where some variables have positive and some negative influences. According to this research results, only product displays (β= 0.275), in-store price promotion labels (β= 0.208), and in-store music (β= 0.217) have a statistically significant positive influence on impulsive buying confirming previous research and determining the position of the merchandising tool in which it pays to invest more. These results provide answers to the first research question (RQ1). The second research question (RQ2) is explained below.

The strong influence of in-store product displays is expected and well known in previous studies [Grewal et al. 2017, Davies and Tilley's 2004, Hubrechts and Kokturk 2012, Sarma 2014], and confirmed in this research as well. In such a situation, the displays of in-store products remain source of additional income for retailers, as many suppliers are willing to pay significantly additional funds. Their presence in space has inevitably benefits for product sales and hardly any product on the shelf positions can measure up to their ability to sell. Although product displays are very lucrative, retailers must avoid situations in which an additional display will be a physical obstacle in the process of browsing and purchasing, and be aware of a possible imbalance in the category caused by too many displays.

Due to the relatively high price elasticity of demand in grocery retail, our results likewise confirmed in-store price promotional labels as one more critical factor that positively influences impulsive buying. While faced with a huge assortment of various products in a certain product category, promotional price labels easily attract consumers' attention of consumers and increase the probability of unplanned purchases.

Earlier studies [Milliman 1982, Berkhout 2016, Yalch and Spangenberg 2000] were highlighting the role of in-store music in shopping behaviour, and this research has also proven that in-store music significantly positively influences impulsive buying in the store – both through the duration of stay and intensity of buying. It appears that in this area of merchandising, there are the largest opportunities for retailers' improvement when it comes to influencing impulsive buying.

Finally, the results indicate that consumers perceived out-of-store price promotions (prices through the Internet and weekly promotional catalogs) as the ones that negatively influence impulsive buying. In other words, if consumers are informed about price promotions outside the store, they think they will buy less impulsively and buy more focused manner. However, the fact that retailers so strongly on out-of-store promotions inevitably confirms a fact of high share impulsive buying of these consumers. Probably, the largest part of this impulsive buying is caused by in-store incentives, but out-of-store promotions are crucial for attracting consumers to the store, and retailers know it. Considering that promotional activities are usually included in demand forecasting [Kmiecik and Zangana 2022], it would be useful for retailers to know the structure of those promotional activities, ie, the ratio of promotions attracting the consumers in stores and those that are incentives for impulsive buying.

It can be concluded that, in grocery retailing, price promotional labels are the strongest available merchandising tool to increase impulsive buying, while in-store product displays are the strongest off-shelf merchandising tool for increasing impulsive buying. At the same time, in-store music represents a somewhat neglected but proven effective area in attempting to increase impulsive buying through an improved store atmosphere.

The main limitations of the research arise from focusing solely on grocery stores and in a relatively narrow geographical area (Republic of Croatia). Therefore, future research should be geographically expanded and investigate the structural causes behind all variables of visual merchandising and its elements.

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ORIGINAL PAPER

USE OF BIG DATA ANALYSIS TO IDENTIFY POSSIBLE SOURCES OF SUPPLY CHAIN DISRUPTION THROUGH THE DOTMLPFI METHOD

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ABSTRACT. Backgrounds: The presented research deals with the investigation of how big data analytics can help predict possible disruptive events in supply chains. The supply chain can be considered a complex system with a wide spectrum of possible sources of internal and external disruptions. Since the individual entities of the supply chains operate in a particular environment and interact with this environment, there is a certain level of mutual interdependency. This set of interconnected interactions within the supply chain will be the unit of analysis.
Methods: There are many internal and external sources of supply chain disruption, which opens up the potential application of Big Data Analysis (BDA) as an early warning tool. To analyse the possible application of the BDA to identify sources of supply chain disruptions, we conduct a bibliometric analysis to define an appropriate structure for supply chain risk classification as well as appropriate keywords that make data collection quicker and easier. The DOTMLPFI methodology was used to systematically identify the most relevant risks threatening the supply chains.
Results: The proposed research approach creates a possible framework to support the operational sustainability and resilience of the supply chain as a system, toward internal and external disruptions. The research results also point out the most explored attributes of supply chain disruption. The conducted bibliometric research and content analysis support the theoretical framework of using BDA as a possible early warning tool, especially for the identification of possible sources of supply chain disruption. The approach of grouping Big Data sources into categories based on DOTMLPFI groups allows to identify the appropriate keywords for their later BDA analysis. The analytical framework provides a starting point for individual supply chain entities to understand risks and systematically collect the appropriate data in the required structure about them.
Conclusion: The complexity of supply chains, together with the increasing possibility of digital applications, requires a new analytical framework for evaluating the overall supply chain, with the possible application of new data sources and analytical approaches regarding the risks threatening the chain. DOTMLPFI methodology allows covering all the relevant categories of supply chain risks, and by proposing relevant keywords and data sources it can help companies to find the appropriate open-source, up-to-date information and be prepared for disruptive events.

Key words: Supply chain disruption, supply chain resilience, Big Data analysis, DOTMLPFI method

INTRODUCTION

Supply chain security and resilience are the key aspects of the long-term sustainability and well-being of current societies. As a complex phenomenon, a supply chain is made up of companies, organizations, and the complex relationships that link those [Rehak et al. 2014]. Therefore, supply chains can be approached from a systems theory perspective. At the same time, current supply chains have to operate in a particularly turbulent and dynamic environment. A very important issue in such circumstances is the supply chain's ability to successfully maintain its operations while adapting to a dynamically changing environment.

The origin of threats to supply chains is most likely to be irregular, catastrophic, or hybrid emerging from hostile intentional or nonintentional activities, e.g. natural or disasters [Freier 2008 p. vii]. Supply chain disruption can happen inside or outside of the supply chain [Narashimhan and Tallurin 2009], intentionally

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or unintentionally [Foltin 2011], in supply chain flows such as material flow, information flow, knowledge flow, control and coordination flow [Neiger et al. 2009]. The consequences of catastrophic events are also investigated by supply chain research teams [Knemaver et al. 2009], similarly to the consequences of socio-economic, political, man-made, and natural disasters [Singh and Singh 2019].

Due to the complexity of supply chains, the number of individual supply chain elements and their interconnections carry an inherent risk [Rehak et al. 2016]. Identification of unexpected events is a prerequisite for the possibility to manage the supply chain resiliently [Stepanek et al. 2013].

The operations and resilience of supply chains can be supported by the application of emerging technologies. Digitalisation helps to optimise processes, create transparency, and monitor the supply chain environment [Bahrami and Shokouhyar 2021; Modgil et al. 2021; Ivanov et al. 2019].

The paper is structured as follows: In the literature review, we interpret supply chains as systems and reveal their vulnerabilities with the possible sources of the supply chain risks. The second part presents the main research goals, the selected methodological approach, and research limitations. Based on the research goal, the third part presents the analytical framework which can be used for supply chain risk classification and an extensive analysis of these risks. The fourth part summarizes the results of the bibliometric analysis and highlights the next possible steps of follow-up research. The originality of the paper was primary in introducing a systematic classification of supply chain risks with possible data sources for prevention.

COMPLEXITY AND VULNERABILITY OF SUPPLY CHAINS

In the presented research, the supply chain is interpreted as 'systems theory views organisations as interconnected processes with a high level of integration and intensive information sharing between business processes of the supply chain' [Fatorachian and Kazemi 2020 p. 3]. Systems thinking enables the identification of system elements, different business processes/actors within the supply chain, and the relationships between them and allows the analysis of the relationships between each system element and its environment.

Supply chain in system approach

Supply chain design can be very complex given the size of the network and the number of factors that influence the design. The SCOR model approaches supply chains from a process-based point of view and applies six topics along which it analyzes the supply chain entities [Huan et al. 2015]. Since there is no other complex theoretical model that is fully applicable for analyzing supply chain operations, especially risk preparedness from multiple aspects, the DOTMLPFI methodology will be adapted. The DOTMLPFI classification approach is used in the military environment as a mnemonic tool to tackle Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities, and Interoperability. Generally, any military planning process at the strategic level should be driven by this acronym, not to forget any important planning aspect on the final operation [Hodicky 2020]. This approach could be applied to evaluate the supply chain operational sustainability and resilience to external and internal sources of disruption.

RESEARCH GOAL, METHODOLOGY AND RESARCH LIMITATIONS

Based on the initial problem description and identification of possible supply chain disruptions, we identified a research gap laying in the limited analytical framework, which could help with the systematic identification of the data sources suitable for overall system evaluation of the capabilities and activities that determine the operational sustainability and resilience of the supply chain.

For this reason, the research goal was formulated as to investigate how big data analytics help to mitigate the negative effects in case of disruptive events threatening the supply chains. The focal research questions (RQ) are:

RQ1: How can supply chain disruptions be systematically analysed from all the relevant aspects?

RQ2: What are the most important keywords to identify the risks which cause disruptions?

RQ3: What data sources are available for companies to collect data on these risks for preventive purposes?

There are many sources in the literature on supply chain disruption and the potential risks to supply chains, but no comprehensive and systematic study has been carried out. The presented research aims to contribute to fill this research gap, and introduce an analytical framework, a structure, which helps the systematic identification of the data sources suitable for general system evaluation of the capabilities and activities that determine the operational sustainability and resilience of the supply chain.

The DOTMLPFI methodology allows for this type of detailed review and integrates the aspects identified in the literature. This DOTMLPFI methodology is primarily used on defence sector as a mnemotechnic tool to help identify suitable conditions, sources, and possibilities to develop and sustain defence capabilities in long-term period. The letters of the abbreviation DOTMLPFI represent the main capabilities areas, when D stands for Doctrine, O for Organization, T for Training, M for Material, L for leadership and education, P for Personnel, F for facilities and I for Interoperability. This approach could be considered as a general approach with possible application to other areas when system capabilities are considered. The purpose of developing an analytical framework in this way is to see for which risks we need to identify data sources that would allow us to build an early warning system.

In DOTMLPFI qualification, the required capabilities of supply chain network [marked as C] could be described (1) [Hodicky and Prochazka 2020]:

$$C_{[t]} = min_i C_i(t),\ i \in I = \{D,O,T,M,L,P,F,I\}, C_i[t] \in \langle 0,1 \rangle \qquad (1)$$

The optimal supply chain system composition supposed to reach $C_{[t]}$ is equal to or approaches the value of 1.

Due to supply chain complexity, the presented research will focus on the main risk sources each representing the DOTMLPFI categories for which we propose a relevant data source.

Bibliometric analysis was used as a methodology. The Web of Science (WoS) and Scopus databases were searched for preliminary determined search phrases to thematically structure papers dealing with supply chain disruptions. With this method, we proved the validity of applying the DOTMLPFI methodology which allows to analyse disruptive events from many aspects. The documents were also subsequently searched using the search terms given in Table 1, to see which types of risks are typically focused on in supply chain disruption articles, what keywords were given in the case of the different types and in which direction researchers should focus their future research.

LINKING THE POSSIBLE SUPPLY CHAIN RISKS WITH BDA DATA SOURCES

Information sharing at the supply chain level is a widely accepted tool for supply chain management [Mentzer et al. 2001]. Sharing the right information with the right actors can provide business benefits to the supply chain, increasing competitiveness. Extensive data analysis plays an important role in predicting these events and mitigating the risks of threats. High quality information can lead to appropriate risk control [Shamala et al. 2017].

Big data is created in multiple organizational processes in high volume, with high velocity and in high variety, which exceeds the capabilities of traditional data processing systems [Wang et al. 2016]. Big data analysis therefore incorporates skills, technologies, and practices to structure and process data and provide useful information for decision makers [Demeter et al. 2020].

However, BDA can support the resilience of supply chains in several ways. According to Papaodopoulos et al. [2017], Big Data has great potential to optimize recovery strategies and for supply network management. Bahrami and Shokouhyar [2021] consider the greatest achievement of BDA the deep understanding the changes in the business and market environment, which allows companies to prepare for disruptions.

In Table 1 the main categories of risks that threaten supply chains are summarized. The DOTMLPFI framework was used to classify risks and indicate strategic planning areas. This approach should be involved as an integral part of risk management.

The Doctrine category summarises the basic principles of system design in the original DOTMLPFI methodology, similarly to the definition of strategic management, with appropriate strategy formulation, implementation, and evaluation [David 2011]. In the analytical framework that examines supply chains, strategic goals were considered, e.g., UN Sustainable Development Goals 2030 [UN 2022], EU Global Gateway 2050 [EU 2021], and environmental circumstances that determine the operational conditions of the supply chain. Within presented research results, these strategic goals also mean possible impacts and potential threats from the political, social, economic, and natural environment, together with threats from the behavior of competitors and the immediate business environment.

In the Organization section, we identify risks within the organization that may have an impact on the sustainable operation of the supply chain. The Training category summarises the risks arising from the skills or lack of skills of supply chain actors and their key skilled personnel, but also indicates the capability to avoid the potential of losing key personnel. In the Materiel category, we identify risks related to the availability, quality, and lack of materials, resources, products, and services used in the supply chain within the operations and the value-creating process, but also raw materials and spare parts. The Leadership and Education category summarises the risks inherent in supply chain leadership and management. It also includes issues related to the appropriate training of workers. The Personnel theme specifically covers issues related to the availability of human resources, its international mobility, and, in the long term, the consequences of industry 4.0 applications and the possibility of replacing some professions with advanced robotic systems [Cellan and Jones 2019]. It also includes risks related to occupational safety, worker health, and workers' rights. The Facility category includes all risks related to the physical infrastructure of the supply chains and its operation, e.g. ports, airports, maintenance facilities, etc. It also covers information and communication infrastructure, including also hardware, software, and data security. The interoperability group covers the area of the acceptation and follows the international standards, regulations, and recommendations.

The BDA application has significant potential in the identification of disruptive events. In this process, it is necessary to identify disruptive events, their accompanying phenomena, and potential triggers. Due to the breadth of influencing factors, it is appropriate to apply a systematic approach, such as the DOTMLPFI methodology.

As possible data sources, spam or topical filters could be applied to filter important information from available data. By applying appropriate filters and classifiers, it is possible to convert unstructured data to structured data, allowing further analytical steps. A possible approach to the description of exemplary data sources according to DOTMLPFI is shown in Table 1. In the following table, keywords were assigned to the risks identified in each category of analysis, which was used to conduct a systematic analysis of the literature and identify the topics that are most emphasized in articles on supply chain disruption.

Table 1: Example BDA sources and keywords of disruption in the DOTMLPFI classification

Source: Own work

Category		Risk types (BCI, 2021, ISO 31000)	Source of Big Data	Examples of Category Keywords
Doctrine [Strategy]		Extreme weather events Natural disaster Regulatory changes Political violence/ civil unrest Enforcement by regulator Political change Exchange rate volatility Energy price shock	Global Disaster Alert and Coordination System	design network natural disaster threat
Organization		Economical integrity Stability and credibility of trade relations Overall economic stability Interdependency risk Organizational culture difference as risk	Logistics Performance Index (LPI) Atlas of Economic Complexity Globe of Economic Complexity	agility viability dynamics
Training		Lack of talents/ key skills People, skills and availability risks	Labor Force Index Poverty Rates GINI Index Shared Prosperity	flexibility collaboration
Materiel		Supply chain disruption Interruption to utility supply Natural resources shortage Product safety recall	EM-DAT	business continuity resilience
Leadership and education		Leadership risk Control risk	post, news, reports	management project

		Agency risk Decision maker risk	Fluctuation % of C-level managers at supply chain companies	
Personnel		Non-occupational disease Health incident Safety incident	post, news, reports Number of safety incidents in the supply chain in a given period of time	human mobility human resources labor force
Facilities		IT and telecom outage Cyber-attack and data breach Introduction of new technology Critical infrastructure failure High cost of borrowing Lone attacker / active shooter incident Malfunction of the Facilities	Cyber-threat real-time map OTCAD Cyber-threat real-time map Digital Attack Map World Container Index Terrorist Attacks Marine Traffic Flight Radar – Live Air Traffic	security sustainability location network
Interoperability		Lack of IT interoperability Disruption to interoperability between trade partners (e.g. visibility and transparency) Non-compliance with international standards	Logistics Performance Index (LPI)	flexibility coordination standard

RESULTS

To identify the thematic structure of articles dealing with supply chain disruptions, a search has been conducted. Using the search string <("supply chain" or 'distribution chain' or "logistics") and ("disruption" or 'threat' or "risk")> in the WoS database, a content analysis was carried out to examine the disciplinary approaches of articles and studies on supply chain disruption. The first search resulted in 19,385 publications, which, after filtering out the natural sciences and other disciplines that did not fit the current topic, 14,926 papers left. As WoS analytics can only handle 1000 articles at a time, the studies with the highest citation counts (Clarivate, 2022) were selected for analysis. The studies are categorised thematically as shown in Figure 1.

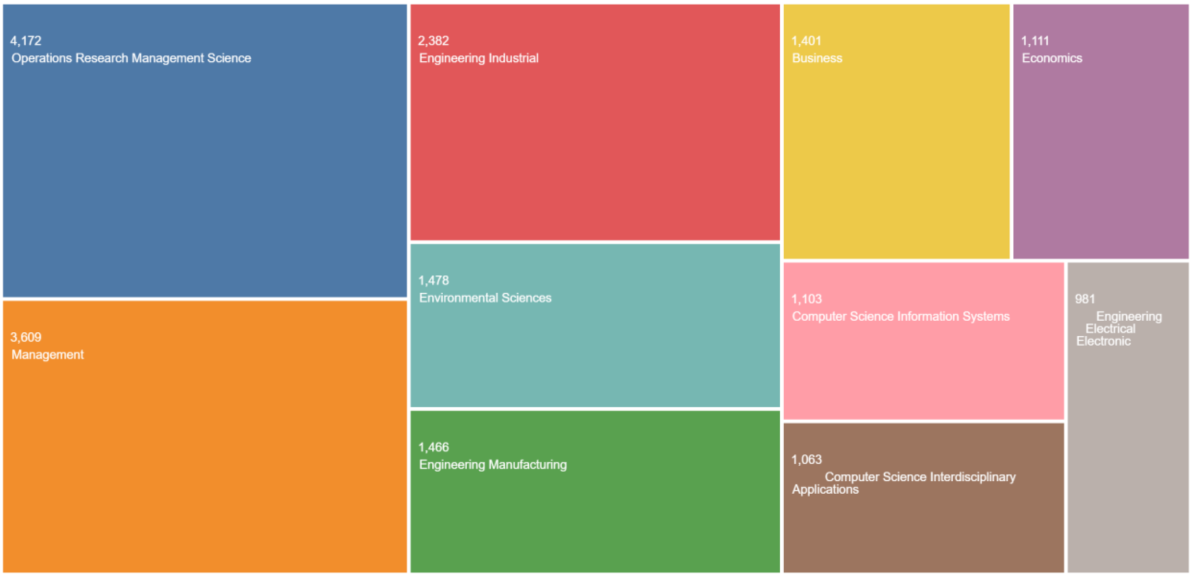

Fig. 1 Thematic structure of articles in the WoS database covering the field of supply chain disruption.

Source: own work

Once the thematic structure of the articles on supply chain disruption was identified, it became apparent that the topic indeed requires the kind of complex approach that the authors have proposed through the DOTMLPFI methodology mentioned earlier. Doctrine includes the economic, business and natural environment elements, while Organization, Training, Personnel and Leadership can also be linked to the business and management themes mentioned in Fig. 1. Materiel and Facility can be covered by the Engineering Industrial, Manufacturing, and Electrical Electronics blocks, while Interoperability and Facility can correspond to Computer Science Information System and Interdisciplinary Applications. This demonstrates that supply chain disruption analysis must simultaneously consider several aspects to help identify all relevant risk factors, and the DOTMLPFI is a suitable and detailed structure to summarise the analytical aspects.

As a second step, a bibliometric analysis has been carried out using also the databases of Web of Science and Scopus. In the first step, the keyword <("supply chain disruption")> was applied to select articles, conference papers, book chapters, etc. which deals with the focal topic. After merging the databases and filtering out the redundancies with R Studio, 1 112 publications remained. In the third step, the list of keywords is applied, which was provided in Table 1. These keywords have been used to reveal the approach of the selected papers in analysing supply chain disruptions.

The following graph (Figure 2) shows the frequencies of keywords in the publications, recognizing that one paper might address multiple supply chain threats.

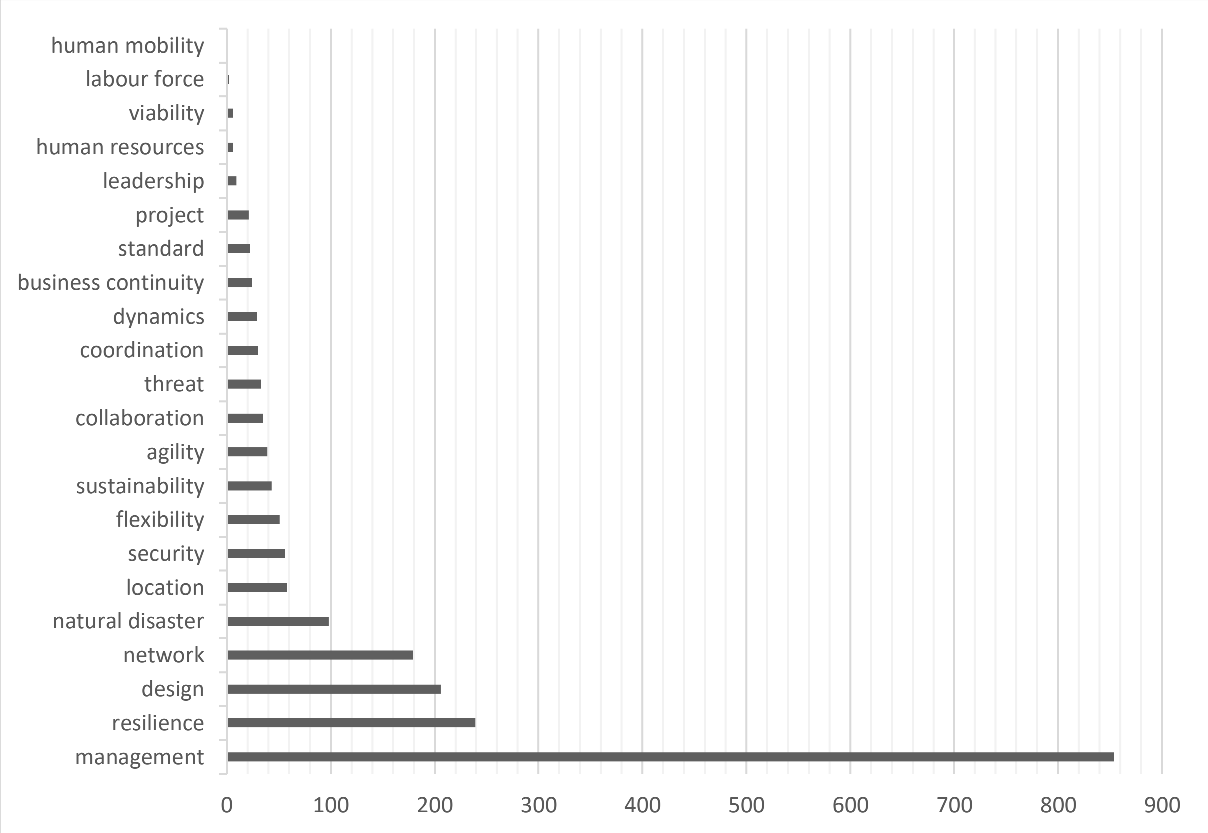

Fig. 2 Frequency of keywords addressing different types of supply chain disruptions

Source: own work

The chart says that the most popular approach when researchers deal with supply chain disruptions is to analyze how to manage them. The next extensively researched areas are how to become resilient to disruptive events and how to design and operate a network that decreases the effects or the exposure of such events. Analyses like this allow further researchers to orient their exploratory efforts towards the risks less discovered and described yet.

CONCLUSIVE REMARKS

The research results systematically examine the possible framework for supporting the operational sustainability and resilience of supply chains and initiate a framework that helps to systematically analyse the potential risks causing supply chain disruptions.

The theoretical contribution of the research lies in structuring supply chain risks and, from a practical point of view, proposing a framework for collecting data sources for early warning systems that may be necessary to identify these risks, prevent them, and detect disruptions in time.

A structured risk categorisation was developed as an analytical framework, in which a possible grouping of risk factors was proposed along the DOTMLPFI categories, applied from the area of defence capability planning. Since the risks that threaten supply chains are very diverse, there is a strong need for a structured categorisation of these risks. If a methodology, such as the DOTMLPFI, can be found to do this systematically, it can be used to identify data sources from which information can be obtained about the threats themselves. The results of the bibliometric analysis, which was conducted to see the thematic structure of the articles and studies indexed in the WoS and Scopus databases dealing with supply chain disruption and threats, supported that DOTMLPFI is a wide-ranging methodology and is appropriate as a framework. It was proved that DOTMLPFI methodology allows covering all the relevant categories of supply chain risk.

The secondary objective of the analysis was to identify the most popular approaches to supply chain disruptions and to risk exploration and provide keywords that reveal the areas most researched and less researched, as well as propose possible bid data sources that companies can reach and can build early warning system on, becoming prepared to the risks listed.

The presented research results create an initial theoretical framework for the next research phases, where selected keywords will be tested and further developed based on real situation and disruption within supply chains. These next analytical steps should be focused on BDA sources, grouped in DOTMPFI, through identified keywords and their possible connection to sources of supply chain disruption.

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ORIGINAL PAPER

SEQUENCING AND PLANNING OF PACKAGING LINES WITH RELIABILITY AND DIGITAL TWIN CONCEPT CONSIDERATIONS – A CASE STUDY OF A SUGAR PRODUCTION PLANT

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ABSTRACT. Background: The study focuses on simplified make-and-pack production in the sugar industry as a case study. The analyzed system is characterized by parallel packing lines, which share one resource with a sequence-independent setup time. Additionally, the special characteristics that occur in many enterprises make scheduling difficult. The special characteristics of the system are the simultaneous occurrence of a variable input stream, scheduling of processes, and including the reliability of machines. Due to the variability of the input parameters, it is appropriate to consider the use of Digital Twin, which is a virtual representation of the real processes' performance. Therefore, this purpose of the paper is two-fold. First, an analysis of sequence determination of the stream-splitting machine was performed with taking into account the impact of logistics system reliability on system performance. Second, the concept of implementing Digital Twin in the analyzed production process is presented.

Methods: The mathematical model for line efficiency was developed on the presented make-and-pack production presented in the selected sugar industry. Different sequences of stream-splitting machines were studied to examine the system's efficiency, availability, and utilization of packaging lines. Two scenarios were investigated with the use of computer simulation.

Results: Computer simulation experiments were performed to investigate the sequencing and planning of packaging line problems. The results obtained for the case company indicated a significant dependence between the preferred packing sequence and the operational parameters.

Conclusions: The simulations confirm the influence of internal and external factors on sugar line packaging processes. The main advantage of the developed simulation model is identifying the relationship between the size of the input stream and the system's availability level, as well as identifying the main constraints on the possibility of implementing the DT concept in the analyzed company.

Keywords: production scheduling, sugar factory, make-and-pack production, food industry, Digital Twin, machine reliability

INTRODUCTION

There is a growing need for manufacturing to become faster and more responsive to changes in the global market. These requirements are more and more often fulfilled by factory automation [Dotoli et al. 2019, Kopacek 2019], which is the basis of the Industry 4.0 concept. The future of enterprises is Smart Factory, which is full autonomy, starting with production planning and ending with its maintenance [VanDerHorn and Mahadevan 2021]. This automation is diverse in the food industry, from fully manual operations to very advanced manufacturing systems [Coldwell et al. 2009]. In these systems, various robots are used mainly for picking and placing operations such as food handling, packing, palletizing, and food serving [Iqbal et al. 2017]. In addition to this, different control strategies are implemented, such as adaptive, intelligent or fuzzy logic controllers [Kondakci and Zhou 2017].

Despite the automation level, the food industry faces scheduling problems, which can also be found in almost any industrial production facility [Harjunkoski et al. 2014]. Scheduling is defined as the decision-making process that

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considers allocating limited resources to tasks over given periods [Branke et al. 2016, Pinedo 2012]. Representation of scheduling problems has three fields: type of problem, constraints, and performance measures [Graham et al. 1979]. As indicated in [Fuchigami and Rangel 2018], there are multiple papers concerning, among others, job shop, flow shop, single machine, and parallel machine problems. Tardiness, makespan, production costs, lateness, and flow time are mostly considered minimization criteria. Also, heuristics, genetic algorithms, computational simulations, and mixed-integer linear programming are used. In the food industry, the flow shop problem is investigated for canned fruit factories (eg [Parthanadee and Buddhakulsomsiri 2010]), bakery production (e.g. [Hecker et al. 2014]), and dairy production (e.g. [Touil et al. 2016]).

A sugar factory can be classified as a simplified make-and-pack production system in which one intermediate product (sugar crystals) is manufactured in the make phase and is packed into different formats in the packing phase. To our knowledge, almost all papers concerning sugar production are focused on the making stage. There are articles that focus on selected operations of sugar manufacturing [Tabriz 2016], energy analysis [Taner et al. 2018], life cycle assessment [Chauhan et al. 2011], sustainability issues [Eggleston and Lima 2015] and operators' training [Merino et al. 2006]. The packing phase is considered only by Pytlak [2014], where the authors' primary objective in the scheduling problem was to minimize the time truck drivers spent at the sugar mill.

Additionally, in the analyzed literature, publications focusing on the types of enterprises with special system characteristics were not found. The special characteristics of the system that exist in many enterprises rely on the simultaneous occurrence of a variable input stream, scheduling of processes, and the reliability of machines. It influences, among others, the efficiency of the entire enterprise.

Following the above considerations and due to the variability of the input parameters, one possible solution is to implement the Digital Twin concept to support the decision-making processes of sugar factory production. DT is a virtual representation of a real process, which enables the detection and elimination of errors in the virtual system before they appear in the real process [Chen et al. 2013]. This is possible thanks to feedback information. DT uses real-time data from the real process. Thanks to artificial intelligence, cloud computing or machine learning, the analyzed data allows for a virtual representation of the production process [Tao et al. 2019]. Digital Twin can be used in the field of logistics and production in many situations. Fig. 1 highlights sample application areas of the DT in an enterprise.

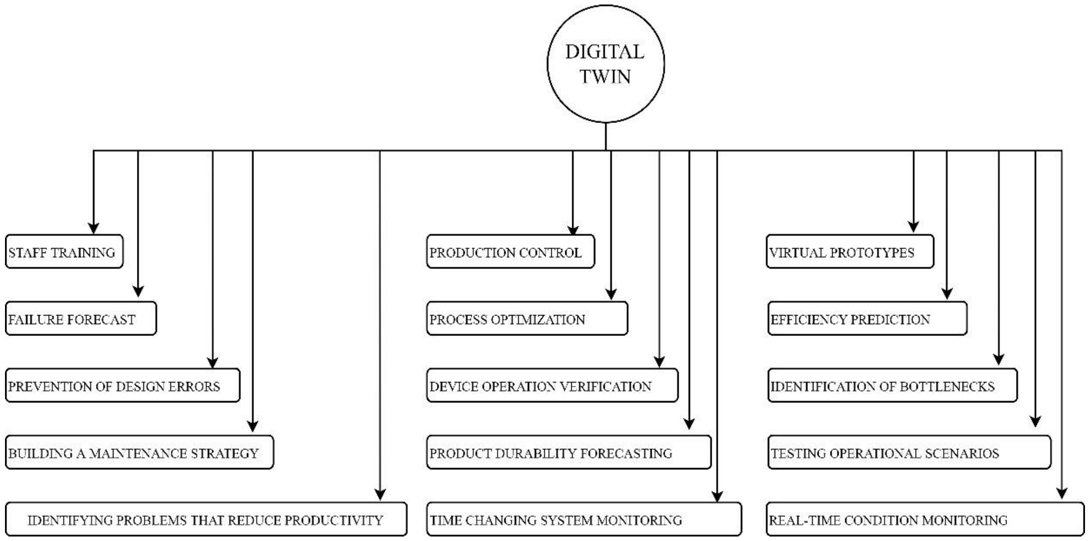

Fig. 1. Sample application areas of the Digital Twin concept in manufacturing companies.

Source: Own work based on [Errandonea et al. 2020, Liu et al. 2021, Tao et al. 2017, VanDerHorn and Mahadevan 2021]

The implementation of Digital Twins brings many benefits for enterprises, like monitoring the operation of the logistics chain, increasing efficiency, time, and cost savings, and reducing the risk of design errors thanks to the possibility of unlimited testing of operational prototypes in virtual reality. In the maintenance sector, using DT, it is possible to anticipate potential failures before they occur, improve processes, and thus create a more efficient organization. The analyzed scientific articles in the field of Digital Twin in internal logistics concern the modelling of challenging production aspects - supporting supply chain management through data monitoring (see, e.g. [Souza et al. 2019]), assistance in data structuring and machine management (see, e.g. [Olivotti et al. 2019]), supporting the life cycle of machines (see, e.g. [Konstantinov et al. 2017]), supporting the educational process of flexible production systems (see, e.g. [Toivonen et al. 2018]), optimizing planning (see, e.g. [Yao et al. 2018]), object recognition (see, e.g. [Um et al. 2018]), or supporting decision-making concerning system design (see, e.g. [Zhang et al. 2017]). However, for these models to be of the highest level, external factors such as supply chains and internal factors should be considered - employee skills and device failures.

As a result, the purpose of this publication is twofold, considering the main problems regarding the final sugar production stage. First, the authors focused on sequence determination of the stream-splitting machine, taking into account the impact of the reliability of the logistics system on system performance. The problem concerns the final stage of sugar production, where parallel packing lines share one resource with sequence-independent setup time. Determining the sequence (scheduling) is of great importance in the period of increased sugar demand, when all packing lines are utilized.

Second, the concept of implementing Digital Twin in the analyzed production processes is presented to improve the decision-making processes in the investigated case company. The possibility of connecting the Digital Twin system with the physical system is also investigated. The developed concept allows for an examination of the effect of variable parameters on efficiency, availability, and real-time system utilization.

Therefore, in the next section, the sugar production process is introduced. On the basis of the presented description, the description of the investigated problem is provided, and the modelling approach is presented. The simulation model of the sugar packaging process is presented, together with the analyzed scheduling scenarios and the results of the case studies. The results obtained provide the implementation possibilities of the basis for investigating the Digital Twin concept. There are also identified system limitations to be overcome during the development of the DT solution. Conclusions finish the paper.

SUGAR PRODUCTION PROCESS

Sugar production can generally be described as a three-stage process (Fig. 2), where beet processing, juice processing, and sugar processing can be observed. These three highlighted stages are related to the type of input material, which changes due to various physicochemical processes. A detailed description of every stage is presented below:

Stage I. Sugar beet processing [Tabriz 2016]

The sugar beets delivered to the factory are being washed to remove dirt from the harvest. Then they are sliced into so-called cossettes, V-shaped pieces, which help to maximize sugar extraction. Cossettes are transported to a diffuser, where raw juice is extracted from them due to leaching. The remaining beet pulp is pressed, dried and used for animal feed. After extraction, the final process of sugar beet processing, the raw juice becomes the new input material for the subsequent processes.

Stage II. Juice processing [Azizi et al. 2016, Urbaniec 2004]

Raw juice extracted from cossettes contains non-sucrose and unwanted chemicals from the extraction process. Because of this, purification must be executed. As a part of this, processes such as liming, carbonation, and filtering are carried out. After purification, the juice with changed composition is called a thin juice.

Evaporation is an intermediate step between purification and the final process of juice processing. The thin juice is transported to a multistage evaporator station, where the thin juice is concentrated into thick juice in the form of syrup. Then this thick juice goes through several steps in the crystallization process. Sugar crystals are separated by centrifuging. The remaining syrup (side product) is called molasses.

Stage III. Sugar processing [Acebes et al. 2019]

Sugar crystals separated in juice processing must be dried and cooled before storage and packing. Usually, rotary or fluidized-bed driers are used. The dried and cooled sugar is stored in silos. Then it is packed in various packaging (e.g. large bags).

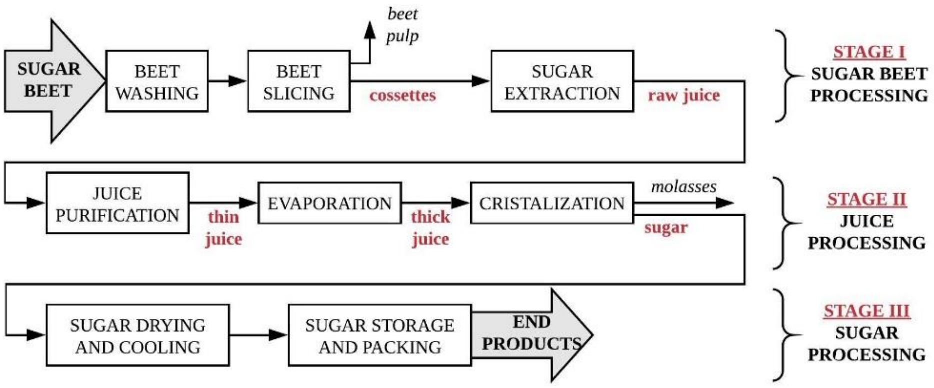

Fig. 2. Sugar production process.

Source: Own work

Sugar production can be classified as a simplified type of make-and-pack production. Make-and-pack production systems are characterized by the make stage, where manufacturing of different intermediates takes place, and the subsequent packing stage, in which those intermediates are packed in different formats [Baumann and Trautmann 2013, Mendez and Cerda 2002, Entrup et al. 2005]. In the case of sugar production, a similar division into make and packaging phases can be noticed. Stages I and II can be classified as the make phase, where an intermediate product (sugar stream) is formed. This intermediate product is sent to different packaging lines during Stage III, the packaging phase.

The authors focused on the final Stage III processes of sugar production, where the sugar stream is divided into different packing lines (Fig. 3).

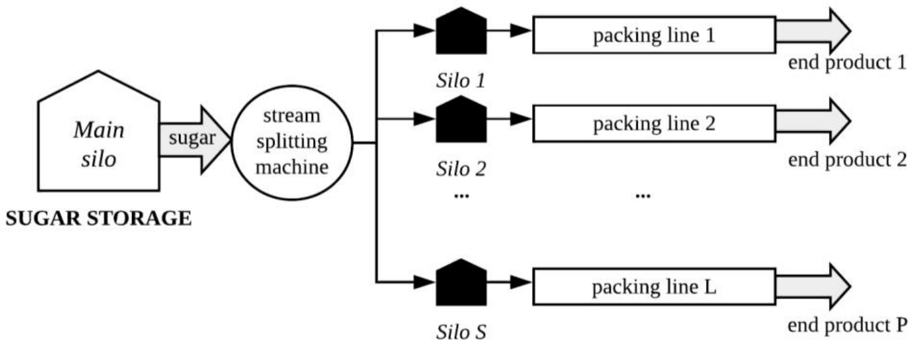

Fig. 3. Sugar storage and packing.

Source: Own work

The stream consisting of dried and cooled white sugar crystals is transported to the main silo, where it is stored. Later, with conveyors, it is transported to different packaging lines, characterized by different efficiencies. Additionally, each line has its own silo with limited capacity and different replenishment demand times. Only one silo at a time can be filled due to the use of the stream-splitting machine.

DESCRIPTION OF THE PROBLEM

As mentioned in Section 2, assigning produced sugar streams to different packing lines can be classified as a sequencing and scheduling problem in the simplified make-and-pack production system. This work addresses this problem and the impact of the reliability of the logistics system on system performance. We try to find the best possible sequence for the stream-splitting machine in the considered case study to minimize the inactivity of every packing line, which can occur due to the lack of material. The idle time affects the machines' reliability of the machines on this line. If there is no material in the silo at the packaging line, the sugar still left in the machines starts to caramelize. As a result, the machines should be completely cleaned of caramelized sugar before restarting the packaging process after the silo is full. The longer the idle time is produced, the more caramelized sugar is created, thus the longer the downstate time.

The problem considered in this work can be formally stated as follows.

Given:

l – the number of packing lines operating in parallel

e_{ti} – the i-th packing line theoretical efficiency in tons per hour, $i \in \{1,2, \ldots, l\}$

e_i – the i-th packing line real efficiency in tons, $i \in \{1,2, \ldots, l\}$

T – the scheduling time horizon in hours

S_t – the stream splitting machine setup time (sequence-independent) in seconds

C_{imax} – the i-th silo maximum capacity at packing line i in tons, $i \in \{1,2, \ldots, l\}$

C_{icurr} – the i-th silo current capacity at packing line i in tons, $i \in \{1,2, \ldots, l\}$

chosen dispatching rules

Determine:

The replenishment sequence controlled by a stream-splitting machine

E – system's efficiency in tons

DESCRIPTION OF THE MODELLING APPROACH

The sugar packing system can generally be described as the operation of two subsystems. The first is a subsystem that supplies sugar to a splitting machine, including the machine itself. The second one is a subsystem of pacing lines. Fig. 4 presents the operation scheme of the simulation model designed to analyze the problem discussed. In pool one, there is a description of the line operation before approaching the splitting machine. In the remaining pools, there is a description of individual lines.

To identify the best sequence for setting the splitting machine, it is necessary to study the real efficiency e_i. In this paper, it was assumed that it could be determined based on the following:

$$e_i = kg(t)_i * e_{ti} * t_{ai} \qquad (1)$$

where:

e_i – i-th line efficiency;

$kg(t)_I$ – i-th line availability;

e_{ti} – i-th theoretical line efficiency;

t_a – availability time of sugar for the i-th line.

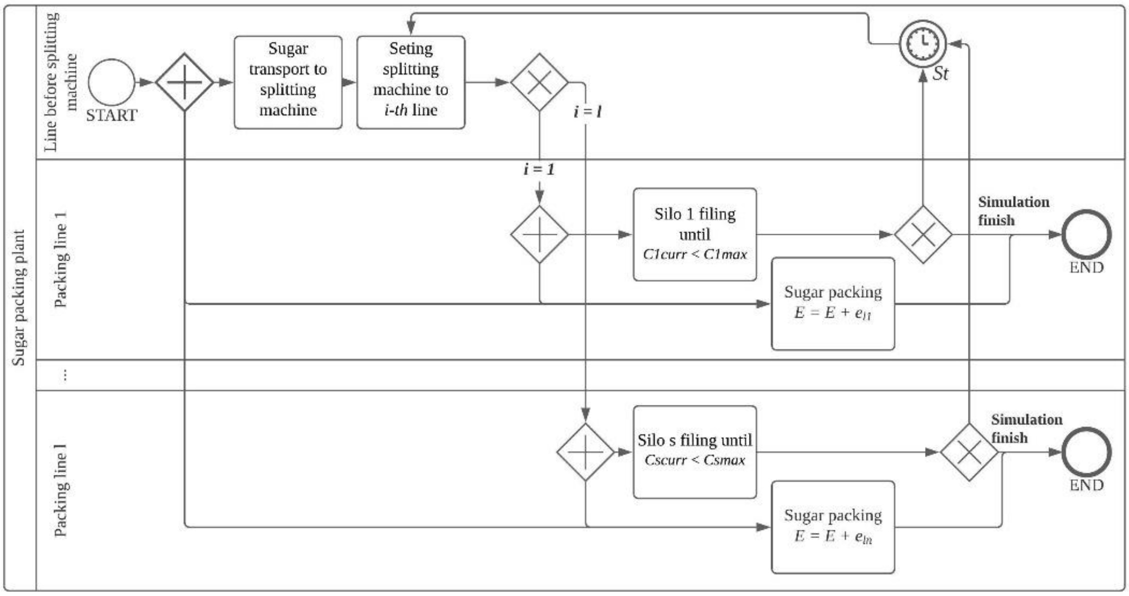

Fig. 4. Sugar packing simulation model algorithm in BPMN notation.

Source: Own work

CASE STUDY RESULTS

Data from a real sugar factory consisting of four packaging lines were used to verify the described method to determine the effectiveness of the sugar packaging system. Table 1 shows the volume of the silos (preceding the lines) and the capacity of each line, the capacity of the line upstream of the splitting machine, and the setup time of the splitter machine. The failures were inflicted on the cumulative distribution function for an exponential distribution $1 - e^{-\lambda x}$, where $\lambda = \frac{1}{3600}$, and the variable x is the lack of sugar time in the silo. The repair time is given with a normal distribution with an average $\bar{x}$ = 1800s and standard deviation σ = 600s.

Table 1. Real system data used in the model

Parameter's name	Symbol	Value for scenario
The efficiency of the line before splitting the machine	E_l	65 t/h
The stream splitting machine setup time	S_t	141 s
Packing line 1 theoretical efficiency	e_{t1}	3.8 t/h
Packing line 2 theoretical efficiency	e_{t2}	15.0 t/h
Packing line 3 theoretical efficiency	e_{t3}	10.0 t/h
Packing line 4 theoretical efficiency	e_{t4}	17.0 t/h
Silo #1 capacity	C_{1max}	8 t
Silo #2 capacity	C_{2max}	8 t
Silo #3 capacity	C_{3max}	8 t
Silo #4 capacity	C_{4max}	8 t

Source: Own work

The level of utilization of the packaging lines depending on the sugar input stream before the split into the individual lines is shown in Fig. 5.

It can be seen (Fig. 5) that with the input stream size from 5 to 25 t/h, only the e_{t4} packing line has a higher utilization. This is mainly due to the reduced utilization of the other lines. The other packaging lines use less than 50% of their level of capacity; however, their utilization increases from 15 t/h of the input stream. Increasing this stream above 35 t/h will not have a significant impact on the utilization of the e_{t1} line. For all lines to be used to the highest degree, the input stream in the described case should be 65 t/h.

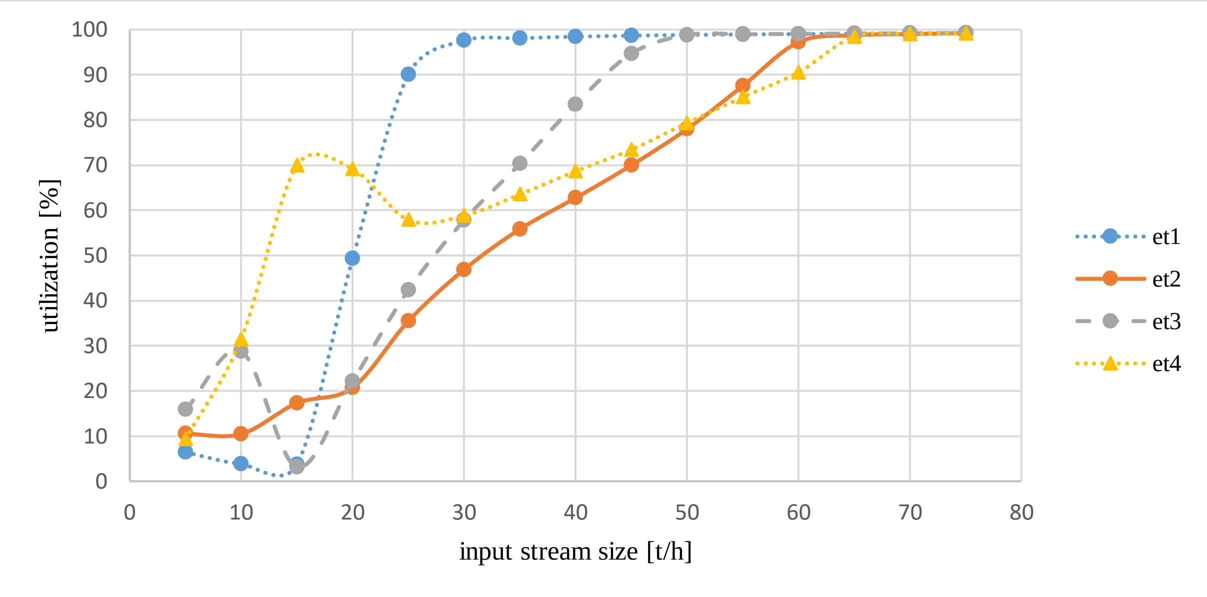

Fig. 5. Utilization of packaging lines depending on the input stream size.

Source: Own work

Another interesting aspect is an analysis of the availability of packing lines depending on the input stream size before sugar is split into the individual lines (Fig. 6). It can be seen that line e_{t4} obtains 100% availability regardless of the input stream size. It means that with the indicated silo capacity and line efficiency, sugar is constantly present in this silo or the lack of sugar time is so short that the sugar does not caramelize in the machines. The availability of the remaining lines decreases when the input stream size is 20 to 25 t/h. This means that this input stream size is too small for all lines to have continuous access to sugar in the silos. As the size of the sugar input stream increases, the availability also increases. All packaging lines achieve maximum operational availability with an input stream size equal to 65 t/h.

The sequence arrangement between four lines was analyzed in the case presented. Therefore, 24 sequences were considered to include all possible sequences of filling the silos. It was assumed that all silos were empty at the beginning of the simulation. The simulation starts with backfilling the first silo, depending on the scenario (scheduling). Twenty-four hours of packing line operation were simulated. Two scenarios were analyzed - one with the lowest and one with the highest overall average system efficiency. The aim was to assess the influence of the the selected sequence of sugar splitting machine on the system efficiency. The average amount of sugar produced for the entire system is 1085.79t, with a standard deviation of 0.66t. The divergence in the amount of sugar packed sugar in the system between the two scenarios analyzed scenarios equals 2.572t. For each packaging line, a different scenario is the most efficient. Indeed, those scenarios which show the highest and the lowest average system efficiency. Therefore, none of the packaging lines reached their maximum efficiency in the scenarios analyzed. The efficiency of the scenarios analyzed in tones is presented in Table 2. Table 3 shows the percentage efficiency of the scenarios analyzed.

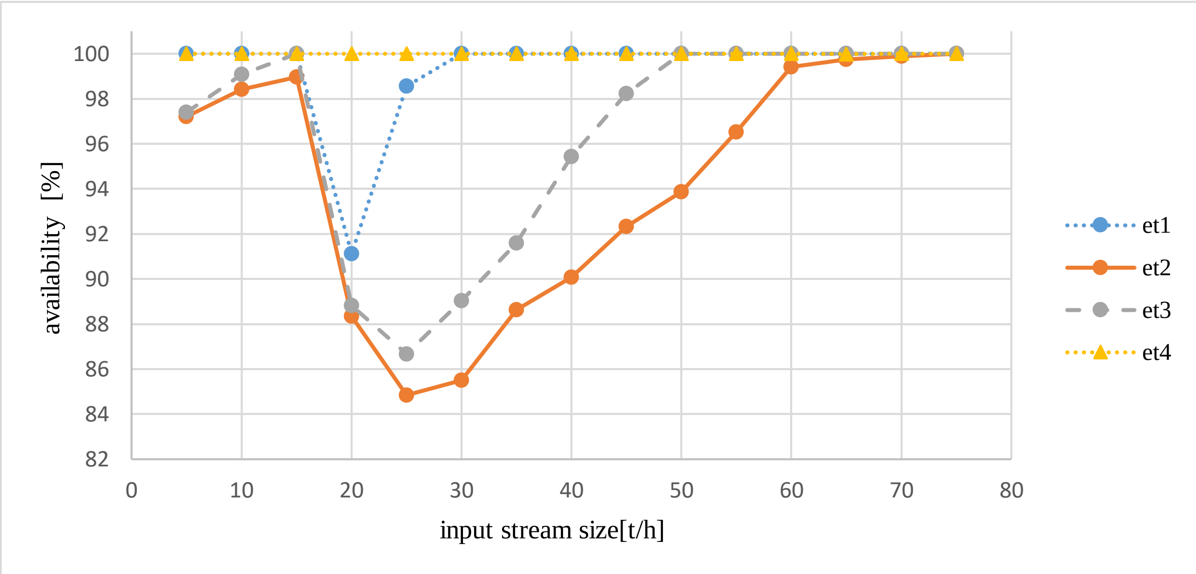

Fig. 6. Availability of packaging lines depending on input stream size.

Source: Own work

Table 2. The efficiency of the analyzed scenarios in tones

	Packing line 1	Packing line 2	Packing line 3	Packing line 4	System
Average efficiency Scenario 1 [t]	90.68	356.94	237.30	399.39	1084.31
Average efficiency Scenario 2 [t]	90.15	354.00	238.50	404.23	1086.88

Source: Own work

Table 3. The percentage efficiency of the analyzed scenarios

	Packing line 1	Packing line 2	Packing line 3	Packing line 4	System
Average efficiency Scenario 1 [%]	99.39	99.66	98.88	98.74	99.1675
Average efficiency Scenario 2 [%]	98.82	98.84	99.38	99.94	99.245

Source: Own work

The time it took to run one simulation in the case studied was also measured. For the analyzed case, it lasts approximately 10s. This time is mainly influenced by the parameters of the computer on which the simulations are carried out. However, it does not change the fact that it is possible to obtain information that allows for the selection of an appropriate scenario in a short time.

The developed model does not take into account downtime resulting from failures of system components. Such a system is influenced by many factors, including input stream size, the number of failures, the size of the silo backfilling stream, packing process time, machinery reliability, and transport arrival time. When scheduling is predicted, only the current state is taken into account, and any introduction of changes requires the design of a new model and subsequent simulations to determine the best new scheduling sequence.

In order to respond in real-time to emerging changes, it is necessary to automate the system by applying the Digital Twin concept. Through the application of this concept, past, present, and future behaviour will be presented and estimated in a short period, which can help in action planning.

The process of implementing the Digital Twin concept in an enterprise is based on five basic implementation stages presented in Fig. 7. The main issue is to identify the intended results and reliable mapping of the physical system in a virtual representation so that the obtained results are at the highest level of accuracy.

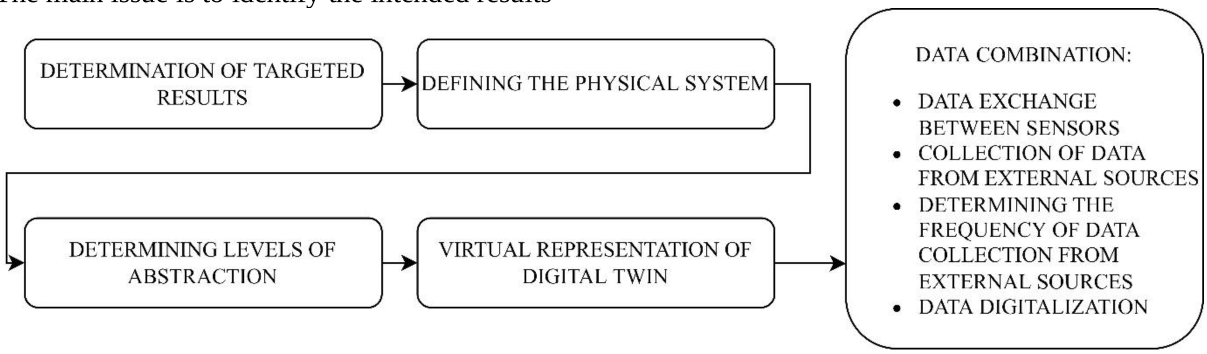

Fig. 7. Implementation stages of Digital Twin concept in an enterprise.

Source: Own work

Using DT, it is also possible to present the results of simulations, which are used for decision-making on subsequent actions. The designed system is modelled with a multilevel approach; high-level details are considered. The database is based on information from sensors and other historical sources - repair reports, failure history, transport arrival time, etc. With the help of the sensors used, information on the sugar content level in the silos, the machines' operating status, and employees' operating status is provided. The input of data from various sources enables better production planning and control. In DT, the data flow is fully automatic. The database is designed to simulate the process in virtual reality, and the best solution can be implemented in the actual process using artificial intelligence and machine learning techniques. The concept of Digital Twin operation is presented in Figure 8.

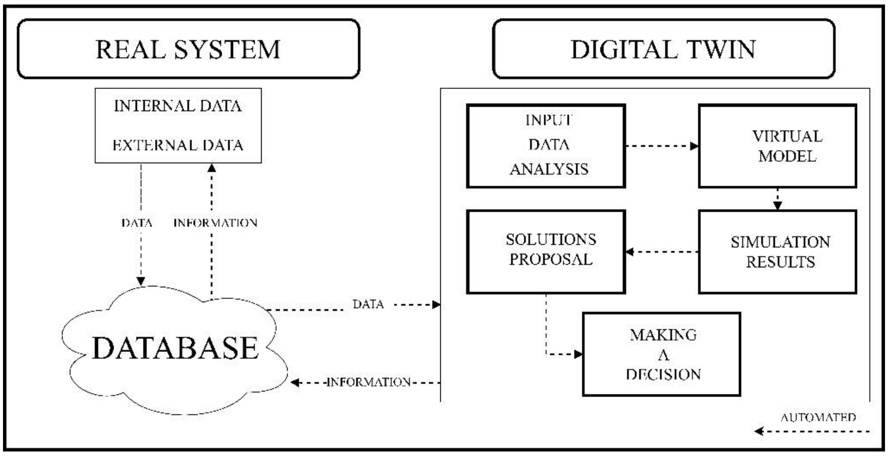

Fig. 8. The concept of Digital Twin operation.
Source: Own work based on [Bestjak and Lindqvist 2020, Rodic 2017]

The company studied was analyzed regarding the possibility of implementing the DT concept. Following the literature, enterprises may face the limitations of the current system. Based on [31] there were developed limitations that may occur during the implementation of the DT concept in every company (Table 4). These technical limitations can be overcome by eliminating them by developing the enterprise or changing the infrastructure.

Table 4. System limitations on implementing Digital Twin in a company

	SYSTEM LIMITATIONS ON IMPLEMENTING DIGITAL TWIN
TERMINOLOGY	common terminology in different data sources to prevent misunderstandings
DATA QUALITY	systematic data download, completeness and accuracy of data, striving to minimize measurement errors
CONNECTIONS	real-time constant data exchange with the physical object and improved network connections to facilitate data transfer
DATA SHARING	sharing data among cooperating units
AUTOMATION	automation of data exchange and analysis
TECHNOLOGY DEVELOPMENT	the combination of technologies under development hinders the evolution of DT and increases the risk of implementation failure (3D simulations, Internet of Things, artificial intelligence, Big Data, machine learning, cloud computing)
COMPUTATIONAL MODELS	increasing the accuracy of models
DATA VISUALIZATION	presentation of results in a way that supports decision-making
REAL-TIME RESPONSE	Digital Twin responding with relatively low delay
COSTS	high costs related to the implementation, incl. IT infrastructure, sensor system,
TIME	Digital Twin implementation is a time-consuming and labour-intensive operation due to the development of computer models with high fidelity, their simulation and integration of the technologies used
SECURITY	data management with regard to ensuring their security and intellectual property rights
REPRESENTATION	the accuracy of the representation of real processes in virtual space is very important

Source: Own work based on [Kosior 2020, Singh et al. 2021, Sing et al. 2018,Tao et al. 2018, VanDerHorn et al. 2021]

Based on the summary presented (Table 4), the main implementation limitations were identified in the company were identified. A problem has been noticed in the connection, data quality, and sharing areas. DT requires real-time input data from the physical object because they are used to update model parameters and make ongoing engineering decisions continuously. Analyzing the data in the system, one can see a situation in which a machine splitting sugar stream between the various silos at the packaging lines performs two activities simultaneously: at the end of the silo backfilling state and in the silo changing state. In real life, it is impossible for the machine to be in two states simultaneously. Abnormalities cause this event in the operation of the silo sugar monitoring system. This malfunction causes a delay in data download, which is around 65s in the analyzed system. For the implementation and efficient use of the Digital Twin in the make-and-pack system, it is necessary to improve the synchronization of sensors with the system so that the data is downloaded in real-time without delay. These delays may be caused by an inadequate connection or incorrect selection of the cooperating devices. Due to the continuous development of sensors and technologies used in Digital Twin (IoT, Big Data, machine learning, etc.), it is necessary to adapt the devices used to the current system. It is also recommended to follow trends and news in this area. It is also necessary to improve the exchange of information with the transport company, to keep track of the arrival time of vehicles.

CONCLUSIVE REMARKS

This paper presents results for sequencing and planning of packaging line problems. The modelling approach was based on conducting simulation experiments. Therefore, the results obtained can be used to optimize case-company production processes.

The strategy selection is essential when the sum of the line efficiency is greater than the line efficiency before the splitting machine. The higher the total efficiency of the packaging lines, the closer the real efficiency to the theoretical one (the real efficiency is a result of the amount of sugar supplied to the system). However, the calculations carried out in Section 5 indicate that even a slight change in the input parameters can completely change the optimal solution. Therefore, each time it is required to build a model and modify the variables, they correspond to reality and then calibrate the system settings according to them. This confirms the rightness of using Digital Twin for scheduling, considering the variability of internal and external factors. However, there remains an open question regarding downloading up-to-date data from the real system.

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ORIGINAL PAPER

MULTI-DIMENSIONAL ANALYSIS OF SYNCHROMODAL LOGISTICS ON THE DEVELOPMENT OF SUSTAINABLE TRANSPORT CORRIDORS FROM THE PERSPECTIVE OF RECONFIGURING EUROPEAN-ASIAN SUPPLY CHAINS

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ABSTRACT. Background: The paper concerns the concept of synchromodal logistics. It has great economic and environmental potential in terms of optimizing cargo transportation using various modes and modes of transport. In the face of unexpected disruptions in the global economic system due to the COVID-19 pandemic, the shift paradigm may result in a thorough verification of numerous solutions in the operational activities of transport, shipping, and logistics companies.

The aim of the article is to evaluate the key indicators that influence the efficiency of synchromodality in logistics. Its implementation would allow the development of sustainable transport corridors from the perspective of the European-Asian supply chains reconfiguration.

Methods: The paper uses questionnaire research and interviews conducted among experts, as well as selected methods of artificial intelligence, to determine the weights of the essential indicators that influence the effectiveness of synchromodality in logistics. Moreover, descriptive methods were used as supporting methods.

Results: Basic indicators influencing the effectiveness of the synchromodal system were determined, which may favor the operationalization of the concept implementation process. These indicators can be one of the tools to assess the prospects for the development of synchromodal logistics.

Conclusions: The implementation of the synchromodal logistics concept offers opportunities to strengthen cooperation in Euro-Asian supply chains to promote the development of sustainable transport corridors in the field of the trans-European transport network. The synchronization of the multibranch network of transport connections, preceded by the flow of information and preferences of the supply chain participants, allows the selection of the most advantageous transport connection proposals in real time, taking into account the criterion of their availability. The main expectations concerning the development of synchromodality relate to the improvement of the level of transport and logistics services, modal shifts, use of the capacity of transport nodes, and reduction of CO_2 emissions.

Keywords: synchromodal logistics, transport corridors, sustainable development, synchromodal efficiency

INTRODUCTION

The contemporary world economy has entered the next stage of structural transformation. It is characterized by an intense penetration of products and services. A kind of binder in the process of structural changes is digital technologies and Big Data, which change the definition of a traditionally perceived product and service. This provides the basis for the implementation of an innovative concept of synchromodal logistics, which allows for the innovative preparation and implementation of production processes of tangible goods and services, including those available in the virtual world [Giusti et al. 2019, Zhang and Pel 2016]. At the same time, the challenge for the leaders of synchromodal supply chains and their organizations is to work out new compromises for cooperation, that is, to replace competition with the idea of transparency and trust.

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Synchromodal logistics can be interpreted as providing efficient, reliable, flexible, and sustainable logistics services through coordination of stakeholder cooperation and real-time synchronization of operations within one or more supply chains using ICT and ITS technologies [Guo et al. 2017]. It is characterized by great potential in terms of optimizing cargo transportation using various modes and modes of transport, in the economic, environmental and social dimensions [Adenso-Díaz et al. 2014, van Riessen et al. 2015].

In the face of unexpected disruptions in the global economic system due to the COVID-19 pandemic, the shift paradigm may result in a thorough verification of many solutions in the operational activities of transport, shipping, and logistics companies. Modern rail transport, due to its greater resistance to turbulence and crisis situations, shows a stable readiness to carry out the transport tasks of freight logistics, which may cause disruptions in the availability and capacity, as well as the competitiveness of logistics companies in EU member states, including Poland. At the same time, it is worth noting that the processes of concentration of freight flows are accompanied by limited possibilities of expanding linear and point-based transport and logistics infrastructure resources, therefore, the importance of efficient use of the already existing infrastructure resources is growing. The context of the negative impact on the environment and climate of modern cargo transport systems, dominated by truck transport, is also very important [Pan et al. 2019].

The implementation of the concept of the synchromodal logistics model offers opportunities to strengthen cooperation in the framework of Euro-Asian supply chains, on the basis of partnership, to promote the development of sustainable transport corridors in the field of the trans-European transport network [Nijole and Šakalys 2020]. The Internatonal Transport Forum estimates that by 2040 the volume of cargo transport between the EU and the Far East will increase 2.5 times, mainly due to China, whose position in the Asian bloc is very strong [Cosentino et al. 2018]. Furthermore, the forecasts indicate a gradual strengthening of the role of rail transport in Euro-Asian supply chains as a result of modal shifts.

The purpose of the article is to assess the key indicators that influence the effectiveness of synchromodality in logistics, whose implementation would allow the development of sustainable transport corridors from the perspective of the reconfiguration of European-Asian supply chains. In connection with the adopted goal, a research hypothesis was formulated, which is: the concept of synchromodal logistics affects the degree of sustainability in the development of transport corridors, and the strength of this impact can be measured using selected indicators that can be the basis for the operationalization of this concept.

MODEL OF FUNCTIONING OF SYNCHROMODAL LOGISTICS

Synchromodal logistics is an innovative approach to the flexible and sustainable use of various modes of transport at a higher level of process organization from the perspective of the supply chain. It is a concept that treats the issues of multimode transport, transport infrastructure and digital technologies, as well as environmental protection and climate change holistically [Aditjandra 2018]. Its goal is to increase the efficiency, flexibility, and implementation of the principles of sustainable development in the organization of logistics processes, thanks to the introduction of the 5PL service and technological solutions provider. The creation and operation of a virtual communication and logistics system changes the development perspective of the transport, forwarding, and logistics services market. The synchronization of the multibranch network of transport connections, preceded by the flow of information and preferences of the participants in the supply chain, allows the selection of the most advantageous transport connection proposals in real time, taking into account the criterion of their availability [Tavasszy et al. 2015, Miletić et al. 2017]. The main expectations related to the development of synchromodality within the European-Asian supply chains concern the improvement of the level of transport and logistics services, modal shifts, the use of the capacity of transport nodes, and the reduction of CO_2 emissions.

The synchromodal logistics was built with particular emphasis on the interdependencies between the critical factors in the development of synchromodal logistics (Figure 1). Theoretical identification of the operational aspects of the freight transport market within the European-Asian supply chains was carried out using the method of desk research as well as statistical analysis and comparative analysis. The systematization of this output and knowledge created the basis for the application of selected methods of artificial intelligence. Thanks to these methods, it was possible to analyze the mutual relations in the economic (Ec), environmental (En), and social (So) dimensions, from the perspective of synchromodal logistics.

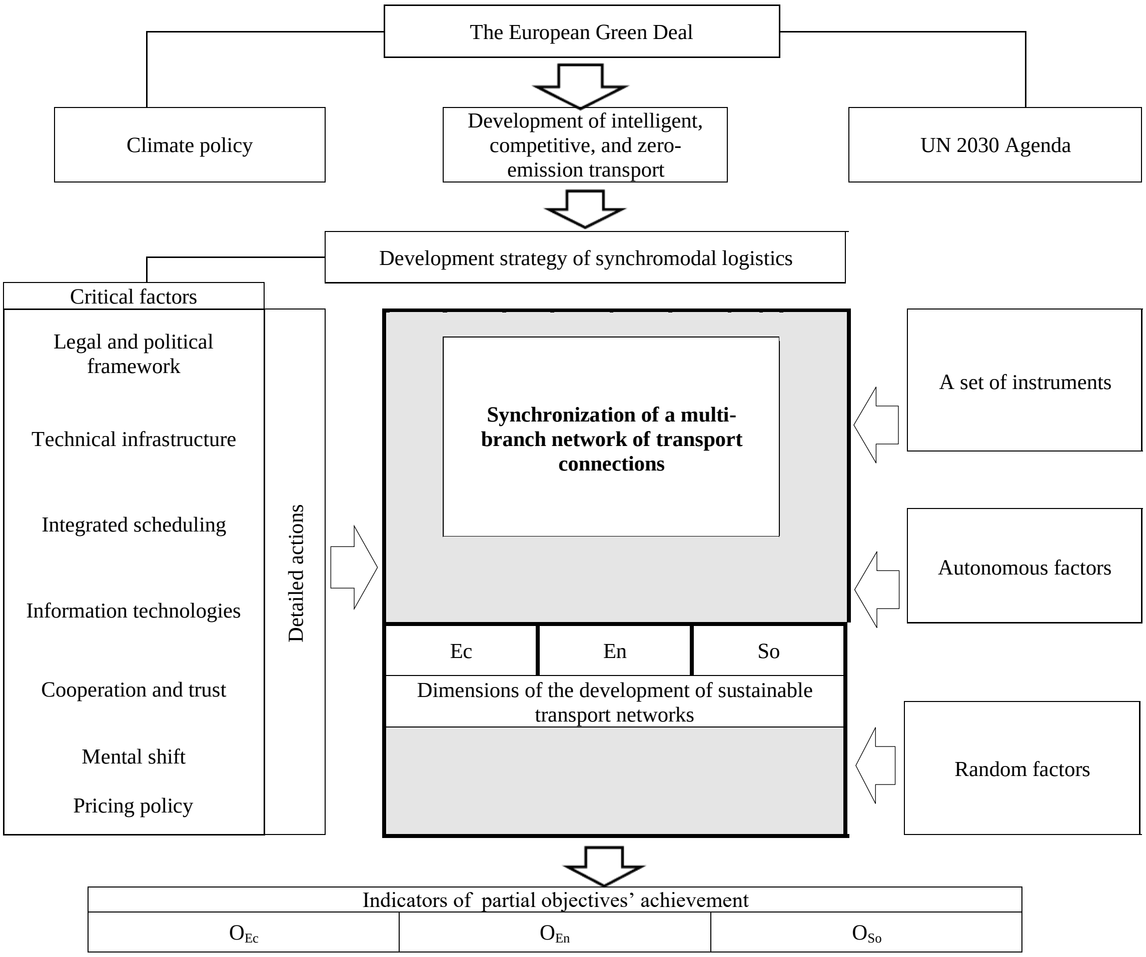

Fig. 1. The model of synchromodal logistics

Source: own study.

The development of synchromodal logistics is one of the future trends in the context of shaping innovative and sustainable logistics. Synchromodality is indicated as a necessary condition for optimal and sustainable transport in the future [Giusti et al. 2021]. This trend is supported, among others, by through the transport policy of the European Union, the European Green Deal strategy, the digital strategy and the UN 2030 Agenda. According to Dong et al. [2018], synchronization is a concept that, in addition to transport, should also be extended to the entire supply chain, for example, inventory management or production planning.

The features of synchromodal logistics that allow the sustainable use of available resources are real-time information, flexibility, cooperation and coordination, and synchronization [Pfoser and Schauer 2016, Singh et al. 2016]. These characteristics are shaped by critical factors that condition the development of synchromodality (Table 1).

Table 1. Critical factors in the development of synchromodal logistics

Symbol	Critical factors	Detailed actions	Effects of activities
F_1	Legal and political framework	Strengthening and coordination of the development strategy Research and development	Increased safety of transport Improving energy security Improving the state of the environment Climate protection
F_2	Technical infrastructure	Development of intelligent transport nodes and corridors Development of the TEN-T network Terminal development	Reduction of infrastructure development and maintenance costs Improving the quality and availability of infrastructure Reduction of CO_2 emissions
F_3	Integrated scheduling	Planning at the network level	Improving operational efficiency Improving the state of the environment Improving the quality of process implementation Consolidation of volumes Optimal use of the time factor Modularization
F_4	Information technologies	Big Data Automation Digitization	Development of monitoring technology Development of new business models Holistic goods network Flexible transport solutions
F_5	Cooperation and trust	Network integration Horizontal and vertical cooperation	Service sharing Pushing instead of pulling
F_6	Mental shift	Dissemination of synchromodal solutions in transport	Increasing the resilience and continuity of transport operations
F_7	Pricing policy	Flexible pricing strategies	Improving the quality of services provided Dynamic integration and modification of services Cost reduction

Source: own study.

Analysis of research on synchromodal logistics [Pfoser et al. 2016, Manerba et al. 2019, Behdani et al. 2014] allowed us to recognize that the path to the development of this forward-looking concept leads through the implementation of seven basic groups of activities related to critical factors, which are listed in Table 1. The first includes activities to strengthen and coordinating the development strategy of synchromodal logistics, resulting from legal and political conditions. The second group consists of activities aimed at improving the organization of transport processes, mainly related to the development of technical infrastructure. The next two groups of activities, characterized by an innovative and innovative nature, are related to integrated planning and information technologies. A great potential for influencing the development of synchromodal logistics lies also in activities resulting from cooperation and trust, mental changes, and pricing policy. The implementation of the above-mentioned activities is to be possible thanks to the instruments, including legal, economic, technological, and information instruments. The final effects of these activities will also depend on the influence of external factors, including autonomous and random factors. They can contribute to a marked acceleration or slowing of certain activities. Their importance and directions of impact on the functioning of global supply chains are confirmed by events accompanying, inter alia, the COVID-19 pandemic.

In the face of the slowdown in the growth of the world economy, countries are constantly looking for new economic ventures. In the era of globalization, they concern the phenomenon of competition not of individual enterprises, but of entire supply chains. Under such conditions, one for the key factors of competitive advantage is a properly organized supply chain, the fundamental element of which is the transport system [Norman et al. 2016, Veenstra et al. 2012]. Its main skeleton is the infrastructure system that determines the transport accessibility of the area, which is considered a factor determining the development of enterprises, regions, and countries. The accessibility of the transport infrastructure and the relationships that prevail in it determine the configuration of the logistics network, allowing for a coordinated and effective implementation of logistics processes [Dong et al. 2018, Intihar et al. 2017]. In their recently published analysis, K. Nübel et al. [2021] examined trends and barriers in infrastructure planning and delivery. The main cause of the sector's problems is the prevalent fragmentation of the value chain and the lack of a long-term vision for infrastructure. To overcome these challenges, value chain integration is needed. The authors suggest that this could be achieved through use-case-based, visionary, and governance-driven creation of federated digital platforms for infrastructure projects. Digital platforms enable full-lifecycle and accountable governance guided by a shared infrastructure vision.

The reactivation of the New Silk Road, also known as the 'One Belt and One Road" initiative, is to be a source of additional value in the logistics network. The reconfiguration of the European-Asian supply chains, as part of the „One Belt and One Road" initiative, is to contribute to the improvement of trade flows within China and with the environment, mainly the countries of Europe, Asia, and Africa. From a synchromodal logistics perspective, this initiative has great potential for the development of sustainable transport corridors.

EFFECTS OF THE DEVELOPMENT OF SYNCHROMODAL LOGISTICS FROM THE PERSPECTIVE OF RECONFIGURING THE EUROPEAN-ASIAN SUPPLY CHAINS

The concept of synchromodal logistics and the measures for its implementation from the perspective of the reconfiguration of European-Asian supply chains are defined at the supranational level. However, the final set of planned measures and their weights are left to the discretion of individual states, which develop autonomous synchromodality development plans. These activities aim to strengthen and coordinating efforts to develop sustainable transport corridors [Aditjandra et al. 2016]. There are several arguments in favor of this approach. The main one is the growing role of transport in building the competitiveness of countries and strengthening their role on international markets. In the opinion of the World Bank, the costs of transport and trade are more important than trade policy in creating a competitive advantage for the national economy. This is because lowering transport costs by 10% causes an increase in national income by about 2.5%, while a 10% increase in them contributes to an average of 20% decrease in the level of trade [Alonso Raposo et al. 2019].

To use the quantitative model of synchromodal logistics (Figure 1) to assess the effects of the development of sustainable transport corridors from the perspective of the reconfiguration of European-Asian supply chains, it was given quantitative characteristics. These characteristics are expressed in the assignment of point values to the critical factors F1, F2... F7, determining the values of the indicators of the partial activities Ec, En and So and the values of the indicators of the direction of their impact, which was obtained thanks to the results of the survey and the use of artificial intelligence methods (Table 2). The representative nature of the sample group of experts made it possible to obtain information of high cognitive value. 13 experts from Poland, who dealt with the studied issues, representing international companies from the transport-forwarding-logistics industry participated in the survey. The scope of the study covered the period from March to June 2021. The completion of the survey consisted of determining the preferred set of assumptions.

The point values assigned to the critical factors of synchromodal logistics, aimed at the development of sustainable transport corridors, made it possible to define the essence of these activities. It was assumed that the total number of points that evaluated the activities under the seven critical factors is 100. According to fuzzy set theory, the sum of the percentages for each of the activities is 100%. These values form a four-point scale of the effectiveness of the subactivities. The highest of these values indicates the most effective, and the lowest indicates the least effective partial effect. Indicators of direction of the impact of partial activities are the input variables of the model. They allow for the expression of the nature of the influence of subactivities on the achievement of sub-goals („1" favorable, „0" neutral, „–1" unfavorable). The indicators of the achievement of partial goals play the role of the output variables of the model. The value of the main goal achievement index is the sum of the values of the partial goals achievement indexes.

Table 2. Averaged assessment of the critical factors of synchromodal logistics in terms of the development of sustainable transport corridors - results of the survey

Critical factors (symbol)	Value	Indicators of partial actions (%)			Indicators of the direction of partial actions impact*			Indicators of partial objectives' achievement		
		Ec	En	So	Ec	En	So	O_{Ec}	O_{En}	O_{So}
F_1	15	47	38	13	1	1	0	6,98	5,69	0,00
F_2	23	48	31	20	1	1	1	10,78	6,94	4,50
F_3	17	43	31	25	1	1	1	7,26	5,29	4,16
F_4	13	42	25	30	1	0	1	5,52	0,00	3,98
F_5	12	47	18	34	1	0	1	5,45	0,00	3,91
F_6	11	38	25	33	1	1	1	4,14	2,77	3,59
F_7	10	41	23	32	1	1	0	4,13	2,25	0,00
Total	100	x	x	x	x	x	x	44,26	22,93	20,14
		Main objective achievement indicator O						87,34		

*1 (favorable), 0 (neutral), -1 (unfavorable)
Source: own study.

The results obtained clearly show the high effectiveness of the critical factors of synchromodal logistics in the development of sustainable transport corridors, while ensuring the achievement of objectives in the economic, environmental, social and spatial dimensions (Table 2). The goal achievement index (O), representing the degree of effectiveness, is 87.34 points. Referring to the above description of the quantitative characteristics of the model to individual categories of activities, it can be concluded that assigning 23 points to activities in the field of technical infrastructure development (F2), the study participants considered them to be the most important for the development of sustainable transport corridors, in line with the concept of synchromodal logistics. The partial activity indicators for factor F1 indicate that it will be the most involved, i.e., 48% involved in the achievement of economic goals (Ec). Moreover, it was assumed that 31% of the value of activities related to the development of technical infrastructure will directly translate into the achievement of environmental goals and 20% to the implementation of social goals.

Indicators of the direction of the impact of partial activities inform about the beneficial impact of the F2 factor on the implementation of all partial goals, i.e., economic, environmental and social. Calculations made with the use of the model allowed for the scoring of these impacts. The positive contribution made by the activities of factor F2 is: 10.78 points for economic goals, 6.94 points for environmental goals, and 4.50 points for the achievement of social goals. The distribution of indications regarding the next two critical factors, i.e. „Integrated planning" (17 points) and „Legal and political framework" (15 points), shows that these activities were found in the study to be relatively effective in the development of sustainable transport corridors. The greatest effects of these activities concern the partial goals of O_{Ec} and amount to 7.26 points (F3) and 6.98 points (F1).

The averaged values of the indicators to achieve the objectives of O_{Ec}, O_{En} and O_{So} show that the critical factors of synchromodal logistics will allow to achieve the highest level of effectiveness in the development of sustainable transport corridors in the economic and environmental dimensions (Figure 1). The values of the target achievement indicators are 44.26 points for economic aspects and 22.93 points for environmental effects. The results obtained with the use of the assumptions of experts 9, 4, 1 and 12 indicate a higher effectiveness in achieving the O_{Ec} goal, while the assumptions of experts for the O_{En} goal were more varied (Figure 2).

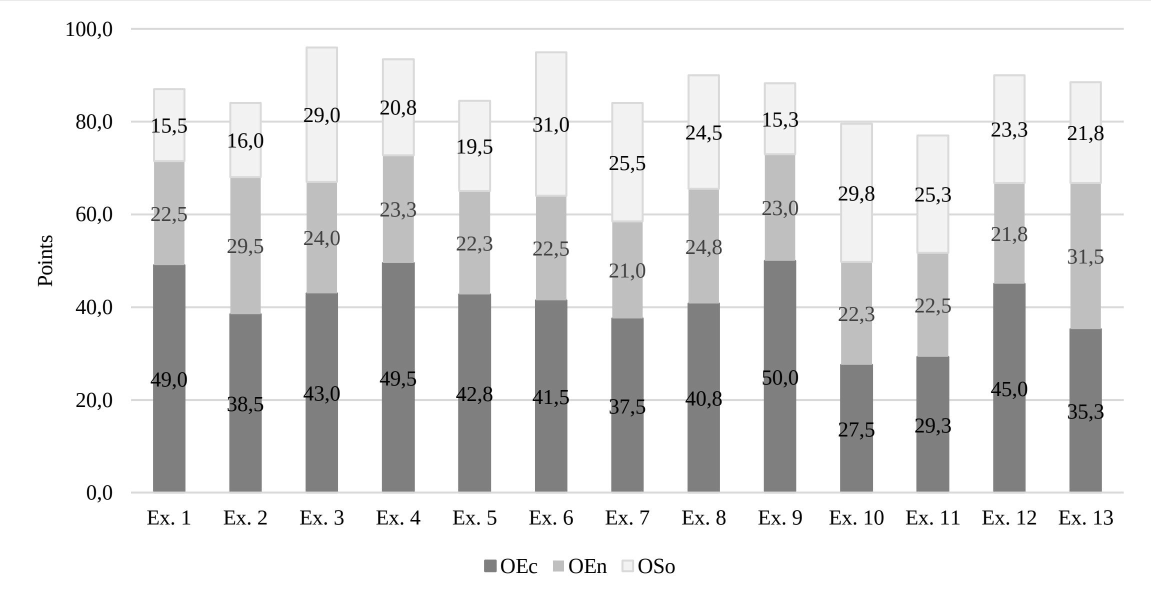

Fig. 2. Experts' indications regarding the impact of critical factors of synchromodal logistics on the effects of the development of sustainable transport corridors

Source: own study.

In all the variants of experts' responses presented in Figure 2, the determined values of the O_{Ec}, O_{En} and O_{So} objectives achievement indicators are relatively stable. The results obtained clearly indicate that the implementation of synchromodal solutions from the perspective of the reconfiguration of the European-Asian supply chains has great potential in the development of sustainable transport corridors.

CONCLUSIVE REMARKS

The research confirmed the possibility of achieving the assumed goal, according to which the implementation of the synchromodal logistics concept would allow the development of sustainable transport corridors from the perspective of reconfiguration of European-Asian supply chains. They also showed that the effectiveness of achieving this goal can be high if the effects of critical factors in the development of synchromodal logistics do not compensate for each other. It is also possible to achieve the sub-goals O_{Ec}, O_{En} and O_{So}.

The use of the model and the assumptions formulated by experts allows the conclusion that the main goal (O) can be achieved with an efficiency of 87.34%. The most important critical factors determining the development of synchromodal logistics were the "Technical infrastructure" (F2), Integrated planning" (F3) and „Legal and political framework" (F1). The highest efficiency (44.26%) was indicated for the implementation of measures in the economic dimension (O_{Ec}). The effectiveness of the implementation of the O_{En} and O_{So} objectives will be 22.93% and 20.14%. Thus, the results obtained from the study allowed for a positive verification of the research hypothesis.

Despite the convergent basic conclusions of the study, it seems appropriate to create a consultative platform to organize the achievements so far in this research area.

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ORIGINAL PAPER

QUEUEING THEORY AS AN INSTRUMENT OF OPTIMIZATION OPERATIONAL AND ECONOMIC SPHERE OF PORT TERMINALS - CASE STUDY

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ABSTRACT. Background: The maritime port terminals, handling cargo and servicing maritime and land means of transport with variable intensity over time, operate as mass service systems where the process of notifying and fulfilling needs usually occur at random. The main research problem was to determine the interdependence between the mechanism of reporting and meeting the demand for terminal services and its effectiveness measured in terms of operational efficiency and profitability.

Methods: The aim of research involves evaluating the terminal operational mechanism and evaluating it under operational categories, that is, operational stability and efficiency, and economic ones, i.e., effectiveness with respect to costs and revenue. To achieve the aim of research, the theory of mass service was applied, with the use of queuing theory as well as case study. The research was conducted in an example of bulk handling terminal, i.e. HES Gdynia Bulk Terminal.

Results: In the article, the authors assumed that the bulk cargo handling terminal in Gdynia operates as a queueing model. Therefore, it was possible to analyse the operating mechanism of the selected port terminal as a logistics system and a link in the supply chain by characterising it in terms of technical and operational efficiency and economic and financial effectiveness.

Conclusions: So far, such terminals have not the subject of this kind research, because researchers focused predominantly on seaports as composite multimodal transport nodes. The results of the conducted research confirm the previously formulated hypothesis, indicating that queueing theory can be used as an useful instrument to optimize the efficiency and effectiveness of bulk cargo terminals.

Keywords: port terminal, mass service system, queuing theory, terminal operating effectiveness, terminal efficiency, terminal added value

INTRODUCTION

Seaports as well as most port terminals that provide large-scale services for cargo and means of transport operate according to the principles typical of a mass service system. To some extent, this is an operating system characterized by the fact that the process of notification regarding the required services and the services provided occurs at random and usually with significant variability in time. It means that potentially at any time, depending on the terminal handling capacity, relative to the intensity and density of notification stream, namely the ratio between the load of this operating system at a given time and the intensity of notifications regarding services for ships or other means of transport, it may generate, within the entry subsystem, the waiting time, namely the queue [Jingjing and Dong 2012, Leon-Garcia 2008]. If the situation lasts longer, congestion is generated, indicating full congestion of the system and its inability to handle the notified requirements. It can be observed by the long queues and longer service gross time, i.e. the increase in the density of incoming notifications. In such a situation, the waiting time regarding ships' service can be n-times longer than the the time of actual cargo handling services at a berth [Deniz Özkan et al. 2022].

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The queue formation and the waiting time before entering the terminal as a mass service system generate additional costs for the terminal users [Layaa and Dullaert 2014]. They are the function of time necessary to wait for service in the system and consequently extended total gross time of meeting the requirements in the port terminal. In fact, these additional costs are real losses incurred by operators that use the services at such terminal. In view of the fact that the services of the terminal, which is an integral part of the global logistics supply chain, must meet the highest ecological and logistics standards, defined in the category of speed, safety, and reliability, as well as availability and mass quality, it means that the costs generated by the terminal will lead to an unjustified increase in the logistics costs within the supply chain, reducing the value created for the final user [Ruiz Estrada et al. 2017, Rudenko et al. 2022]. As a result, the terminal with such operating characteristics will gradually lose its share in partial markets, which will translate into its economic and financial position (EBITDA).

Ensuring the required efficiency and operational effectiveness, within the supply chain, as well as the economic effectiveness of a terminal of low standard with regard to meeting the notified requirements in the context of logistics (time and costs), and also as a mass service system always prone to generate queues of the means of transport waiting for services, which occurs, in particular, when there is no balance between the subsystem of notifications and the sub-system of provided services, requires taking investment-related as well as organizational and management-related actions. In this respect, particularly important is applying the model of port terminal management and implementing the strategy of its development based on the mathematical models developed under the theory of mass service and the queuing theory. Only in this way is the port terminal operator able to ensure efficiency and effectiveness of terminal operations, optimizing the unit costs of cargo handling services [Woo et al. 2011]. At the same time, such activities reduce the time and costs of services, generating an added value within the supply chain comprising the said terminal.

These matters and, in particular, issues related to the analysis of the notification stream related to ship service and services at the port bulk cargo handling terminal fall within the scope of research undertaken by the authors. The main issue and also the aim of research involves defining, under the queuing theory, the nature of the operational mechanism of the terminal as an operating system featuring mass services, and assessing the mechanism under operational categories, i.e., operational stability and efficiency as well as economic categories, i.e., effectiveness regarding costs and revenue, for the terminal operator and maritime transport operators.

The undertaken research is based on the assumption that at present, i.e., in the era of logistics development, smart supply chains and electronic business as well as large-scale implementation of operating solutions based on IT technologies (the era of digitalization), port terminals, including mass terminals of universal nature of operations, retain the previously developed operational characteristics which allow to classify them as mass service operating systems. Thus, the hypothesis formulated was verified in the framework of the conducted research process by applying mainly research methods such as queueing theory (QT) and case study (CS). The 2016–2019 study period was intentionally chosen to explore and present how terminals of this type operated in the pre-pandemic period. The following years, 2020-2022, as a result of numerous disruptions that occurred in both sea shipping and global supply chains at that time, fundamentally changed the previously existing model of servicing these terminals. The research covering this period will be presented by the authors in the next study in 2023. The key problem is to compare the two periods with each other.

The results and conclusions resulting from the analysis covering the years 2016-2019 were presented in part in the title Conclusion. Research was carried out at the example of universal port bulk cargo handling terminal, HES Gdynia Bulk Terminal. The article presents new content and results not yet published by other authors, pointing to the possibility of using the queuing theory instrument. This topic is rarely taken up in the context of mass terminals, and the attempts made relate to ships calling regularly at ports.

HES Gdynia Bulk Terminal is located at the main entrance to the Port of Gdynia (Fig. 1.). It is integrated into its facilities by road and rail transport. In its offer, the terminal provides 24h cargo handling services for dry bulk cargo (coal, coke, ores, grain, fodder, aggregates, ground grain), liquid (chemicals, liquid fuel) and general cargo. HES terminal provides 225 714 m^3 storage area in warehouses and 106 852 m^2 of yard space. The terminal is spreading along five quays. Liquid cargo handling includes dangerous cargo of 3, 6, 8 and 9 class chemicals under the IMDG code. The Duńskie Quay is equipped with tanker service berth of up to 210 meters in length and up to 11 meters of draught. The dry bulk cargo handling is provided in a four-chamber warehouse with loading and unloading system, located at the Śląskie Quay. The warehouse is intended to store products of ca. 60,000 tons of total mass. It is also connected through a conveyor belt system with a warehouse located at the Szwedzkie Quay of about. 40,000 tons of storage capacity.

HES Gdynia Bulk Terminal is part of the HES International capital group with affiliated companies.

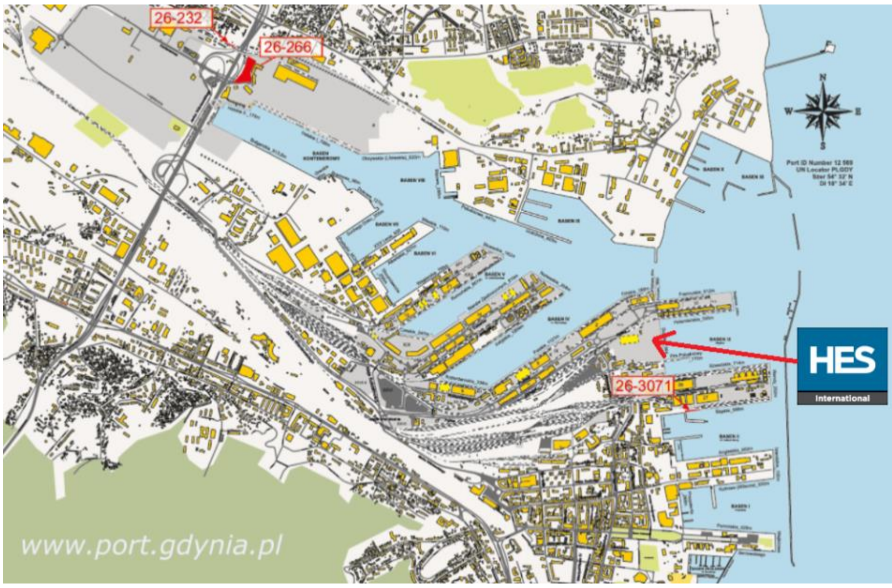

Fig. 1. Location of HES terminal on the map of the Port of Gdynia. Source: [www.port.gdynia.pl].

HES GDYNIA BULK TERMINAL AS A MASS SERVICE SYSTEM

- The calculations were based on data obtained from HES Gdynia Bulk Terminal, which, however, only to some extent allowed to consider how the terminal operates as a mass service system.
- The analysis covers the Szwedzkie Quay, the Śląskie Quay, the Holenderskie Quay, the Duńskie Quay and the Breakwater.
- The number of bulk carrier calls at the terminal in 2019 is 242 ships.
- In the first quarter of 2019, (I-III), the number of calls to the terminal totalled 61. In the second quarter (IV-VI), the number of ships totaled 61. In the third quarter (VII-IX), the number increased to 77, whereas in the fourth quarter (X-XII) the number of ships amounted to 63. In the first, second, as well as the third and fourth quarters, the frequency of ship calls is similar.
- The average deadweight tonnage (DWT) of a ship that landed at the HES terminal in 2019 totaled 40791 t. As many as 37 Capesize ships called at the terminal, as well as 15 Handy ships,, 31 Handymax ships and 23 Panamax ships (Fig. 3.).

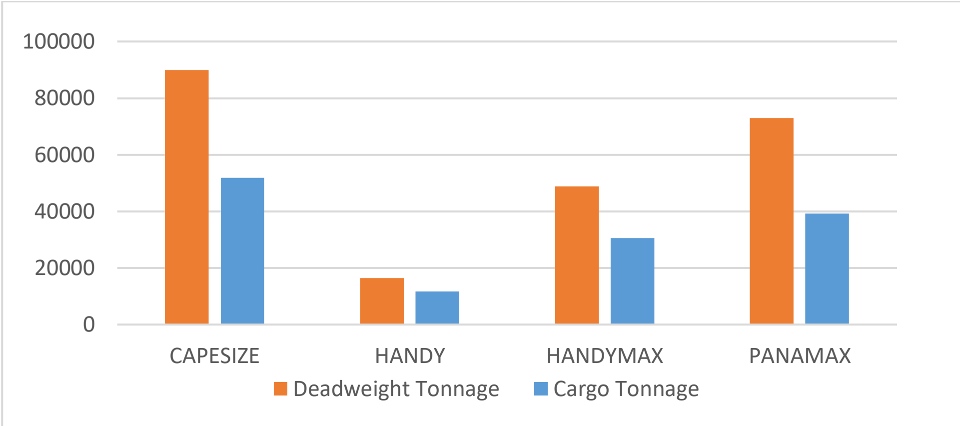

Fig. 3. Average deadweight tonnage and average cargo tonnage of ships calling at HES Gdynia Bulk Terminal.
Source: own work.

- The average ship service time is understood as the ship's time at berth until the reloading operations are complete.
- The average service time totals 48 h for 242 ships that arrive at the terminal in a year.
- Due to the lack of an access barrier to the terminal (no queue) $t_0=0$
- On average, ships arrive at the terminal every 34 h, which indicates an intensive notification stream (Fig. 4.). Server utilization totals $\rho=0.71$, which indicates significant use of the terminal while maintaining system stability.
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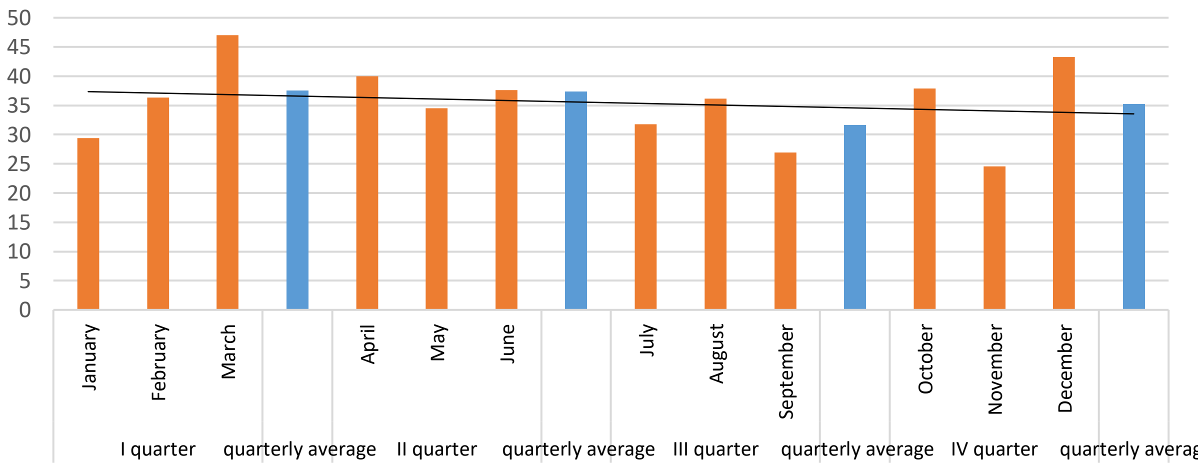

Fig. 4. Average time between ships' arrivals to the HES terminal in a given month.
Source: own work.

QUEUING MODEL OF THE PORT BULK CARGO UNLOADING TERMINAL IN GDYNIA

The statistical data of HES Bulk Terminal Gdynia show that the arrival rate of cargo λ totals 6 075 346 tons for the year of 2019 Eq.(3). In practice, the daily side handling rate (terminal handling capacity) means servicing 3 Panamax ships, 1 Handy ship, and 1 tanker at the same time. The data provided by the terminal prove that the average berth occupancy totals 50.34%; therefore, for the purpose of further calculations, it was assumed that the terminal handling rate totals 11,000,000 tons/year Eq. (4).

The parameters for the observed model include [Hess et al. 2007]:

- cargo arrival rate

λ = 6 075 346.1 t/year (1)

- cargo service rate

μ = 11 000 000 t/year (2)

The indices of unloading bulk cargo terminal operation are computed according to the appropriate queuing theory formula [Bose 2002, El-Naggar 2010]:

- traffic rate

$\rho = \lambda/\mu = 0.5522$ (3)

- the probability that there is no ship/cargo at the terminal, i.e., the berth is unoccupied

$p_0 = (1 - \rho) = 0.4478$ (4)

- the average quantity of cargo in queue

$L_q = \rho^2/1 - \rho = 0.6810$ t (5)

- the average amount of cargo at the terminal (in queue and being serviced)

$L = \lambda/\mu - \lambda = \rho/1 - \rho = 1.2330$ t (6)

- the average amount of cargo which is just being serviced

$L_{serv} = L – L_Q = \rho = 0.5522$ t (7)

- the average queuing time of cargo, that is, the queuing time of cargo prior to being serviced

$W_Q = L_Q/\lambda = 0.9811$h/1000 t (8)

- the average time of cargo's stay at the terminal, i.e., queuing time of cargo and duration of its unloading

$W = L/\lambda = 1.7782$h/1000 t (9)

- the average duration of cargo service-cargo unloading

$W_{serv} = W – W_Q = 0.7971$h/1000 t (10)

Table. 1. Unloading terminal operation indices for years 2016 and 2019.

Indices	Unit	2016	2017	2018	2019
ships	number	256	219	249	242
λ	ton/year	4 011 179.5	5 356 291.6	6 006 161.9	6 075 346.1
μ	ton/year	11 000 000	11 000 000	11 000 000	11 000 000
ρ	-	0.3646	0.4869	0.5460	0.5523
p_0	-	0.6353	0.5130	0.4540	0.4477
L_Q	ton	0.2092	0.4621	0.6566	0.6813
L	ton	0.5739	0.9491	1.2026	1.2336
L_{serv}	ton	0.3646	0.4869	0.5460	0.5523
W_Q	hour/1000 tons	0.4569	0.7557	0.9577	0.9824
W	hour/1000 tons	1.2533	1.5522	1.7540	1.7787
W_{serv}	hour/1000 tons	0.7964	0.7965	0.7963	0.7963

Source: own work.

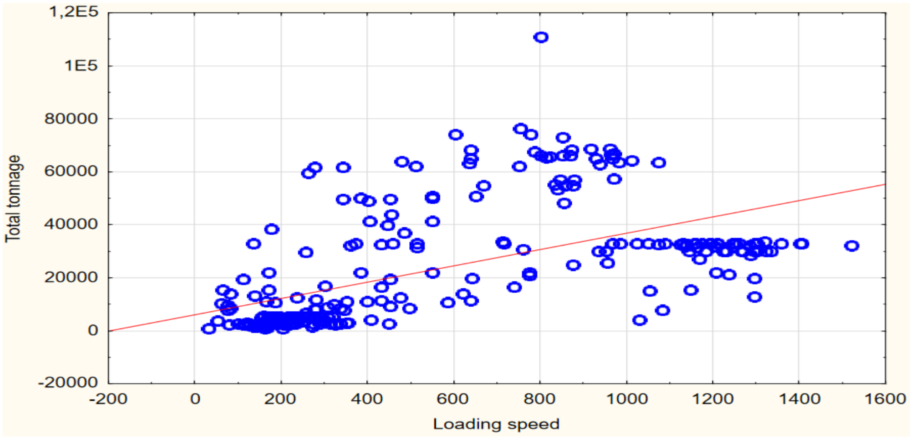

Fig. 5. Average loading speed scatterplot – 2019 year.
Source: own work.

It can be seen that in 2019 the cargo arrival rate in relation to cargo service rate, traffic rate ρ is 55% Eq. (5), and the probability that the berth is unoccupied amounts to 45% Eq. (6). Furthermore, the scatterplot shows that the larger the vessel, the faster the loading. However, the average handling speed totals 556.19 ton/h and does not depend on seasonality and external factors, since in the first quarter of 2019 the average handling speed totalled 555.28 ton/h, in the second quarter – 533.17 ton/h, in the third quarter – 515.13 ton/h, and in the fourth quarter – 609.19 ton/h (Fig. 5). The fastest cargo handled at the terminal is diesel oil; the loading speed is 1093.84 ton/h. The largest number of ships serviced at the terminal include ships carrying soybean meal (58 ships) and diesel oil (64 ships).

TERMINAL OPERATIONAL EFFICIENCY AND ITS ECONOMIC AND FINANCIAL RESULTS

The conducted analysis of HES terminal operation as a mass service system indicates that at the current level of cargo handling capacity and the existing intensity and density of the notification stream, it fails to generate the waiting time for service in the entry subsystem. The gross time of the ship's stay in the port is determined in these conditions practically exclusively by the actual time of the ship's service at the terminal. The time comprises the time of handling operations at the berth and the preparatory and completion procedures.

It means that within the current operational conditions:

1. the terminal is characterized by high operational efficiency measured by the time of service for all types of bulk cargo ships, notified in advance by the shipowners' agents making use of the terminal services,
2. the shipowners whose ships enter the terminal do not actually incur any indirect costs, being the function of service awaiting time.

Therefore, during the research period, the maritime transport operators fell within a group of beneficiaries of such a market system based on the relationship between the effective demand defining the notification stream and its distribution in time and the potential supply of terminal services, determined by cargo handling capacity of all berths. Consequently:

- the total terminal costs that constitute a significant component of port-related costs of the shipping operators who make use of the services provided by the HES terminal in Gdynia, as well as their
- unit costs calculated per 1 ton of cargo tonnage carried on the ship's side or 1dwt, or GT, between 2016 and 2019, at the average berth occupancy of 51 % (whereas realistically 46.5 % - 53.1 % - compare Fig. 6), were relatively very low. Since they were determined only by the level of fees for the loading and unloading operations and other related services at the terminal and in the port in Gdynia.

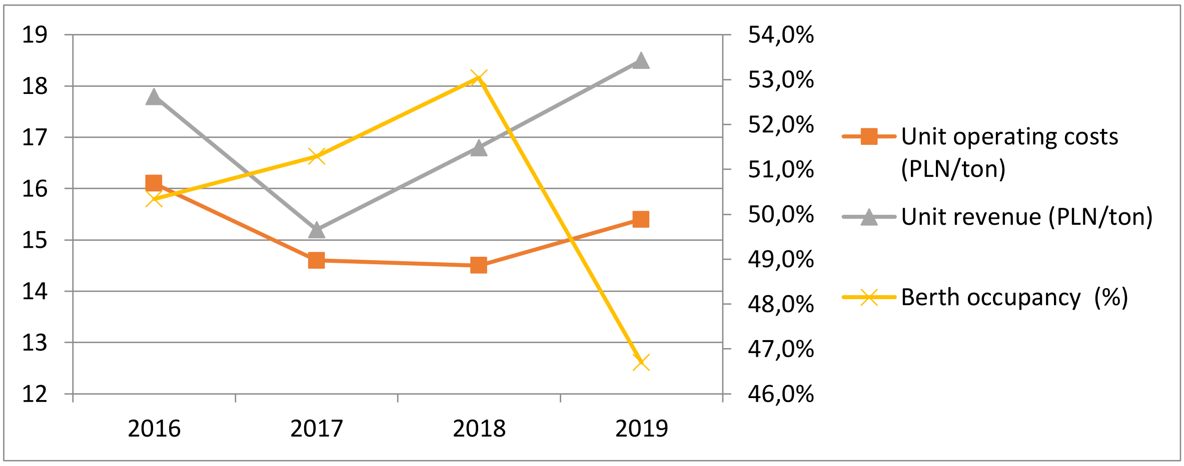

Fig. 6. The unit operating costs and unit revenue from basic operating activity of the terminal (in PLN/ton) between 2016 and 2019, in the function of average berth occupancy between these years (in %).
Source: own work.

This mechanism of completing the ship service processes ensured by the HES terminal, as a mass service system related to meeting the notified requirements of maritime transport operators, with respect to loading and unloading services, characterised by high operational and logistics efficiency, generated specific results for the terminal and maritime operators. By evaluating these results through the economic criteria, it can be concluded that in such conditions, we could observe the transfer of added value generated by the terminal to the shipping sector, that is, a group of shipping operators who used the terminal services. This situation, typical of mass service systems, the entry subsystems of which do not generate queues and over-congestion, reflects one of the possible forms of added value of transfer between two „maritime" links of the international logistics supply chain.

However, at the same time, during the studies, the terminal operator, as another entity within the supply chain, effectively implemented its own management strategy of the ship handling processes, meeting the handling requirements notified by the shippers and shipping operators, and the related transport processes smoothly and effectively. The average costs of its operational activity in the period analysed (in PLN/ton) were relatively stable, fluctuating between 14.4 and 16.1 PLN/t. (Fig. 6.) However, it is also characteristic that if the rate of change related to these costs is assessed as average values for each year, a clear regularity can be observed between the level of terminal unit operating costs and the average level of using the handling potential at berths (Fig. 6.). This cause-and-effect relationship measured by the correlation between these two factors, which define directly and indirectly the operational efficiency and economic effectiveness of the terminal, as a mass service system, was, as expected, inversely proportional (negative correlation).

It meant that:

1. the level of average terminal operating costs mainly determines the fixed costs, regardless of the variables within the conditions of the handling process, and in the structure of these costs relatively low is the share of depreciation costs of fixed assets involved in the process; moreover, the costs are calculated under linear method, i.e., fixed write-off rate on an annual basis,
2. in such a situation, the number of serviced ships, namely the intensity and density of the notification stream and the volume of handled cargo tonnage at the terminal not only translates into the level of berth occupancy, but also exerts significant impact on developing the level of unit operating costs of the cargo handling terminal; with the increase in berth occupancy, i.e. the load of the terminal as a mass service system, we

could observe the degression of these costs or their increase, when the berth occupancy indicator was going down, as in 2019,

3. the rate of change in the level of unit operating costs relative to, variable at that time, berth occupancy indicator reflected in the accounting system with some delay in time (since these are average annual values) was to a larger extent dependent on: a/ the volume of cargo tonnage handled at the terminal berths than on the number of ships and b/ the level of fixed costs degression with the increasing load of the system than on the increase in variable costs.

In such conditions, the terminal as an operating system as characterised above could implement, with a high probability of success, the strategy based on the business model focused on achieving the optimal level of technical production, aiming to minimize the average unit operating costs of the performed cargo handling operations. These min. costs are obtained at such a level of production measured with the berth occupancy indicator when the curve of these costs crosses the curve of short-term marginal costs.

The costs of terminal basic operating activity participated in the analysed period on average at ca. 88% in revenue from the sale of services, falling between 91 and 83%, although from 2017, we could observe a steady declining tendency of the share of these costs in the value of generated revenue. It means that these costs represented: 1/ the main component defining the level of revenue generated by the terminal managing company and 2/ determined to the largest extent the level of profitability of the conducted operating activity. This profitability, in turn, in the absolute and unit-related dimensions, was determined by the rate of changes in the level of costs and revenue. However, as long as unit operating costs increased only and slightly in 2019 compared to 2018 (the lowest level at that time), unit revenue was characterized by a relatively high growth rate from 2017 (Fig. 6.). As a result, the unit cargo handling profitability (1 ton of cargo) showed an increasing tendency.

The analysis of these relations in the context of costs – revenue, both total and unit costs of the terminal perceived in the framework of average level of using the berth cargo handling potential (Fig. 6.), indicates that:

1. unit operating revenue, which being the function of the price level for the handling of cargo and other services of the terminal, and the volume of cargo tonnage handled in this transport system always remained on a higher level than the costs of such activity, and the rate and direction of changes in the analysed period reflected, to a large extent, the tendencies regarding changes in unit operating costs (positive correlation),
2. however, from 2017, the total revenue of the terminal management company and its unit operating revenue increased faster than the costs of this activity, developing to a large extent regardless of its level of, which probably resulting mainly from the increase in fees for cargo handling services and a more significant degression of unit fixed costs relative to the increase in unit variable costs at the same level of berth occupancy,
3. however, this detachment of terminal revenue from the basis of its operating costs, increasing gradually from 2017, namely some sort of ‘shears opening’ visible in the analysis of these financial parameters per unit (Fig. 6.), fails to correlate – in particular in revenue - with the cargo handling activity of the terminal as a mass service system, measured by the average use of the berth cargo handling potential; nevertheless, this could involve changes in the size structure of ships serviced at berths – their deadweight and tonnage and volume of cargo loaded and unloaded at the terminal,
4. the trend was particularly visible from 2018, in the context of unit revenue of the cargo handling company relative to the level of berth occupancy, which did not occur in the entire analysed period when the growth rate of revenue per unit closely correlated with the growth rate of berth occupancy (strong positive correlation at 85 %).

The conducted analysis of unit costs and basic operating revenue of the HES terminal in the function of using the cargo handling capacity of its berths indicates that the terminal as a logistics system and a link in the supply chain operated in the analysed period:

1. efficiently not only in the logistics categories, servicing ships and meeting the notified cargo handling requirements with high technical and operational efficiency, and also in a safe and reliable manner.
2. effectively in both financial and economic categories, generating:

   a. significant revenue per unit in the operating activity and gross profit within the conducted basic activity (financial results),
   b. high added value thanks to the possibility to reduce fixed costs because of the technologically and economically optimal use of the cargo handling potential, measured by the berth occupancy indicator.

CONCLUSION

To analyse the processes within the terminal, queuing theory was applied, as one of the research methods verifying the service processes. In the article, the authors assumed that the bulk cargo handling terminal in Gdynia operates as a queueing model. Therefore, it was possible to analyze the operating mechanism of the selected port terminal as a logistics system and a link in the supply chain by characterising it in terms of technical and operational efficiency and economic and financial effectiveness, as well as logistics efficiency [Merk and Dang 2012], [Ye et al. 2020]. By applying the mass service theory, based on the conducted statistical analysis of data, it was possible to determine the character of the stream of notifications from ships calling at the HES terminal, on a monthly and annual basis, identifying in the analysed period its intensity and density, i.e., the number of entries into the subsystem per unit of time and their distribution in time, and the mechanism of handling these notifications at the terminal as a mass service system. The results of conducted research indicate that

1. there is no significant correlation between the number of ships' calls and the time of their service at the terminal; since there was no waiting time for entry into the system in the analysed period of time,
2. the sub-system of ship services in the context of logistics efficiency operated effectively, which indicated that it was adjusted in the technical and operational aspects (cargo handling capacity in terminal berths, berth occupancy in time) to the stochastically defined entry subsystem requirements, determined by the character of ships' notification stream distribution,
3. the absence of waiting time for ship service meant that the gross time of the stay in the port was solely defined by the actual time of service at the terminal, which indicates that under such conditions we could observe the actual transfer of added value generated by the terminal operator to the group of shipping operators who made use of the services provided,
4. the shipping operators using the services of the terminal as a mass service system were included in a group of main beneficiaries, and the scale of their benefits define by the savings in gross time of ship's service in the port determined the level of daily charter rate,
5. on average the terminal achieved a relatively high level of cargo handling potential use, measured by the berth occupancy indicator, which provided its operator with the possibility to obtain significant reductions in the unit fixed costs, being the main component of business operating costs;
6. in such conditions, in the analysed period, by obtaining regular surplus in operating revenue over the costs of operations (increase in handling profitability per unit), the terminal operator could implement the operating strategy focused on achieving the optimum of the technological production,
7. as a result of gradual detachment of the terminal operating revenue (high growth rate) from the basis of its operating costs, the level of which as unit costs was correlated in general with the cargo

handling activity of the terminal as a mass service system, measured by the average level of utilizing its berth cargo handling potential, such a tendency cannot be observed to the same extent at the terminal revenue per unit; the correlation in this respect is subject to significant change in time, which indicates that it is determined by many other factors, not included in the analysis,

8. the current state of relative balance between the entry subsystem and the sub-system of notification handling at the terminal as a mass service system, as well as the scale of generated benefits, fail to provide grounds for making in the nearest future large-scale investments, leading to increasing the terminal cargo handling capacity, and only at the very most, modernizations and purchase of fixed assets within intangible assets.

In conclusion, it can be determined that in the era of the logistics supply chain development and mass implementation of digital technologies, seaports and port terminals and not only the container terminals, by maintaining the character of operating systems typical of mass service systems operate equally efficiently and effectively in the supply chain system as its other entities, generating no additional logistics costs being the function of cargo handling service time. Instead, they have the possibility to generate added value, which is sometimes transferred in large part to other entities in the global value chain.

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ORIGINAL PAPER

IDENTIFYING THE COGNITIVE GAP IN THE CAUSES OF PRODUCT NAME AMBIGUITY IN E-COMMERCE

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ABSTRACT. Background: Global product identification standards and methods of product data exchange are known and widespread in the traditional market. However, it turns out that the e-commerce market needs data that have not already received much attention, for which no standards have been established in relation to their content. Furthermore, their current quality is often perceived below expectations. This paper discusses the issues of product name and highlights its problems in the context of e-commerce. Attention is also drawn to the source of liability for erroneous data.
Methods: The research methodology is based on the analysis of data of products available on the Internet through product catalog services, online stores, and e-marketplaces, mainly in Poland, but addresses a global problem. Three research scenarios were chosen, comparing product names aggregated by GTIN, starting with e-commerce sites and ending with product catalogs working with manufacturers. In addition, a scenario of name-photo compatibility was included.
Results: The results show that the product name, which in the real world is an integral part of the product as it appears on the label provided by the manufacturer, in the virtual world is an attribute consciously or not modified by the service provider. It turns out that discrepancies appear already at the source - at the manufacturer's level - publishing different names for the same product when working with data catalogs or publishing on product pages contributing to the so-called snowball effect.
Conclusions: On the Internet, products do not have a fixed name that fully describes the product, which causes problems in uniquely identifying the same products in different data sources. This in turn reduces the quality of data aggregation, search, and reliability. This state of affairs is not solely the responsibility of e-commerce marketplace vendors, but of the manufacturers themselves, who do not take care to publicize the unambiguous and permanent name of their products in digital form. Moreover, there are no unambiguous global guidelines for the construction of a full product name. The lack of such a template encourages individual interpretations of how to describe a product.

Keywords: basic product data, product catalog, e-data catalog, master data, data quality, dirty data

INTRODUCTION

In recent years, the popularity of e-commerce has increased significantly. Moreover, the COVID-19 pandemic has further accelerated it [Lone et al., 2021]. Unfortunately, it is noted that many companies still decide to obtain product data by copying them from other e-stores, downloading them from social databases available on the Internet with an untested source and in a different format, or writing data from product labels according to their own guidelines. Furthermore, companies, competing for customers on the Internet, also decide to introduce their modifications of product attributes, including photos and product names, trying to attract the attention of a potential buyer. It shows how e-commerce produces poor quality data, which is the so-called "dirty data" [Guoling & Qinyun, 2008]. "Dirty data" is a phrase that denotes out-of-date, inconsistent, or incomplete data [Zhou et al., 2011] that cannot be properly searched, aggregated, and analyzed. Operations on such data generate costs within the organization [Haug et al., 2011], and also reduce the credibility of the company in terms of the products sold [Qalati et al., 2021]. In addition, inconsistencies in the data are one of the causes of product returns, which, in turn, due to the need

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to organize additional transportation, negatively affects the environment [Kawa & Pierański, 2021].

This paper aims to present the quality issues related to product names in e-commerce. It shows the scale of the problem, examples of occurrence, possible reasons why such errors occur, and who is responsible for them. The intention is to draw attention to the problem of the content of text data in product catalogs and to the consequences of the lack of guidelines in this regard and, as a result, to initiate a discussion on the need for standardization in this area.

The paper is prepared as follows: Chapter 2 provides a review of the literature on data quality. Chapter 3 shows the meaning of the product name, which is one of the most important attributes of the product catalog. Chapters 4, 5, 6, and 7 present the research results and discussion. Finally, Section 8 provides a summary of the conclusions.

IMPORTANCE OF PRODUCT DATA QUALITY

In general terms, data quality is described as the ability of data to satisfy stated and implied needs when data are used under specified conditions [ISO 25012]. In the literature, data quality is often defined as "fitness for use" [Wang & Strong, 1996], [Batini et al., 2009] and it is understood as the ability of a data collection to meet users' requirements. As early as 1968, it was found out that the desired attributes defining quality are relevance, timeliness, and accuracy [Feltham, 1968]. As noted by Reeves & Bednar [1994], there are five definitions related to the concept of quality: value, compliance with specifications, compliance with requirements, fitness for use, and meeting and/or exceeding customer expectations. The concept of quality is usually considered as a multidimensional concept, for example, Wand & Wang [1996] proposed the decomposition of data quality into four internal dimensions: complete, unambiguous, meaningful and correct, while Cichy & Rass [2019] identified twenty of them. When we consider high quality, the data/information must be relevant, accurate, factual, complete, reliable, structured, precise, readable, and reasonable [Zmud, 1978].

In the case of e-commerce, the identification of the needs of product data is an issue that should be considered broadly and in a proper perspective. Product data, used locally on the e-shop website, may be used for other purposes in the long run. They can be used to synchronize and integrate, such as with price comparison sites, e-marketplace platforms, or even to increase the visibility of an e-store by search engines through the use of structured data, but they can also be used to exchange information on a logistical level. The lack of standardization in such terms will completely block the possibility of using modern technologies and minimizing the so-called "Human Factor" [Żuchowski, 2022]. It is worth emphasizing it even if the company does not see such a need at present and the scope of data is considered sufficient to conduct its business. If, after some time, it turns out that the data are not complete - that is, it does not meet the requirements of business partners in the minimum dimension for integration [Niemir & Mrugalska, 2021] (for, e.g., the set does not have GTIN numbers, there are no data on the product brand or the data are disordered – wrong format of product name or wrong format of main photo is used), it will certainly be a significant barrier or even prevent cooperation due to the costs of changes in the product database. Marsh [2005] confirmed it in his research, where due to "dirty data" 88% of data integration projects completely failed or exceeded the assumed budget, while 33% of organizations delayed or withdrew from IT implementations.

MEANING OF PRODUCT NAME

In traditional trade and communication, a key product attribute is GTIN (Global Trade Item Number) which uniquely identifies the product, while in e-commerce, product identification begins with its name [Niemir & Mrugalska, 2021]. For example, in a stationary store, the customer identifies the product by packaging, and the purchasing process begins with scanning of the bar code, i.e. GTIN identification, the IT system uses it to determine the price, stock levels, etc. The name of the product appears only on the receipt and in many cases, it does not identify the product and is only illustrative. In the case of online purchases, the product is identified and searched for by the name. The GTIN does not matter at this stage, and the purchase takes place at the level of the internal e-shop ID associated with the name. It shows why the product name is so important. Unfortunately, it turns out that just as the GTIN number is a permanent element, given by the manufacturer, the name of the product is interpreted by everyone in their own way.

MATERIALS AND METHODS

The research methodology was based on the analysis of data from product databases from various sources and was divided into four different scenarios. The first scenario referred to the study of the problem on a large scale. Three different product catalogs were compared in terms of the similarity of product names for products with the same GTINs in each database. We have selected product catalogs that were created in cooperation with manufacturers and were used to provide data-sharing services. This choice aimed to prove that this quality problem is common and occurs at the very source. The other scenarios were already case studies. In the second scenario, we focused on information from e-stores, knowing that in many cases their owners obtain product data on their own. It allowed us to verify to what extent their interpretation of the product name corresponds to reality. After downloading product data from several e-stores (web scraping), they were compared with each other, and one of the most frequently repeated, popular products were selected for further analysis. The third scenario was developed on the basis of data from the e-marketplace, i.e., a platform associating producers, distributors, and sellers, where data of offered products are entered through a common tool. E-marketplaces are places where problems with product names and their aggregation are particularly visible. Their customers are often small, inexperienced sellers. In such a case, it is easy to imagine the consequences of misunderstanding the need to enter the name of the product instead of the name of the offer. The largest Polish platform of this type was selected for the purpose of the research, and the product was selected on the basis of the available summary of data aggregated according to GTIN. The last scenario concerned a deeper problem as it was related to the interpretation of the text. It showed how the name could contribute to misconceptions about the product. The product for the analysis was selected experimentally on the basis of the authors' observations, using the Google Search Engine.

PRODUCT NAME IN SELECTED E-STORES

The study of the quality and consistency of product name data began with an analysis of the offers of dozens of online stores offering FMCG (Fast Moving Consumer Goods) products to the Polish market. The acquired data was aggregated using GTIN (Global Trade Item Number, a unique product number encoded in the form of a barcode). Of repeated product listings with the same GTIN numbers in different stores, 100 of them were selected, whose numbers were registered in different countries. Germany, UK, Greece, Portugal, Poland, Hungary, Sweden, Switzerland, Italy, Netherlands, and Austria. Products included beverages, candy, cleaning products, and cosmetics. Then, it was examined whether the product names were identical across the various offerings. The result was clear: for each of the selected products, their names were different in different stores.

To analyze the problem in detail, a popular Polish food product was selected from among the products that had an unusually large number of name variations. Its manufacturer maintains the official website, of the product on its website but without information about the GTIN number and the full name that describe this product. The header of the page (the leading H2 header of the page) reads "Lemon Flavor", and there is also a photo of the product. The product is registered in the official GS1 Polska register as "Lemon cake flavor 9mlx20pcs EXP". For research purposes, the manufacturer's brand name was anonymized with the value "[BRAND]", leaving the original letter size. The names of this product were originally in Polish, but they were translated without losing the context. The results obtained are presented in Table 1.

It needs to be underlined that under this GTIN there is a single product, not 20 items (the collective packaging has a different GTIN number) and the net content of the product is 9 ml, not 10 ml, 9 Ml (mega liter?) or 10 g. During the additional search of websites by product name, an identical product with a wrongly marked GTIN number was also found. From the point of view of Internet search engines, especially intelligent ones, the terms, such as "glass" and especially "bot", probably an abbreviation for "bottle", are very misleading information. It adversely affects the accuracy of the results. For NLP / AI algorithms, in addition to the above, the inflection of the word and its use in context also play a role. One thing is "lemon flavor", and another thing is "lemon fruit".

Table 1. Different names for an example product.

[BRAND] LEMON FLAVOR 10ML	FLAVOR [BRAND] CITR 9ML
[BRAND] Lemon Flavor 9 Ml	flavor [Brand] lemon
[BRAND] Lemon cake flavor	Flavor [Brand] Lem 9ml [Manufacturer]
[Brand] Lemon cake flavor 10 ml	LEMON FLAVOR 10ML [BRAND]
[Brand] lemon cake flavor 10ml bot	LEMON FLAVOR
[Brand] Lemon cake flavor 9 ml	LEMON FRUIT FLAVOR [BRAND]
[BRAND] Lemon Cake Flavor 9 Ml	LEMON FLAVOR 10ML * [BRAND] * EU
[BRAND] Lemon cake flavor glass	LEMON FLAVOR 10ML [BRAND]
[Brand] flavor for cakes, creams, and punch, lemon 10 ml	LEMON FLAVOR 9ML [BRAND]
[Brand] Lemon Cake Flavor 10g.	CAKE FLAVOR [BRAND] 9ML LEMON FRUIT IO
[BRAND] Lemon Aroma for cakes, creams and punch 10ml	LEMON CAKES FLAVOR [BRAND] 9ml
[BRAND]: LEMON FLAVOR	LEMON CAKES FLAVOR 9ML [BRAND]
[BRAND] -LEMON CAKE FLAVOR 10G A18.	

Source: Own work.

From the analyzed example, it is possible to observe quite common differences in product names, probably due to the fact that e-commerce database operators enter data from product labels without any guidelines or under their own internal regulations. This situation causes that the names of the same product are different each time: the text starts with either brand or common name, purpose, etc. ending with net content, type of packaging, or internal store markings. The research additionally shows that in some stores information about the product is incomplete or incorrect, which is an even more serious problem. This detailed case also made it possible to observe that the quality problem arises not only at the retailers' level, but also already at the manufacturer's level. The product data on its official product website is incomplete, while the registered data in GS1 Poland assigned to this GTIN is incorrect.

Due to doubts that the problem of quality and differences in names does not lie in the specifics of the local market and language, name analysis was also carried out for several products available on the German and British markets while maintaining the same research methodology. The results were identical.

Comparing the situation to a traditional purchase - this problem will not occur - we buy a product that we can see. The label of most of products is usually designed to make the brand and the main characteristics of the product easy to read. The customer should not be misled. Also, the label of the product is the same in each store because it comes from the manufacturer. As long as the GTIN number is on the product label and in the database of the store's IT system, the number is assigned appropriately - there are no problems with the purchase.

PRODUCT NAME / OFFER IN THE E-MARKETPLACE

In further research, an observation of a product with the same GTIN entered for multiple offer names and categories was made on a Polish shopping platform. It is an example where a buyer, trying to search for different products, receives multiple offers with the same product. The platforms currently try to solve such problems by creating their own product catalogs (Amazon, eBay, Allegro), aggregating such data by GTIN number, and then displaying the product using the agreed common product name. However, in spite of the fact that it is one of the most interesting ways to solve such a problem, it will be effective at a local level – in an e-marketplace. Additionally, it will be only the solution if the platform has reference data and the same GTIN is present in all aggregated data sources. In practice, unfortunately, the solution is not 100% effective.

For a selected exemplary product, a total of 771 pairs were calculated for the set: offer name (product) + product category. The product appeared in 10 different categories and 283 different names, and the data described the toy as a microphone with a battery-powered speaker and the possibility of connecting an additional audio source via Bluetooth and having lighting effects. Depending on the trader and a specific offer, the product was classified as: “light gadget”, “electronic gadget”, “portable speaker”, “karaoke equipment”, “wireless microphone”, “GSM accessory” and finally as “a toy”. Instead of the name of the product, the offer contained various information, from the common name to the description of the customer's needs. For example: “for a girl”, “to the phone [provided phone model name]”, “karaoke glowing LED”, “as a gift for CHILDREN”, “light and loud LED lights”, “to party”, “Father's Day gift idea”.

The example shows the situation where the seller uses the attribute of the offer to attract attention at the cost of reliable information about the product, just to increase the sales. The selected product did not have a positioned brand or even a recognizable product name. Its producer was probably just entering the market. The described situation could temporarily give the seller profits but globally aggravates the problem of data quality. The e-marketplace also loses due to such activities, several dozen or more pages with the same product under different names of offers certainly does not encourage the buyer to continue the search. This action does not also position the brand, manufacturer, or product. However, similar scenarios are impossible in traditional commerce.

MISCONNECTION OF NAME AND PHOTO

Complex and multi-criteria problems can appear when we comply a product name with its photo. For example, such situations can result from color interpretation. In order to check it, "woman mint pants" were entered in the Google search engine. The data was obtained from e-stores where a photo was attached to a product and a name including the above phrase was inserted. In the study, all stores were analyzed in detail to confirm the word "mint" in relation to the name to eliminate situations when the search engine retrieved data, e.g. from the description of the product page. The search results are presented in Figure 1 in the same order as it was displayed on the page.

In order to start the analysis of this case, two questions can arise: "what color of pants can you see in the photos?" or "what color of pants will you get as a customer"? Celadon, turquoise, or mint? We can differentiate many reasons for this situation such as incorrectly entered product name by the operator of the online store database or badly loaded photo that does not represent the actual product or even photo with poor quality, e.g. distorted colors, wrong color definition. Of course, one can ask the question who introduced such a name? An e-shop employee or a manufacturer of the cloth?

Another problem is the photo itself - the shot, the background, the number of products in a single photo as well as the presentation of the model or the cloth itself. These are problems of data standardization, which is lacking not in terms of the field name that defines the photo, but in terms of the content [Niemir & Mrugalska, 2022]. From the photo, you cannot read what the subject of the purchase is - pants, a set of pants + blouse, handbag, or shoes. As was mentioned before it is also not known what will be the color of the product when it is finally delivered.

Today’s e-consumers are accustomed to situations where the filtered results do not correspond to their questions. In comparison to a purchase in a stationary store, such situation will never occur as we buy the real product which we can consciously see, touch and sometimes even feel and smell.

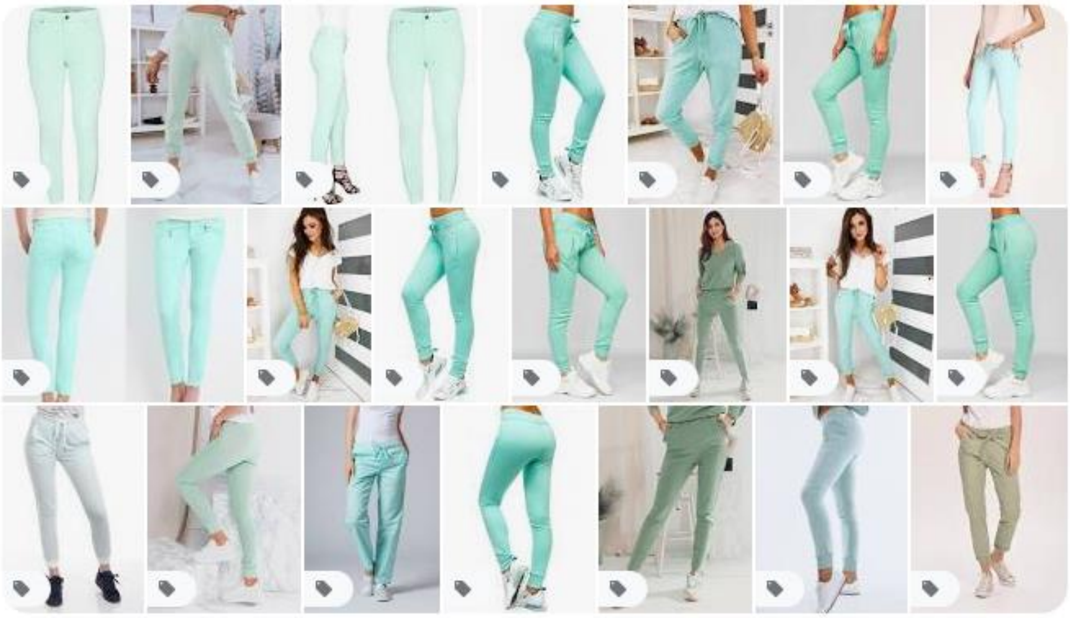

Fig. 1. An example of photos of products for the searched phrase "Woman mint pants ".
Source: Google Image Search.

SIMILARITY OF NAME IN PRODUCT CATALOGS

Due to previous research results, which proved that in some cases ambiguities arise at the very source of the data, i.e. the manufacturer, it was decided to perform an additional study to confirm this thesis. Three data catalogs that provide data services for the e-commerce market, whose information is verified in cooperation with manufacturers, were selected. The research was conducted for products appearing at once in all three catalogs, i.e. having the same GTIN. An additional selection criterion was the availability of a given product on the Polish market, regardless of its origin and the country of the manufacturer. Full aggregation was obtained for 9266 products surveyed. A test was then carried out to see if the name of a given product was the same (exact match of text strings without case comparison) and, if not - whether it was similar. The similarity of the names was verified with an algorithm that ignored differences in the order of words/letters and numbers in the name, while the number of letters and numbers in both cases had to match. The results of this study are shown in Figure 2.

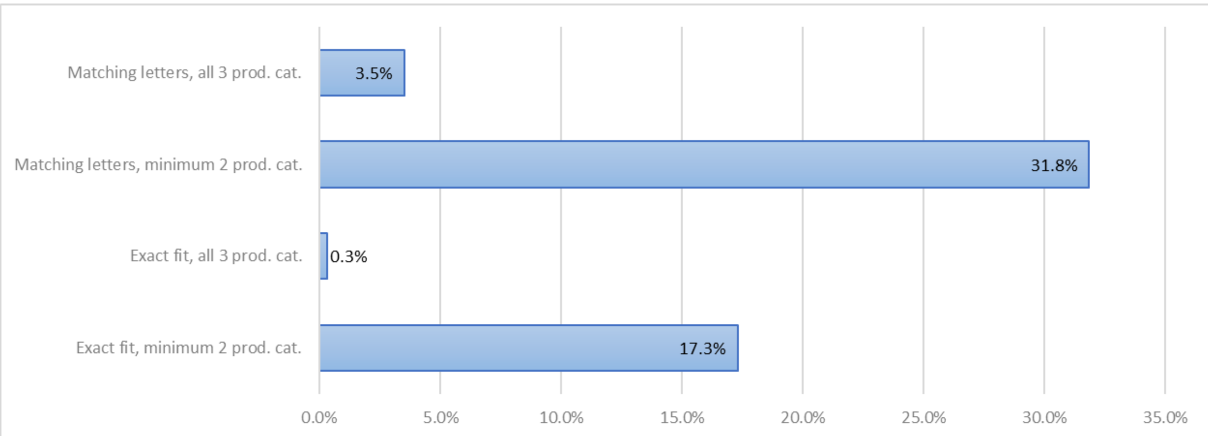

Fig. 2. Conformity of product name.
Source: own work.

The complete concordance of the product names in all 3 catalogs practically did not occur, the concordance was recorded for only 30 of them. Omitting one catalog, the concordance reached only 17.3% of the total set. The study of similarities, comparing the occurrence of the same letters and numbers with the same number of them in both names, gave better results, although the study itself should be treated as an overview, due to the flawed nature of the algorithm. Despite this, the similarity of the names still remained low.

CONCLUSIVE REMARKS

The lack of clarity in the names of products sold via the Internet is a significant problem, especially when we take into account data aggregation, data verification with the real product, and data search by phrase. In the virtual world, the basic attributes of products, especially the name and photo, which directly reflect reality, should not be freely interpreted. As in the GTIN, the basic product data should derive from the manufacturer and be closely related to the product - be "stuck to the product" just as a label. It is not that only retailers should care about the quality of the description of the products they offer, but it is the manufacturers, who should describe the attributes in a standardized way and publish the data associated with the product in such a way that anyone can easily read it and verify its accuracy in their own database, which, however, is not currently happening. The results of this research clearly show that the data can be incorrect or incomplete at the source, further increasing the number of errors and even compounding them throughout the supply chain. Particularly in e-commerce, when we do not see the product being sold, but only its data, the product name should contain fully reliable information that strictly describes the specific product and should unambiguously identify it, just like a product label in the real world. Therefore, the product name should contain at least such data as the brand name, common name, product variant, and net content. There is no chance of correct verification and unambiguous traceability of the product without such information arranged in the right order. Similarly, the photo of the product - the one that is the main and most important - should reflect the actual purchase. So, if the purchase relates to one product, the photo should only present that specific product. If such a product is, for example, "pants", then the main photo should not be a drawing or a sketch, be presented on a model, be presented in a specific scenery, etc. The standardization of this area is not easy because the problem affects all products in all industries, and each restriction in both the text of the product name and the presentation of the product as the image may be difficult in specific situations. Nevertheless, it is worth taking steps to standardize the data and taking the responsibility, as a manufacturer, for their correct definition and dissemination together with the product release on the market.

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ORIGINAL PAPER

THE IMPACT OF BLOCKCHAIN TECHNOLOGY ON OPERATIONAL AND STRATEGIC RISKS IN THE SUPPLY CHAIN - A SYSTEMATIC LIT-ERATURE REVIEW

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ABSTRACT. Purpose: Nowadays, the amount of data generated by companies is increasing dramatically every year. More and more processes are being digitised, forcing the use of ever newer techniques. With the growing amount of data, companies are facing the problem of ensuring easy access to data and its security. An increasingly popular solution is blockchain, whose implementation, however, entails a number of risks.

Design/Methodology/Approach: The article focuses on the analysis of the literature on blockchain and its use in the supply chain, regarding the changes and benefits brought by the introduction of the use of blockchain technology. The scope of the literature includes articles found in the Web of Science database, from 2016-2021.

Findings: Authors provides a brief introduction and description of blockchain technology both in general and in relation to the supply chain based on 45 articles. After a static part, the author describes the risks associated with the introduction of the technology and presents possible ways to solve them.

Conclusions: Authors of articles increasingly recognize the importance of blockchain technology to mitigate the risks of doing business. As a result, more and more solutions based on this technology are appearing, also in the supply chain.

Originality/Value: Strategic and operational risks associated with the implementation of blockchain are poorly described in the scientific literature. Through his analysis, the authors expand the supply chain literature with additional theoretical coverage.

Keywords: blockchain, supply chain, operational management, strategic management, blockchain application in supply chain

INTRODUCTION

More and more data is all around us and the amount is growing rapidly. In the 2020 1.7 megabytes of new data was created every second for every human being on the planet and the total accumulated digital universe of data grew to around 44 zettabytes. Because of that, more data was generated in the last several years than in the whole human race history (McCrea, 2017).

To visualize the scale, we can say that Google process more than 24 petabytes of data per day, Facebook upload more than 10 million photos per hour and CERN (European Organization for Nuclear Research) processes on average one petabyte of data per day, with transfer rates of 60 GB/s and 1 exabyte total data storage. (Tan et al., 2020; CERN Data Centre, 2020).

Big amount of data leads to the major issues - how to provide access in real time to them in a secure way. One of a solution resistant to almost any alternation of its data is blockchain (Jagtap et al., 2021). Nowadays many big companies work with blockchain technology or think about how to implement them. IBM in association with Maersk developed TradeLens – a solution for open and neutral supply chain, mainly for the container logistic, as a result of the research in the container shipping. Maersk found that the shipping goods from East Africa to Europe can

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require approval from around 30 officials from different authorities. This situation is turning as a big threat for the whole process of transport, because costs of the physically moving container can be sometimes even equal to the cost of moving - the cost of the trade-related paperwork processing is estimated to be between 15 and 50 percent of the costs of the physical transport. Moreover, due to long time food can spoilage and the documents might be subjected to fraud, so to keep track of all the paperwork companies need to use standardized interface, where every partner is empowered to have full visibility of the container status (Jagtap et al., 2021; Hackius and Petersen, 2017).

American multinational retail corporation Walmart also tried blockchain technology. Their solution works in food supply chain and test the transparency across Walmart's food supply chain for pork and tracing packages of sliced mangoes from its US stores back to its source Mexico farms. For the second one, the results were outstanding and reduced time needed for tracking mango origins from 7 days to 2.2 seconds (Kamath, 2018).

According to Brigid McDermott (IBM's Vice President of blockchain business development) blockchain can solves many business problems by providing data immutability. Therefore, blockchain is a new, promising technology which is called that it "*is poised to become the most exciting invention after the Internet*", resolving the lack of security via network computing (Zhao et al., 2016).

In this article, the authors focus on blockchain control in the supply chain. The main thesis is to determine the impact of blockchain technology on the level of operational and strategic risk in relation to the management of supply chain companies. The aim is to answer the question whether blockchain is able to reduce operational and strategic risks and to look for ways to solve the problems that have arisen. The analysis will be performed based on a bibliometric and network analysis technique and by evaluating 45 articles published in the years of 2016-2021.

REVIEW OF THE LITERATURE ON BLOCKCHAIN

What is blockchain

Blockchain was invented by Satoshi Nakamoto, the man who hides their personality, and being unmasked until today (Hackius and Petersen, 2017). The word of blockchain can be divided into 2 terms. First is "block" which is basic unit of blockchain and represents transactions, while second – "chain" links transactions into one chain. This two words combination is not accidental. Each block of blockchain contains a list of transactions which is linked to the previous block in the chain (Jović et al., 2020). Due to blockchain structure these transactions cannot be later modified or removed. That lead to improving the level of trust, because the longer the chain is, the harder to make modifications in previous block (Treiblmaier, 2018).

Blockchain design is different, depending on the technology application. In terms of openness and access to data we can distinguish three most common types of blockchain:

- Private (or permissioned) blockchain is a peer-to-peer network built on a platform managed by a single centralized institution. Users have well known each other and there is no anonymity. Access to the blockchain is restricted to specific participants and can be only granted by the validator of the system.
- Public (or permissioned-less) blockchain is a network with available access and open for anyone who can meet the requirements of blockchain technology. Open access brings anonymous users, usually without any relations with lack of trust among them. Popular example of public blockchain is bitcoin.
- Consortium blockchain is a type between public and private blockchain combining elements from both and refers to a blockchain whose accord procedure is constrained by prechosen hubs. The most notable difference from either system is consensus level (Kouhizadeh and Sarkis,

2018; Park, 2020; Gomathi et al., 2021; Saberi et al., 2018).

Blockchain in supply chain

Basic facts

Interest in blockchain technology has been seen in many business sectors. There is no surprise that this also concern the field of logistics and supply chain management (SCM). The interest in blockchain technology has been growing more and more and can be visible by the activities of practitioners devoted to this topic and journalist describing a new trend in logistics as well (Kummer, 2020). Both of them look at blockchain technology as a disruptive technology, which is poised to play a major role in managing, controlling, and most importantly securing devices (Khan and Salah, 2017).

Table 1. Difference between various type of blockchain

Attribute	Public blockchain	Private blockchain	Consortium blockchain
Access to the blockchain	Anyone	Restricted to single organization	Restricted to multiple selected organization
Consensus	Permissionless operated by anyone who can validate blocks	Permissioned operated by a single entity	Permissioned operates under the leadership of a group of entities
Network type	Decentralized	Partially decentralized	Hybrid between public and private blockchain
Participants know each other	No	Yes	Yes
Transaction speed	Slow	Fast	Fast
Security level	High	Low	Mixed

Source: own work.

Blockchain technology can simplify many procedures by coordinating transparency and documentation in accordance with the provisions. If there is a delay in some part of supply chain, the situation can be easier detected in the network and therefore implemented a contingent plan, to prevent harmful results of a delay in a supply chain. In traditional system multiple level of suppliers, distributors, service providers and retailers lead to inefficient communications record-keeping. In blockchain, numerous emails and telephone communications are replaced by a commonly agreed smart contract, which can save a huge amount of time and resources (Cai, 2018). Blockchain has many advantages which can leads to the conclusion that blockchain has the potential to solve some of the current problems with supply chains (Farouk and Darwis, 2019).

Advantages of blockchain in supply chain

The hotspot for blockchain initiatives in supply chain were food, diamond and pharmaceutical products. (Ghode et al., 2019; Etemadi et al., 2021). For example, for the food supply chain, a combination of radio frequency identification (RFID) and blockchain can track goods in real time based on hazard analysis and critical control point (HACCP) principles. Due to its ability to record events in the food supply chain, blockchain can detect unethical suppliers and counterfeit products (Saberi et al., 2018).

Next potential of blockchain supply chain advantage is secure money transaction. Using blockchain in money transfer of supply chain could reduce the timing of international monetary transactions of this nature to less than an hour. In addition to this blockchain technologies have higher ability to avoid fraud and generate efficient transactions. Third party during the transaction are not necessary, that is why blockchain reduced transaction cost and improving trust within the supply chain network (Wang et al., 2018; Ghode et al., 2020).

Another advantage can be seen in multimodal transport, where multiple players at different stages of the supply chain generate a lot of data. Each player must have access to the relevant data, which necessitates the use of a system for each player to communicate (Bhushan et al., 2020). The emergence of technologies such as blockchain brings new life to this system. Higher quality real-time information flow can prevent disruption, resilience and the ripple effect (Etemadi et al., 2021). It is also related with security and safety of the data because this technology is false authentication resistant like preventing malicious users from launching DoS attacks or potential double-spending problem (Kshetri, 2017; Fernández-Caramés et al., 2019; Bhushan et al., 2020; Firdaus et al., 2019).

Disadvantages or treats of blockchain in supply chain

However along with the advantages, blockchain has also some disadvantages. Due to the huge total investments by the technology, not every company can afford to these changes. Many small and medium companies along with logistics operators lack knowledge about the blockchain. Building and deploying a private block-chain network requires much knowledge and its complexity and the associated cost are major obstacles for the adoption of the technology (Ismail and Materwala, 2019; Treiblmaier, 2019). In addition, the implementation of new technology is always high risk. (Tan, 2020).

On the other hand, in order to function properly, the logistics industry has to collect and store a large amount of data every day and therefore a high level of energy consumption is required to maintain the network. The development of this technology entails environmental concerns as it violates the original intentions of green development. In addition, when a large number of devices are connected to the system, real-time data collection leads to network congestion, which reduces the quality of service. Therefore, data transmission is also a huge challenge for the logistics industry (Tan, 2020; Wang et al., 2018).

It is also important to mention that any database (including blockchain-based database) is at risk of cyber-attack. One of the factors, which opens a window for cyber-attacks is the latency of transactions. Number of participants accessing to blockchain platform is crucial. Limited set of participants can cause more vulnerability to blockchain based system (Kshetri, 2017; Tribis et al., 2018; Sobb et al., 2020).

RESEARCHING METHODOLOGY AND DATA STATISTICS

Defining keywords

To gather articles, the authors used the Web of Science website. The search was based on several stages shown in the figure below.

The first step was to properly define the criteria. For this purpose, an advanced search was applied using keywords related to blockchain in the supply chain.

After finding articles on Web of Science, the author searched for articles whose topics of work and their keywords indicate a significant similarity with the topic of this article. Selecting a target group of articles, along with removing any duplicates that appeared, significantly narrowed down the number of articles needed to be reviewed. The next step was to read the articles and subject them to a more in-depth analysis, which resulted in a further number of articles being rejected. The final step was to prepare a second round of article searches. These activities were already focused directly on the topic of this article.

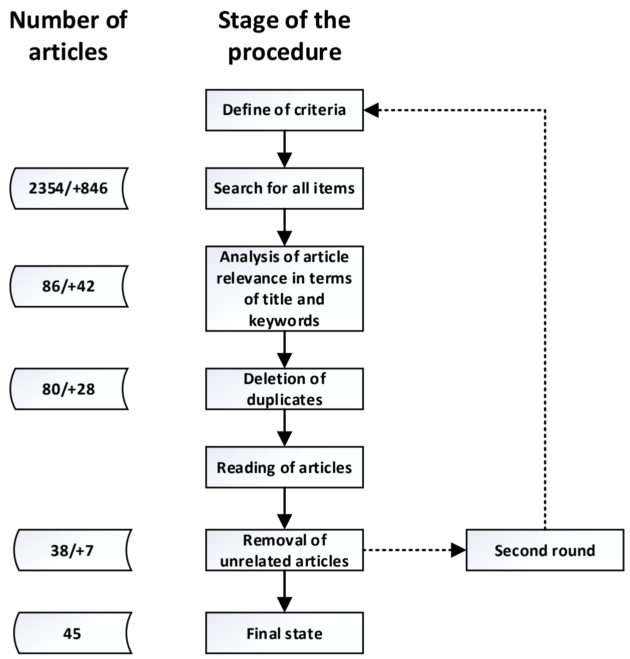

Fig. 1. Author's procedure for the collection of articles

Source: own work.

Table 2. Top 10 contributing countries

Country	Frequency	Country	Frequency
United States	10	Austria	2
China	8	Italy	2
United Kingdom	5	United Arab Emirates	2
India	4	Brazil	1
Australia	2	Croatia	1

Source: own work.

Data analysis

In this section, the author focuses on the statistical approach to the articles used in the paper. The aim is to further deepen the analysis and to identify the main trends followed by authors of articles around blockchain technology use in the supply chain.

Based on a table comparing the number of publications by authors in the countries concerned, it can be said that the top four definitely stand out. The results of the list indicate that these countries are crucial in shaping the theoretical view of blockchain in supply chains.

The number of publications in relation to the year of publication indicates a significant interest in the topic in 2020. The years 2018 and 2019 also stand out. Such a high share of articles over these years may be the aftermath of the increase in interest in blockchain technology in recent years, which only highlights the importance and timeliness of the topic under analysis and the dynamically developing cooperation between the business and scientific spheres, resulting in more and more solutions based on blockchain technology.

The above figure showed a graphical visualisation related to the keywords used across all the articles analysed. As it turns out, the results are heavily mixed. However, most of the keywords resulting from blockchain are related to logistics, supply chain, business and social economy, science and technology or technology in general.

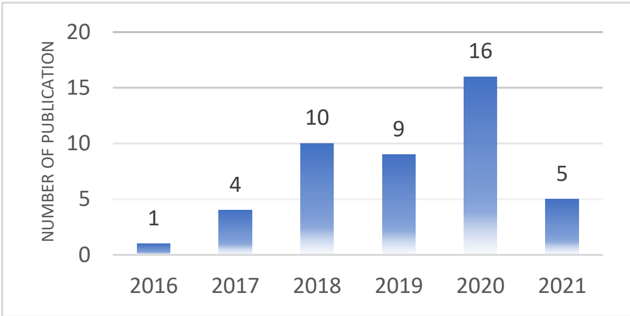

Fig. 2. Number of publications over the years

Source: own work.

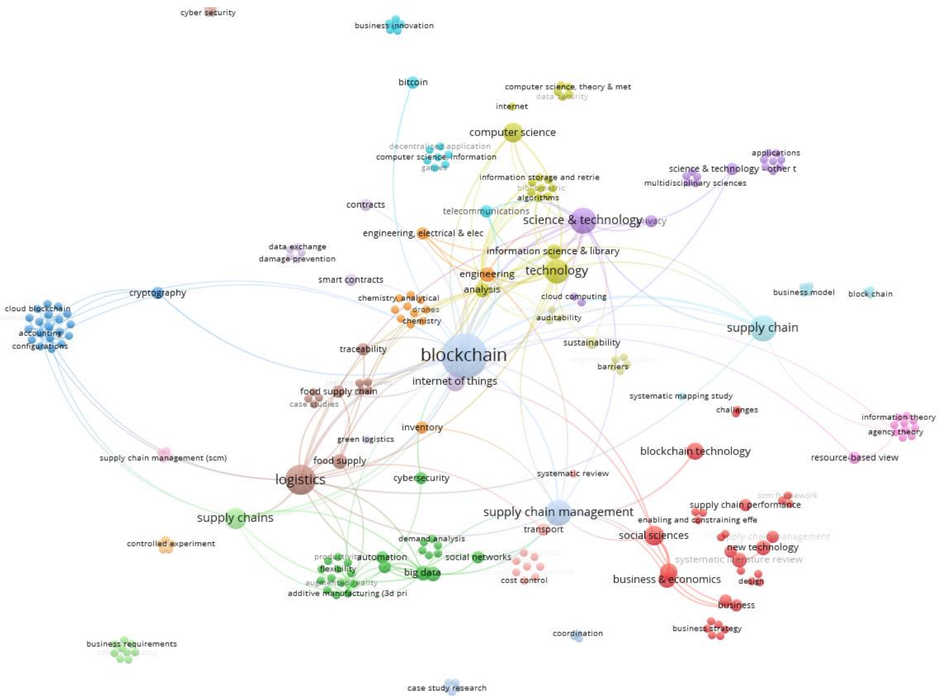

Fig. 3. Network visualization for keywords

Source: own creation.

OPERATIONAL AND STRATEGIC RISK IN BLOCKCHAIN BASED SUPPLY CHAIN

Introduction

Implementation of a new technology is almost always subject to risk. Blockchain's implementations are also not without challenges (Wang et al., 2020). In supply chain there are many non-predictable factors which can influence both goal definition and methods to ensure goal achievement. That is why strategic and operational planning in logistics management are difficult processes with high strategic risk. Many firms face the problem of external pressure which leads on the one hand to push the introduction of technology due to competitive pressure and on the other hand to delay its adoption when there is no support from top management. On the other hand, high organisational readiness and information and communication readiness are the main factors enabling firms to adopt new technologies in the supply chain (Sternberg et al., 2020).

Moreover, for analysing strategic sustainability and a complex cyber-physical system it proves necessary to implement more modern methods. Blockchain – one of the proposed solutions - can accelerate assessing the strategic risks even during the first steps of strategic creation and depending on the environment yields a smaller level of operational risk compared to the traditional supply chain counterpart (Raikov, 2019; Choi T-M, 2020).

In addition to analysing the many benefits of blockchain technology and the decisions of other supply chain participants to adopt and integrate this technology, particular attention should be paid to highlighting the barriers and operational and strategic risks, in adopting this technology. The authors of the article (Sternberg et al., 2020) and (Hopkins and Hawking, 2017) point to many barriers. Some of these are:

- Lack of standardisation and technological issues,
- Possible attacks,
- Information exchange,
- Necessity and trust,
- the “garbage in, garbage out" - (GIGO) problem (Sternberg et al., 2020; Hopkins and Hawking, 2017).

Further analysis will be based on the listed risks for operational and strategic management in the supply chain.

Lack of standardisation and technological issues

Fraud in supply chains is a serious problem for both organisations and their customers (Falcone et al., 2020). One of the main sectors dealing with fraud is pharmaceutical market. According to the World Health Organization (WHO), in 2017 alone, counterfeit drugs had a significant 10% share of the pharmaceutical market in low- and middle-income countries (Pournader, 2020). The challenge is exacerbated in the case of internet sales. The online drug market remains highly unregulated, but blockchain can help prevent illicit product from entering companies' supply chains. Theorists have already proposed a blockchain-based model for drug supply chain management to create transparent data on drug transactions and implement network surveillance and thus solve some challenges such as poor traceability or lack of real-time information. Blockchain-based traceability systems can help companies comply with regulations and record ownership transfers (Hastig and Sodhi, 2020; Xue et al. 2020). However, to prevent fraud it is necessary to structure the medicines market and introduce clear business requirements regarding traceability. Therefore, European Union (EU) has passed the Falsified Medicines Directive, which forces the pharmaceutical firms and other actors in their supply chains to implement full traceability by 2019. Similarly in the United States, Drug Supply Chain Security Act (DSCSA), gives a deadline for 2023. As it turns out, the elimination of the supply chain of counterfeit medicines is essential in order to increasing control of the adverse effects of these medicines, which have a significant impact on increasing resistance to medicines among patients, not treating or may even cause the death of the purchaser. This in turn leads to a risk of human error in operational management and subsequent allocation of the wrong medicine. Using blockchain (or other technologies) in the supply chain to digitise and automate transactions could improve the responsiveness and operational efficiency of pharmaceutical companies (Pournader, 2020; Hastig and Sodhi, 2020).

Possible attacks

From an operational risk perspective, it is important to mention the impact of blockchain technology on resilience or limiting the negative impact of a system-wide failure. The decentralised form of blockchain results in a better solution to these risk factors due to the dispersion of information and security among many participants rather than the concentration on a single player. As past events have shown, the introduction of blockchain technology could protect against cyber-attacks on Equifax or the US National Security Agency, where millions of customer records were stolen. One giant attack vector from millions of data points in the old model becomes millions of attack vectors, making it much less cost-effective to hack end users one at a time. This in turn leads to a transfer of risk to endpoints that are responsible for managing their own digital assets (Etemadi et al., 2021; Hald and Kinra, 2019).

Access and exchange of information

Another risk in supply chain management is related to information flow. The right approach to running a business necessitates the appropriate exchange of information, which, as a fundamental element of dynamic supply chain capabilities, can affect business performance. Previous technologies that used common data structures risked a lack of control over data and systems. Due to these issues and the need to ensure data is accurate and up-to-date, businesses are increasingly turning to blockchain-based solutions. In addition, some customers and consumers may start to turn to suppliers that provide more complete information about the history of their products, and this could lead to radical changes in the market and force some sectors of the supply chain to adopt the new technology (Falcone et al., 2020; Hald and Kinra, 2019).

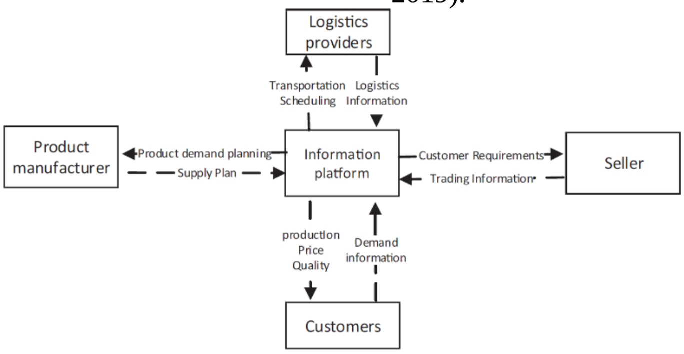

Fig. 5. Information sharing structure

Source: Xue et al. 2020

The supply chain is sensitive to changes in demand. This is particularly evident in long supply chains consisting of many links, where a small change in a customer's order can lead to radical changes in the chain's businesses. Blockchain can lead to the resolution of the bullwhip effect, which in a traditional system could lead to demand for predictive failure and blind production. Blockchain technology plays an important role in promoting the creation of a customer-centric information exchange structure and the implementation of information exchange in the supply chain. The key to eliminating bullwhip is to implement proper information exchange in the supply chain, which in turn will reduce information distortion. However, the implementation of blockchain technology in supply chain partner networks is complex because the full use of the technology is only revealed when partner companies choose to implement the new technology and share information, and employees actively use the technology's capabilities (Falcone et al., 2020; Xue et al. 2020).

The "garbage in, garbage out" - (GIGO) problem

Data falsification by employees or by an IT system is one of the next risks in supply chain management. This action can be intentional or the result of human/system error. Blockchain technology, as an embedded software agent, provides continuous validation, verification and distribution of transactions in real-time based on specific processes that are encoded into the system of all transactions in the block, making data and transaction fraud significantly more difficult. Blockchain only performs those operations that have been coded, defined and applied by their designers, so that participants, data controllers and accountants across the supply chain will only perform the tasks that have been designed for them. Because traditional third parties - such as banks, brokers and other organisations - are driven by human intervention, there is the potential for opportunism, favouritism and bias. In addition, the use of smart contracts without a centralised entity (e.g. banks or logistics providers) to control operations, along with their digitisation with assets, allows for a trading environment free of intermediaries with full transparency and trust among each group of stakeholders involved in the trade (Falcone et al., 2020; Pournader, 2020).

However, for blockchain to work properly it is necessary to provide the right data. A human error during data entry, such as a supply chain link reporting a lower inventory level than it actually is, will lead to a smart contract automatically placing an order. Such data, if incorrect, is relatively difficult to correct and requires additional time. In addition, there is always the risk that the private key of a node in the blockchain (in this context, a node represents a tier of the supply chain or transport intermediary) is lost or corrupted and prevents the use of the blockchain (Pournader, 2020).

Confidence and trust building

Trust between supply chain participants allows for joint decision-making and therefore better responsiveness of the entire supply chain to movements or trends, or market disruptions. This problem became crucial during the COVID19 outbreak, where it is necessary to increase operational supply chain flexibility, improve response traceability, real-time coordination and the ability to reconfigure resources during recovery phases and ensure a robust and resilient supply chain. Blockchain technology eliminates some of the above issues and ensures secure information exchange while building trust. This is due to many factors, the most important of which is the visibility of data to participants and the reduction of fraud. Additionally, a blockchain-based data chain, unlike a traditional central mechanism, updates and maintains its database in a distributed form, which in itself enforces, to some extent, increased trust between participants in the new technology (Teodorescu and Korchagina, 2021; Etemadi et al., 2021; Sternberg et al., 2020; Hastig and Sodhi, 2020).

Summary

The introduction of blockchain technology into a business must always be analysed in advance in terms of the benefits of its implementation. Changing standard operating procedures and policies can be a difficult and risky task. The change must also include new business processes. The scalability, interface and speed of the new technology must also be taken care of. From an operational efficiency perspective, blockchain is able to automate the verification of transaction attributes in an inexpensive way, and the operational risk of a blockchain-supported supply chain brings a lower level of operational risk compared to a traditional supply chain counterpart (Fernández-Caramés et al., 2019; Choi T-M, 2020).

However, from a strategic management perspective, there are significant risks before the introduction of blockchain. The technology does not address all the problems in supply chains. It is therefore not a one-size-fits-all solution. Blockchain is a new technology, so companies need to assess whether they want to be at the forefront of change or wait until the technology matures. It is important for players to identify the right network and underlying platform to participate in, as it involves different levels of risk to business strategy as well as the limitations of the supply chain ecosystem. Additionally, companies also need to pay attention to how entities will be impacted after the shift to blockchain. Some companies believe that they will need to implement blockchain in the near future to have a competitive advantage, although in reality there is not always a need (Hastig and Sodhi, 2020; Choi T-M, 2020).

DISCUSSION&CONCLUSIONS

The literature review conducted showed that blockchain allows to reduce operational risk, thus supporting supply chain management. The impact of blockchain on the strategic risk of supply chains is significantly lower. However, risk mitigation alone is usually not enough for companies to decide to redesign their business structure.

To achieve true efficiency in the use of blockchain or any other technology, it is necessary to redesign, not just automate, existing processes (O'Leary, 2017). This is particularly important because research indicates that 80% of the effort to implement blockchain relates to changes in business processes - only 20% of the effort is to implement the technology itself. The division of effort suggests that companies can implement most of the traceability activities through process changes before implementing blockchain (Hastig and Sodhi, 2020). Such a change is therefore both time-consuming and costly. Furthermore, the currently available blockchain case studies lack a common standard, making it difficult to systematically transfer these cases to industry programmes. The reason for this is largely due to the immature nature of the technology. For many researchers, access to early initiatives can be a major barrier (Patelli and Mandrioli , 2020; Wang et al., 2020). Furthermore, most larger companies have already invested in ERP, APS, CRM or other IT systems that they use. Therefore, a blockchain-based solution would need to integrate with these existing systems to varying degrees. Furthermore, these companies and their supply chain partners would need to redesign the processes involved in using these systems (Hastig and Sodhi, 2020).

On the other hand, the purpose of blockchain is not just to mitigate risk. The main value that makes more and more companies decide to implement it lies elsewhere and depends mainly on the company and the industry it is in. For Walmart it has been to increase transparency across the food supply chain, for Maersk and IBM it has been to reduce the time and cost of documenting cargo movements and prevent fraud, while DHL, together with Accenture, is focusing in using blockchain to track pharmaceutical products from origin to consumer and prevent tampering and errors. It can therefore be seen how broadly blockchain technology is used. The literature review shows that blockchain will have a significant impact on the development of businesses in the coming years.

By accelerating turnover, increasing efficiency and facilitating relationships with partners through digital platforms, blockchain will lower barriers to entry across the supply chain - driving innovation and momentum in the industry and enabling reverse logistics at no additional cost (Farouk and Darwis, 2019). Blockchain can support decision-making on everything from warehousing to delivery to payment. The technology has gained attention mainly due to its combination with smart contracts (Kumar et al., 2019).

Currently, blockchain is still in its early stages of development. An example of 10 practical applications of blockchain in supply chains, described within the Appendix, shows that some of the examples are at the design stage or in the early stages of existence. The wide range of application possibilities makes it difficult to introduce clear standards of practice for the transformation of businesses and the implementation of blockchain applications into them. This in turn does not accelerate the development of the technology itself. Despite this, it is noticeable that there is considerable interest in blockchain technology especially by large enterprises, which are becoming precursors of development. The advantages of blockchain technology, led by: increased security of the technology, prevention of cyber-attacks, making it more difficult for data falsification and mistakes to be made by employees, increasing trust between supply chain participants, facilitating the flow of information, increasing the transparency of the entire supply chain, all of which impact on risk, will be one of the key benefits to implement blockchain to companies. The next few years are probably crucial for the companies and the direction in which the blockchain technology will develop.

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ORIGINAL PAPER

FACILITY LOCATION PROBLEM MATHEMATICAL MODELS – SUPPLY CHAIN PERSPECTIVE

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ABSTRACT. Background: Supply chains are the networks linking sources of supply with demand points and composed of so-called actors, i.e., producers, distributors/wholesalers, retailers, and customers/consumers. As in every network, supply chains contain vertices and arcs, the former represented by factories and warehouses (including distribution centers). Such facilities cause long-term and expensive investments. As a result, decisions on location and number of them belong to the strategic level of management and require quantitative analysis. To do this, mathematical models of the Facility Location Problem (FLP) are constructed to allow an application of optimization methods.

Methods: Mathematical optimization or programming is the selection of the best solution, with regard to some criterion, from a set of feasible alternatives. The fundamental of mathematical optimization is the formulation of mathematical models of analyzed problems. Mathematical models are composed of objective function, decision variables, constraints, and parameters. These components are presented and compared in the paper concerning FLP from a supply chain perspective.

Results: The ten mathematical models of the FLP are presented, including the two original ones. The models are classified according to such features as facility type they concern, including the desirable, neutral, and undesirable ones. The models and their components are characterized. In addition, their applicability and elasticity are analyzed. Finally, the models are compared and discussed from the supply chain point of view.

Conclusions: However, the FLP mathematical models are relatively similar; the most important element of them for supply chain appropriate representation is an objective function. It strongly influences the possible applicability of FLP models and their solutions, as well. The objective functions having broader applicability turned out to be the maximized number of supply/demand points covered by facilities and the minimized number of facilities necessary to cover supply/demand points. However, not to locate all allowed facilities (use all the location sites) or as many as supply/demand points, but an appropriate number of them, it is necessary to take into account facility fixed costs. Thus, when locating logistics facilities, the minimized total cost of serving supply/demand points is the most appropriate objective function.

Keywords: logistics, distribution network design, facility location, mathematical modelling

INTRODUCTION

The distribution network design belongs to a group of problems so-called Facility Location Problem (FLP) [Eiselt and Marianov, 2011], also known as location analysis or theory, and is a branch of Operational Research (OR). Facility location is a critical component of strategic planning for a wide spectrum of public and private companies [Owen and Daskin, 1998]. The FLP concerns the optimal placement of facilities to minimize transportation costs to, between, and from analyzed facilities along with their variable and fixed costs of operation and (or not) individual minimum/maximum capacities. It leads to Capacitated and an Uncapacitated Facility Location Problems (CFLP/UFLP) [Sliva and Serra, 2007]. One can also distinguish continuous and discrete versions of the FLP. In the continuous FLP (ConFLP), the selection for a new facility can be any location within the space, whereas for the discrete FLP (DisFLP), there is a given set of choices for the facility's location [Eiselt and Marianov, 2011]. On the other hand, demand can also be continuously or discretely distributed in a network, giving a node- or an arc-based FLPs [Lin and Lin, 2018].

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One of the very first problems that can be considered as the FLP was already proposed in the 17th century by P. de Fermat and is known as "a geometric median of three points" [Brimberg, 1995]. The problem was formulated as follows "given three points in a plane, find a fourth point such that the sum of its distances to the three given points is as small as possible" [Dorrie, 1965] and first solved geometrically by E. Torricelli in the year 1645.

In the year 1909 A. Weber used a classical three-point version of the Fermat problem to model possible industrial locations in order to minimize transportation costs from two sources of materials to a single customer or market – so called the Fermat-Weber problem [Drezner and Hamacher, 2004]. This is one of the simplest and first formulations of the ConFLP. A direct numerical, iterative solution method was proposed by E. Weiszfeld only in 1937 [Weiszfeld, 1937]. The method was further developed and popularized by H. Kuhn and R. Kuenne, among others [Kuhn and Kuenne, 1962].

Throughout the years, the FLP got many different mathematical formulations and was solved using numerous different methods [Conceição et al., 2012; Gupta and Könemann, 2011; Ambrosino and Scutellà, 2005; Klose and Drexl, 2005; Vygen, 2005; Drezner and Hamacher, 2004; Klamroth, 2002; Korupolu et al., 2000; Magnanti and Wong, 1984; Or and Pierskalla, 1979].

The purpose of this paper is to present mathematical models of the FLP in the generic and internally consistent manner, allowing for their analysis and comparison from the supply chain perspective. The addition of the models lacking in the already existing literature, but being a logical extension of the models presented there is the second aim of this paper.

The paper is divided into four parts. First, there is the introduction presenting the general background of the raised topic, i.e., the FLP and the most fundamental works related to it. In the next two Sections the particular mathematical formulations of the FLP and their classification along with the comparison are presented, respectively. The paper ends with conclusions and further work planned.

FLP MATHEMATICAL MODELS

Presented in this Section, mathematical models of the FLP are both relatively generic (concern single- and multi-source versions of the problem, by defining decision variable as a binary one or not, also capacitated and incapacitated versions of the problem, by adding or not the constraint (3) and internally consistent too (considering the proposed notation).

Indices:

- predefined supply/demand points i; set I = {1, 2, 3, … i, …},
- predefined facilities j to be located; set J = {1, 2, 3, … j, …}.

Decision variables:

- location variables $x_i \in \{0,1\}$; set X = $\{x_1, x_2, x_3, \dots x_j, \dots\}$,

$$x_j = \begin{cases} 1 \text{ if facility is located at candidate site } j \quad \text{or} \quad \text{if facility } j \text{ is open} \\ 0 \text{ othewise} \end{cases} \tag{1}$$

- assignment variables $y_{ij} \in \{0,1\}$; set Y = $\{y_{11}, y_{12}, y_{13}, \dots y_{ij}, \dots\}$,

$$y_{ij} = \begin{cases} 1 \text{ if supply/demand point } i \text{ is assigned to/served by facility } j \\ 0 \text{ othewise} \end{cases} \tag{2}$$

assuming that $y_{ij} \leq x_j$ for each j.

Parameters:

D coverage distance (travel time, cost) within which facilities can serve supply/demand points,

$d_{ij}(x_j)$ distance (travel time, cost or other measure of transport intensity) function between supply/demand point i and facility j located at point x_j,

$FC_{j\,max}$ maximum capacity of facility j,

$l_j(x_j)$ total location (opening, building, setup, fixed) cost of facility j located at point x_j,

P predefined maximum or exact number of facilities j to be located (opened, built, fixed),

$t_{ij}(x_j)$ unit (per distance d_{ij} and weight w_i), variable transportation cost function of moving a unit weight per unit distance between facility j located at point x_j, and supply/demand point i, or vice versa (usually, in a majority of models, the value of parameter t is predefined, thus, constant for particular pairs of i and j giving the DisFLP),

W the total value (weight) of the whole industry/market,

w_i supply/demand point i weight.

Symbols:

$|\ \ |$ cardinality symbol,

$\lfloor\ \ \rfloor$ rounding down symbol (towards minus infinity, to the largest integer that does not exceed value in the bracket),

$\lceil\ \ \rceil$ rounding up symbol (toward plus infinity, to the smallest integer that is not less than the value in the bracket).

Capacity constraints and boundary condition (for the CFLP models):

$$\sum_{i\in I} w_i \cdot y_{ij} \leq FC_{j\,max} \ll \sum_{i\in I} w_i \quad \forall j \in J \tag{3}$$

$$\sum_{j\in J} FC_{j\,max} \geq \sum_{i\in I} w_i \tag{4}$$

Minimized distance (travel time or cost) **between a limited number of facilities *j*** (|J| ≪ |I|), that is crucial here, **and supply/demand points *i***. The distance calculated as optionally weighted summed up (5a), average (5b) or maximum (5c) one [Ahmadi-Javid et al., 2017; Boonmee et al., 2017; Klose and Drexl, 2005; Owen and Daskin, 1998; Hakimi, 1964]. The two former correspond to the minsum or *p*-Median Problem, whereas the latter corresponds to the minmax or *p*-Center Problem. Moreover, for the UFLP the supply/demand points i are just assigned to the closest facilities j.

$$\min_{x_j \in X, y_{ij} \in Y} \sum_{i\in I}\sum_{j\in J} w_i \cdot d_{ij}(x_j) \cdot y_{ij} \tag{5a}$$

$$\min_{x_j \in X, y_{ij} \in Y} \sum_{i\in I}\sum_{j\in J} \left(w_i \cdot d_{ij}(x_j) \cdot y_{ij}\right) \Big/ \sum_{i\in I}(w_i)$$

$$\text{if not weighted divided by } |I| \text{ or even } |J| \text{ instead of } \sum_{i\in I}(w_i) \tag{5b}$$

$$\min_{x_j \in X, y_{ij} \in Y} max\left(w_i \cdot d_{ij}(x_j) \cdot y_{ij}\right) \quad \forall i \in I, \forall j \in J \tag{5c}$$

subject to:

$$\sum_{j \in J} y_{ij} \geq 1 \quad \forall i \in I \tag{5d}$$

and optionally to:

$$\sum_{j \in J} \left[\sum_{i \in I} y_{ij} \Big/ \left(1 + \sum_{i \in I} y_{ij} \right) \right] \leq or = P \tag{5e}$$

Minimized pairwise distance (travel time or cost) **between** (minimum 2) **facilities *j***, all located within a limited space. The distance calculated as optionally weighted summed up (6a), average (6b) or maximum (6c) one. To the best of the author's knowledge, it is a new one FLP model, not reported in the literature so far.

$$\min_{x_{j,j'} \in X, y_{ij,j'} \in Y} 0{,}5 \cdot \sum_{j \in J} \sum_{j' \in J} \left\{ d_{jj'}(x_j, x_{j'}) \cdot \sum_{i \in I} [w_i \cdot (y_{ij} + y_{ij'})] \cdot \left[\sum_{i \in I} y_{ij} \Big/ \left(1 + \sum_{i \in I} y_{ij} \right) \right] \cdot \right.$$
$$\left. \cdot \left[\sum_{i \in I} y_{ij'} \Big/ \left(1 + \sum_{i \in I} y_{ij'} \right) \right] \right\} \quad j \neq j' \tag{6a}$$

$$\min_{x_{j,j'} \in X, y_{ij,j'} \in Y} 0{,}5 \cdot \sum_{j \in J} \sum_{j' \in J} \left\{ d_{jj'}(x_j, x_{j'}) \cdot \sum_{i \in I} [w_i \cdot (y_{ij} + y_{ij'})] \cdot \left[\sum_{i \in I} y_{ij} \Big/ \left(1 + \sum_{i \in I} y_{ij} \right) \right] \cdot \right.$$
$$\left. \cdot \left[\sum_{i \in I} y_{ij'} \Big/ \left(1 + \sum_{i \in I} y_{ij'} \right) \right] \right\} \Big/ \sum_{i \in I} [w_i \cdot (y_{ij} + y_{ij'})] \quad j \neq j' \tag{6b}$$

$$if\ not\ weighted\ divided\ by\ |I|\ or\ even\ |J|\ instead\ of \sum_{i \in I} [w_i \cdot (y_{ij} + y_{ij'})]$$

$$\min_{x_{j,j'} \in X, y_{ij,j'} \in Y} max \left(d_{jj'}(x_j, x_{j'}) \cdot \sum_{i \in I} [w_i \cdot (y_{ij} + y_{ij'})] \cdot \left[\sum_{i \in I} y_{ij} \Big/ \left(1 + \sum_{i \in I} y_{ij} \right) \right] \cdot \right.$$
$$\left. \cdot \left[\sum_{i \in I} y_{ij'} \Big/ \left(1 + \sum_{i \in I} y_{ij'} \right) \right] \right) \quad \forall j \in J, \forall j' \in J, j \neq j' \tag{6c}$$

subject to:

$$\sum_{j \in J} y_{ij} \geq 1 \quad \forall i \in I \tag{6d}$$

and optionally, assuming that all (6e) or specified (6f) facilities j or a given (minimum or exact) number of them (6g) are already located (opened, built, fixed) or that specified, the maximum coverage distance (travel time or cost) between facilities j and supply/demand points i has to be met (6h), subject to:

$$\sum_{i \in I} y_{ij} > 0 \quad \forall j \in J \tag{6e}$$

$$\sum_{i \in I} y_{ij} > 0 \quad \exists j \in J \tag{6f}$$

$$\sum_{j \in J} \left[\sum_{i \in I} y_{ij} \Big/ \left(1 + \sum_{i \in I} y_{ij} \right) \right] \geq or = P \tag{6g}$$

and/or

$$y_{ij} = 0 \leftrightarrow d_{ij}(x_j) > D \quad \forall i \in I, \forall j \in J \tag{6h}$$

Minimized number of facilities *j* needed (7a) **or the total cost of their location** (opening, building) (7b) **to cover** all demand (or specified level of demand) subject to specified, maximum coverage distance (travel time or cost) between facilities j and supply/demand points i, corresponding to the Set Covering Problem [Boonmee et al., 2017; Klose and Drexl, 2005; Owen and Daskin, 1998].

$$\min_{x_j \in X, y_{ij} \in Y} \sum_{j \in J} \left[\sum_{i \in I} y_{ij} \Big/ \left\lceil 1 + \sum_{i \in I} y_{ij} \right\rceil \right] \tag{7a}$$

$$\min_{x_j \in X, y_{ij} \in Y} \sum_{j \in J} l_j(x_j) \cdot \left[\sum_{i \in I} y_{ij} \Big/ \left\lceil 1 + \sum_{i \in I} y_{ij} \right\rceil \right] \tag{7b}$$

subject to:

$$\sum_{j \in J} y_{ij} \geq 1 \quad \forall i \in I \tag{7c}$$

$$y_{ij} = 0 \leftrightarrow d_{ij}(x_j) > D \quad \forall i \in I, \forall j \in J \tag{7d}$$

The value of the parameter l_j in fact, depends on the sum of weights w_i of supply/demand points i assigned to facility j, and thus l_j is a function of y_{ij}. As a result, the value of l_j is not strictly constant (however, it can be perceived as a fixed cost but precisely as a step or threshold-like one) and should be scaled. It corresponds to the so-called modular capacity version of the FLP.

Maximized number of (all or new) **supply/demand points *i*** (8a) **or** (all or added) **amount of demand** (8c) **covered** (partially covered if 8b-d is applied) **or** (all or added) **market share gained** (8d) subject to the specified maximum coverage distance (travel time or cost) between a limited number of facilities j ($|J| \ll \infty$), that is crucial here, and supply/demand points i, corresponding to the Maximal Covering Problem or the p-Cover Problem [Boonmee et al., 2017; Owen and Daskin, 1998].

$$\max_{x_j \in X, y_{ij} \in Y} \sum_{i \in I} \left\lfloor \sum_{j \in J} y_{ij} \leftrightarrow d_{ij}(x_j) \leq D \right\rfloor \tag{8a}$$

$$\max_{x_j \in X, y_{ij} \in Y} \sum_{i \in I} \left\lfloor \sum_{j \in J} y_{ij} \leftrightarrow d_{ij}(x_j) \leq D \right\rfloor \quad (8b)$$

$$\max_{x_j \in X, y_{ij} \in Y} \sum_{i \in I} \sum_{j \in J} w_i \cdot y_{ij} \leftrightarrow d_{ij}(x_j) \leq D \quad (8c)$$

$$\max_{x_j \in X, y_{ij} \in Y} \frac{1}{W} \cdot \sum_{i \in I} \sum_{j \in J} w_i \cdot y_{ij} \leftrightarrow d_{ij}(x_j) \leq D \quad (8d)$$

subject to:

$$\sum_{j \in J} y_{ij} \leq 1 \quad \forall i \in I \quad (8e)$$

$$\sum_{i \in I} w_i \leq W \quad (8f)$$

and optionally to:

$$\sum_{j \in J} \left\lceil \sum_{i \in I} y_{ij} \Big/ \left(1 + \sum_{i \in I} y_{ij}\right) \right\rceil \leq or = P \quad (8g)$$

Minimized number of supply/demand points *i* (9a) **or amount of demand** (9c) **uncovered** (partially uncovered if 9b-d applied) **or lost market share** (9d) subject to specified, minimum (un)coverage distance (travel time or cost) between a limited number of facilities *j* (|J| ≪ |I|), that is crucial here, and supply/demand points *i*, corresponding to the *p*-Cover Problem [Ahmadi-Javid et al., 2017; Boonmee et al., 2017].

$$\min_{x_j \in X, y_{ij} \in Y} |I| - \sum_{i \in I} \left\lfloor \sum_{j \in J} y_{ij} \leftrightarrow d_{ij}(x_j) \leq D \right\rfloor \quad (9a)$$

$$\min_{x_j \in X, y_{ij} \in Y} |I| - \sum_{i \in I} \left\lceil \sum_{j \in J} y_{ij} \leftrightarrow d_{ij}(x_j) \leq D \right\rceil \quad (9b)$$

$$\min_{x_j \in X, y_{ij} \in Y} \sum_{i \in I} w_i - \sum_{i \in I} \sum_{j \in J} w_i \cdot y_{ij} \leftrightarrow d_{ij}(x_j) \leq D \quad (9c)$$

$$\min_{x_j \in X, y_{ij} \in Y} 1 - \frac{1}{W} \cdot \sum_{i \in I} \sum_{j \in J} w_i \cdot y_{ij} \leftrightarrow d_{ij}(x_j) \leq D \quad (9d)$$

subject to:

$$\sum_{j \in J} y_{ij} \leq 1 \quad \forall i \in I \quad (9e)$$

$$\sum_{i\in I} w_i \leq W \tag{9f}$$

and optionally to:

$$\sum_{j\in J}\left[\sum_{i\in I} y_{ij} \middle/ \left(1+\sum_{i\in I} y_{ij}\right)\right] \leq or = P \tag{9g}$$

Minimized total delivery/distribution/ operating cost being a trade-off between fixed and variable or, in accordance with the decision variables, location and assignment, or just warehousing and transportation cost components (10a), corresponding to both the Set Covering Problem and the minsum or *p*-Median Problem, being, to some degree, a combination of them [Ahmadi-Javid et al., 2017; Guastaroba and Speranza, 2014; Rahmani and MirHassani, 2014; Klose and Drexl, 2005; Sridharan, 1995].

$$\min_{x_j \in X, y_{ij} \in Y} \sum_{j\in J} l_j(x_j)\cdot\left[\sum_{i\in I} y_{ij} \middle/ \left[1+\sum_{i\in I} y_{ij}\right]\right] + \sum_{i\in I}\sum_{j\in J} t_{ij}(x_j)\cdot w_i\cdot d_{ij}(x_j)\cdot y_{ij} \tag{10a}$$

subject to:

$$\sum_{j\in J} y_{ij} \geq 1 \quad \forall i \in I \tag{10b}$$

and optionally to:

$$\sum_{j\in J}\left[\sum_{i\in I} y_{ij} \middle/ \left(1+\sum_{i\in I} y_{ij}\right)\right] \leq or = P \tag{10c}$$

If it is the DisFLP and weights $w_i = 1$ for all supply/demand points *i*, the problem is called the Simple Plant Location Problem – SPLP [Galli et al., 2018; Cornuejols et al., 1990].

There is also a group of reverse or opposite ways of formulating objective function, and thus defining the so-called obnoxious/undesirable FLP.

Maximized distance (travel time or cost) **between facilities *j* and supply/demand points *i*** all located within a limited space. The distance calculated as optionally weighted summed up (11a), average (11b) or minimum (11c) one [Boonmee et al., 2017; Owen and Daskin, 1998; Kuby, 1987; Drezner and Wesolowsky, 1980; Church and Garfinkel, 1978]. The model corresponding to the maxsum/anti-Median Problem or the maxmin/anti-Center Problem.

$$\max_{x_j \in X, y_{ij} \in Y} \sum_{i\in I}\sum_{j\in J} w_i\cdot d_{ij}(x_j)\cdot y_{ij} \tag{11a}$$

$$\max_{x_j \in X, y_{ij} \in Y} \sum_{i\in I}\sum_{j\in J}\left(w_i\cdot d_{ij}(x_j)\cdot y_{ij}\right) \middle/ \sum_{i\in I}(w_i)$$

$$if\ not\ weighted\ divided\ by\ |I|\ or\ even\ |J|\ instead\ of \sum_{i\in I}(w_i) \tag{11b}$$

$$\max_{x_j \in X, y_{ij} \in Y} min\left(w_i \cdot d_{ij}(x_j) \cdot y_{ij}\right) \quad \forall i \in I, \forall j \in J \tag{11c}$$

optionally, assuming that all (11d) or specified (11e) facilities *j* or a given (minimum or exact) number of them (11f) is already located (opened, built, fixed) or that specified minimum (un)coverage distance (travel time or cost) between facilities *j* and supply/demand points *i* has to be met (11g), subject to:

$$\sum_{i \in I} y_{ij} > 0 \quad \forall j \in J \tag{11d}$$

$$\sum_{i \in I} y_{ij} > 0 \quad \exists j \in J \tag{11e}$$

$$\sum_{j \in J} \left[\sum_{i \in I} y_{ij} \Big/ \left(1 + \sum_{i \in I} y_{ij}\right) \right] \geq or = P \tag{11f}$$

and/or

$$y_{ij} = 0 \leftrightarrow d_{ij}(x_j) < D \quad \forall i \in I, \forall j \in J \tag{11g}$$

Maximized pairwise distance (travel time or cost) **between** (minimum 2) **facilities *j***, all located within a limited space. The distance calculated as optionally weighted summed up (12a), average (12b), or minimum (12c) one [Owen and Daskin, 1998]. The model corresponding to the *p*-Dispersion Problem.

$$\max_{x_{j,j'} \in X, y_{ij,j'} \in Y} 0{,}5 \cdot \sum_{j \in J} \sum_{j' \in J} \left\{ d_{jj'}(x_j, x_{j'}) \cdot \sum_{i \in I} \left[w_i \cdot (y_{ij} + y_{ij'}) \right] \cdot \left[\sum_{i \in I} y_{ij} \Big/ \left(1 + \sum_{i \in I} y_{ij}\right) \right] \cdot \right.$$
$$\left. \cdot \left[\sum_{i \in I} y_{ij'} \Big/ \left(1 + \sum_{i \in I} y_{ij'}\right) \right] \right\} \quad j \neq j' \tag{12a}$$

or

$$\max_{x_{j,j'} \in X, y_{ij,j'} \in Y} 0{,}5 \cdot \sum_{j \in J} \sum_{j' \in J} \left\{ d_{jj'}(x_j, x_{j'}) \cdot \sum_{i \in I} \left[w_i \cdot (y_{ij} + y_{ij'}) \right] \cdot \left[\sum_{i \in I} y_{ij} \Big/ \left(1 + \sum_{i \in I} y_{ij}\right) \right] \cdot \right.$$
$$\left. \cdot \left[\sum_{i \in I} y_{ij'} \Big/ \left(1 + \sum_{i \in I} y_{ij'}\right) \right] \right\} \Big/ \sum_{i \in I} \left[w_i \cdot (y_{ij} + y_{ij'}) \right] \quad j \neq j' \tag{12b}$$

$$if\ not\ weighted\ divided\ by\ |I|\ or\ even\ |J|\ instead\ of \sum_{i \in I} \left[w_i \cdot (y_{ij} + y_{ij'}) \right]$$

$$\max_{x_{j,j'} \in X, y_{ij,j'} \in Y} max\left(d_{jj'}(x_j, x_{j'}) \cdot \sum_{i \in I} \left[w_i \cdot (y_{ij} + y_{ij'}) \right] \cdot \left[\sum_{i \in I} y_{ij} \Big/ \left(1 + \sum_{i \in I} y_{ij}\right) \right] \cdot \right. \tag{12c}$$

$$\cdot \left[\sum_{i \in I} y_{ij'} \middle/ \left(1 + \sum_{i \in I} y_{ij'} \right) \right] \Bigg) \quad \forall j \in J, \forall j' \in J, j \neq j'$$

subject to:

$$\sum_{j \in J} y_{ij} \leq 1 \quad \forall i \in I \tag{12d}$$

and optionally, assuming that all (12e) or specified (12f) facilities *j* or a given (minimum or exact) number of them (12g) is already located (opened, built, fixed) or that the specified minimum (un)coverage distance (travel time or cost) between facilities *j* and supply/demand points *i* has to be met (12h), subject to:

$$\sum_{i \in I} y_{ij} > 0 \quad \forall j \in J \tag{12e}$$

$$\sum_{i \in I} y_{ij} > 0 \quad \exists j \in J \tag{12f}$$

$$\sum_{j \in J} \left[\sum_{i \in I} y_{ij} \middle/ \left(1 + \sum_{i \in I} y_{ij} \right) \right] = or \geq P \tag{12g}$$

and/or

$$y_{ij} = 0 \leftrightarrow d_{ij}(x_j) < D \quad \forall i \in I, \forall j \in J \tag{12h}$$

Minimized number of supply/demand points *i* (13a) **covered** (partially covered not applicable) subject to specified maximum coverage distance (travel time or cost) between facilities *j* and supply/demand points *i*, both located within a limited space and corresponding to the Minimum Covering Problem [Boonmee et al., 2017; Berman et al., 1996].

$$\min_{x_j \in X, y_{ij} \in Y} \sum_{i \in I} \left[\sum_{j \leftrightarrow d_{ij}(x_j) \leq D} \sum_{i \in I} y_{ij} \middle/ \left(1 + \sum_{j \leftrightarrow d_{ij}(x_j) \leq D} \sum_{i \in I} y_{ij} \right) \right] \tag{13a}$$

subject to:

$$\sum_{j \in J} y_{ij} \geq 1 \quad \forall i \in I \tag{13b}$$

and optionally to:

$$\sum_{j \in J} \left[\sum_{i \in I} y_{ij} \middle/ \left(1 + \sum_{i \in I} y_{ij} \right) \right] = P \tag{13c}$$

Maximized number of supply/demand points *i* (14a) **uncovered,** (partially uncovered not applicable) subject to specified minimum (un)coverage distance (travel time or cost) between facilities j and supply/demand points i, both located within limited space and corresponding to the Minimum Covering Problem. To the best of the author's knowledge, it is a new one FLP model, not reported in the literature so far.

$$\max_{x_j \in X, y_{ij} \in Y} \quad |I| - \sum_{i \in I} \left[\sum_{j \leftrightarrow d_{ij}(x_j) \le D} \sum_{i \in I} y_{ij} \Big/ \left(1 + \sum_{j \leftrightarrow d_{ij}(x_j) \le D} \sum_{i \in I} y_{ij}\right) \right] \tag{14a}$$

subject to:

$$\sum_{j \in J} y_{ij} \ge 1 \quad \forall i \in I \tag{14b}$$

and optionally to:

$$\sum_{j \in J} \left[\sum_{i \in I} y_{ij} \Big/ \left(1 + \sum_{i \in I} y_{ij}\right) \right] = P \tag{14c}$$

And finally, there are also two other ways of formulating objective functions in the FLP mentioned by Boloori Arabani and Farahani [2012] in their survey paper. They are the profit maximization and risk minimization ones. But even these authors comment on profit maximization, that it is an objective that has received less attention in the literature, and give no examples of its applications. Whereas risk minimization if mentioned, the only context is the multicriteria formulation of the FLP. In the multicriteria context according to Farahani, Steadie Seifi and Asgari [2010], environmental and social objectives based on energy cost, land use and construction cost, congestion, noise, quality of life, pollution, fossil fuel crisis, and tourism are becoming customary. But, as the authors plainly expressed, one of the most important difficulties in tackling these problems is to find a way to measure such criteria.

For some further surveys of the FLP models see, for example, Turkoglu and Genevois [2020], Mangiaracina et al. [2015], Bruno et al. [2014], Farahani et al. [2014], Hale and Moberg [2003] or Eiselt and Laporte [1995].

Regarding supply chains and storage facilities, for example, warehouses, distribution and logistics centers location many, specific criteria are taken into account, such as technical (including road network density, number of potential contractors, storage infrastructure) and economic (including capital expenditures, annual operating costs) ones [Kauf and Laskowska-Rutkowska, 2019]. And, as the cited authors conclude, usually, however, the choice of location for a logistics center boils down to finding the lowest costs; thus, economic factors are given priority.

FLP MODELS CLASSIFICATION AND COMPARISON

Based on the survey of FLP models presented in the previous section, the following classification of a generic objective function utilized in a majority of the FLP formulations is proposed. The notation is based on two standard mathematical symbols: x <• y meaning that x is covered by y and ¬ a logical negation, meaning that it does not, does not exist, and also assuming that i represents supply/demand points and j, j' ($j \neq j'$) represent facilities:

- **Min *Dij*** – Minimized distance D (or time, cost) between i and j (Eqs. 5a–e).
- **Max *Dij*** – Maximized distance D (or time, cost) between i and j (Eqs. 11a–g).
- **Min *Djj'*** – Minimized pairwise distance D (or time, cost) between j and j' (Eqs. 6a–h).

- **Max *Djj'*** – Maximized pairwise distance *D* (or time, cost) between *j* and *j'* (Eqs. 12a–h).
- **Min *Ni<·j*** – Minimized number *N* of *i* covered by *j* (Eqs. 13a–c).
- **Max *Ni<·j*** – Maximized number *N* of *i* covered by *j* (Eqs. 8a–g).
- **Min *N¬i<·j*** – Minimized number *N* of *i* uncovered by *j* (Eqs. 9a–g).
- **Max *N¬i<·j*** – Maximized number *N* of *i* uncovered by *j* (Eqs. 14a–c).
- **Min *Nj·>i*** – Minimized number *N* of *j* required to cover *i* (Eqs. 7a–d).
- **Min *Cij*** – Minimized (total) cost *C* of serving *i* by *j* (Eqs. 10a–c).

The above objective function types have been confronted with possible fields of their applications, or in the other words, types of facilities to be located, identified based on the cited in this paper literature, that are:

- **C** – Correctional (e.g. prisons, jails).
- **CI** – Chemical Industry (e.g. chemical plants).
- **E** – Educational (e.g. kindergartens, primary schools, high schools, libraries).
- **EDS** – Express Delivery Services (e.g. courier deliveries, food deliveries).
- **EI** – Energy Industry (e.g. nuclear reactors / power plants, oil storage tanks, filling stations).
- **ES** – Emergency Services (e.g. fire stations, EMS – Emergency Medical Service / EMT – Emergency Medical Technician centers, EMS/EMT ambulances/vehicles).
- **F** – Financial Services (e.g. banks).
- **HS/RF** – Humanitarian Services / Relief Facilities (e.g. shelters, storage of emergency food, water, medicine and other supplies).
- **HSC** – Health Care Services (e.g. infirmaries, clinics, hospitals).
- **M** – Military (e.g. ammunition dumps).
- **PDT** – Production-Distribution-Trade (e.g. factories/plants, warehouses / distribution centers, retail shops / outlets – demand side).
- **T** – Telecommunication (e.g. concentrators, routers, terminals).
- **TH** – Transport Hubs (e.g. airports).
- **T&S** – Trade and Services (e.g. retail shops / outlets, franchises, restaurants – supply side).
- **WD** – Waste Disposal (e.g. landfills / garbage dumps, recycling sites, waste disposal plants, wastewater treatment plants).

However, given that the above examples of facilities are solely those mentioned directly in the cited literature, the applications of the analyzed objective functions can concern many more similar facilities as well.

Tab. 1 presents typical fields of application (types of facilities) of particular objective function types utilized in the FLP models, distinguishing the Desirable (alluring), the Neutral (ambivalent), and the Undesirable (obnoxious) facilities. The Desirable and Undesirable facilities are more or less intuitively comprehensible. The exception could be filling stations classified into the EI group of facilities, thus the group of the Undesirable ones, whereas this particular type of the EI facilities is more similar to the Neutral ones. In turn, the Neutral (ambivalent) ones need some explanation. This type of facility, on the one hand, should be located close to supply, and especially demand points if only to shorten delivery time (e.g., in the light of the Same Day Delivery strategies) or to increase accessibility (access time); on the other hand, some features or side effects of their presence in a given location (e.g. any form of pollution, as air, noise, light, thermal, visual, …, but also increased traffic, especially of heavy duty vehicles), weigh in favor of locating them relatively far away from demand points (especially individual customers – B2C). The most problematic seem to be transport hubs (the TH facilities), covering mentioned above airports [Owen and Daskin, 1998], but also a variety of other facilities such as train or bus stations (or just stops) as well. Moreover, not only passenger transport facilities should be taken into consideration, but also freight transport including, for example, intermodal hubs or harbors too (or other similar to the PDT facilities).

Table 1. Types of facilities vs. types of objective functions utilized in the FLP models

	Facilities	**Objective functions** Min *Dij*	Max *Dij*	Min *Djj'*	Max *Djj'*	Min *Ni<·j*	Max *Ni<·j*	Min *N¬i<·j*	Max *N¬i<·j*	Min *Nj·>i*	Min *Cij*	**Elasticity ≈**
Desirable (alluring)	E	×					×	(×)		(×)	×	50%
	F	×					×	(×)		(×)	×	50%
	HS/RF	×					(×)	(×)		×		40%
Neutral (ambivalent)	EDS	(×)			(×)		(×)	(×)		(×)	×	60%
	ES	×					×	(×)		×		40%
	HCS	×					×	(×)		(×)	×	50%
	PDT	×			(×)		×	(×)		(×)	×	60%
	T		(×)		(×)		(×)	(×)		(×)	×	60%
	TH	×	×		(×)	×	(×)		(×)	(×)	(×)	80%
	T&S	(×)		×			×	(×)		(×)	(×)	60%
Undesirable (obnoxious)	C		×			×			(×)			30%
	CI		×			×			(×)			30%
	EI		×			×			(×)			30%
	M		×			×			(×)			30%
	WD		×			(×)			(×)			30%
Applicability ≈		60%	50%	10%	30%	40%	70%	60%	40%	70%	50%	

(×) applications possible according to the author, but not reported directly in the cited literature

Source: Own work based on [Boonmee et al., 2017; Farahani et al., 2014; Boloori Arabani and Farahani, 2012; Jayaraman, 1998; Owen and Daskin, 1998; Berman et al., 1996; Sridharan, 1995; Kuby, 1987].

It can be observed in Tab. 1 that the objective functions utilized to locate the Desirable and the Undesirable facilities are fully disjunctive. However, this is not the case, when the neutral facilities are considered. Here, many different objective functions are utilized in research and practice. Presented in Tab. 1 elasticity and applicability indicate if locating given type of facilities many or just very selected objective functions can be applied and, on the other hand, if a given objective function type can be utilized for many or just very selected types of facilities, respectively. Moreover, some of the objective functions are mutually opposing, thus divergent, or unanimous, thus convergent (see Tab. 2). Should such objective functions aim at completely different or exactly the same results, solutions of the FLP? It cannot be generally stated. However, the only criterion not positively or negatively connected with the other is the cost (Min *Cij*).

Tab. 3 presents a comparison of particular objective function types utilized in the FLP models being a component of such models and their other fundamental components such as decision variables and constraints. It can be observed that, on the one hand, independently of an objective function utilized, the models are very similar, on the other hand, they can concern, cover different versions of the FLP, including the continuous (ConFLP) and discrete (DisFLP), the single-sourcing (SSFLP) and multi-sourcing (MSFLP), and also the uncapacitated (UFLP) and capacitated (CFLP) ones.

Table 2. Cross-comparison of the types of objective functions utilized in the FLP models

	Objective functions									
Objective functions	Min *Dij*	Max *Dij*	Min *Djj'*	Max *Djj'*	Min *Ni<·j*	Max *Ni<·j*	Min *N¬i<·j*	Max *N¬i<·j*	Min *Nj·>i*	Min *Cij*
Min *Dij*	=	≠				≈	≈			
Max *Dij*	≠	=			≈			≈		
Min *Djj'*			=	≠	≈			≈		
Max *Djj'*			≠	=						
Min *Ni<·j*		≈	≈		=	≠		=		
Max *Ni<·j*	≈				≠	=			=	
Min *N¬i<·j*	≈						=	≠	=	
Max *N¬i<·j*		≈	≈		=		≠	=		
Min *Nj·>i*						=	=		=	
Min *Cij*										=

= unanimous (identical) ≈ unanimous (similar) ≠ opposite

Source: Own work based on [Boonmee et al., 2017; Farahani et al., 2014; Boloori Arabani and Farahani, 2012; Owen and Daskin, 1998; Jayaraman, 1998; Berman et al., 1996; Sridharan, 1995; Kuby, 1987].

Table 3. Components of FLP mathematical models vs. types of objective functions utilized in them

	Objective functions									
Other components of FLP models	Min *Dij*	Max *Dij*	Min *Djj'*	Max *Djj'*	Min *Ni<·j*	Max *Ni<·j*	Min *N¬i<·j*	Max *N¬i<·j*	Min *Nj·>i*	Min *Cij*
Location decision variables – x_j	D/C	D/C	D/C	D/C	D/C	D/C	D/C	D/C	D/C	D/C
Assignment decision variables – y_{ij}	ℝ/B	ℝ/B	ℝ/B	ℝ/B	ℝ/B	ℝ/B	ℝ/B	ℝ/B	ℝ/B	ℝ/B
Capacity constraints	×/–	×/–	×/–	×/–	×/–	×/–	×/–	×/–	×/–	×/–
Demand satisfaction constraints	×	–	×	×	×	×	×	×	×	×
$\sum_{j \in J} y_{ij}$	= 1	–	= 1	≤ 1	= 1	≤ 1	≤ 1	= 1	= 1	= 1
Number of facilities constraints	×/–	×/–	×/–	×/–	×/–	×/–	×/–	×/–	–	×/–
in relation to P	≤/=	=/≥	≤/=	=/≥	=	≤/=	≤/=	=	–	≤/=

D discrete C continuous ℝ real B binary × obligatory – not applicable ×/– optional

Source: Own work based on [Boonmee et al., 2017; Farahani et al., 2014; Boloori Arabani and Farahani, 2012; Jayaraman, 1998; Owen and Daskin, 1998; Berman et al., 1996; Sridharan, 1995; Kuby, 1987].

The analytical elements of the FLP mathematical models can be distinguished as obligatory and optional components. The obligatory one is the assumption that a set of demand points, their number, location, and demand are known a priori. Whereas the optional four are: the location space (continuous or discrete), the number of facilities to be located (given or any), their capacity (constrained or not) and fixed costs (included or not). It is fundamental to know how these components (or lack of them in a model) influence the solution of the FLP defined by the number of facilities located. Based on Tab. 4 it can be concluded that the crucial is either the number of facilities to be located or their fixed costs, whereas the capacity and the location space are the secondary ones and thus can be optional. It makes the facility fixed costs a very important parameter of the FLP models, but still optional. The number of facilities to be located has to be flexible (given or maximal), whereas, their capacity limitations remain optional.

Table 4. Passible solutions of the FLP (i.e., the number of facilities located) as a result of its model's components

Facility capacity	**Number of facilities to be located**						**Facility fixed costs**
	given (exact)		given (max)		any		
constrained (capacitated)	all	all	all	all	as many as demand points	as many as demand points	not included
constrained (capacitated)	all	all	many (one to all)	many (one to all)	many (one to the number of demand points)	many (one to the number of demand points)	included (fixed charged)
unconstrained (uncapacitated)	all	all	all	all	as many as demand points	as many as demand points	not included
unconstrained (uncapacitated)	all	all	many (one to all)	many (one to all)	many (one to the number of demand points)	many (one to the number of demand points)	included (fixed charged)
	continuous	discrete	continuous	discrete	continuous	discrete	
	Facility location space						

Source: Own work.

CONCLUSIVE REMARKS

The FLP mathematical models are relatively similar as far as their components are considered (see Tab. 3). However, the small differences in the models are important and strongly influence possible results (solutions of the FLP) and to some extent a solution process as well. The most crucial element of the FLP models influencing their applicability is an objective function. It decides mostly if the model can be applied to locate the Desirable, the Neutral, or the Undesirable facilities. The less unanimous or similar to the other of analyzed objective functions analyzed turned out to be the Minimized (total) cost *C* of serving (supply/demand points) *i* by (facilities) *j* function (Min *Cij*). Moreover, this type of objective functions can be formulated in many different ways taking into account specific features of a particular FLPs, which is important in case of an optimal logistics or physical distribution networks design. And to locate an appropriate number of facilities, not all allowed or as many as demand points by assumption, it is necessary to include facility fixed costs into the FLP model. The other model components are much more flexible here, i.e. facilities can be capacitated or not, and the location space can be discrete or continues.

Comparing this research with the three most similar, recent and comprehensive ones [Turkoglu and Genevois, 2020; Mangiaracina et al., 2015; Farahani et al., 2014] it can observed that the FLP models are mostly quantitative, including optimization, but also simulation ones. The remaining ones, that is, 1/7 are conceptual or empirical, including case studies. The same proportion can be observed concerning the types of objective functions. Here, mostly used is the minimized cost being the most flexible criterion, as pointed out in this research. The remaining ones, as previously 1/7, are profit maximization, that is, still economic criterion including in fact costs, also service level and the other mixed quantitative and qualitative criteria when Multi-objective functions are applied, however, they are applied quite rarely. And, however, the facility fixed costs are not always directly pointed out, the most crucial factor affecting distribution costs is the demand level influencing capacity of facilities. In turn the capacity affects the total distribution costs by the economies of scale, that is, nothing but the fixed cost. Among the most widely considered objectives, in addition to costs and profits, are also maximization of the demand coverage or number of customers served, the minimization of customer travel distance, waiting time or cost, and also the minimization of the number of facilities. It can be concluded that the results of this research stay in accordance with the three compared ones; however, this research is both more mathematically oriented and wider, i.e., covers much more higher number of facility types. And thus, it makes the comparison done in this research, that is, the survey of models not the literature, much more comprehensive and, hopefully, useful.

The passible solutions of the FLP were only qualitatively analyzed in this research. Thus, further works will be to implement selected of the discussed in this paper FLP mathematical models in the OPL (Optimization Programming Language) and analyze them qualitatively by solving with the use of the IBM ILOG CPLEX Optimization Studio software for a selected, different, and specific instances of the FLP. All this still concerning supply chain perspective.

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ORIGINAL PAPER

OPTIMIZATION OF STOCHASTIC PRODUCTION-INVENTORY MODEL FOR DETERIORATING ITEMS IN A DEFINITE CYCLE USING HAMILTON-JACOBI-BELLMAN EQUATION

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ABSTRACT. Background: Inventory control is essential for a manufacturer to achieve the desired profit in successful supply chain management. This paper deals with the production-inventory system under the decrease in production rate. The model includes three stages: before the decrease in production, after the decrease in production, and after a period of inventory shortage. Throughout the stages, the stochastic inventory model is always affected by random factors and the deterioration of inventory quality.
Method: The article uses the economic order quantity (EOQ) framework to evaluate costs in the production-inventory model. To optimize the manufacturer's profit with the stochastic factor, Hamilton–Jacobi–Bellman (HJB) equation is presented to find the production rate to make the inventory model to guarantee its intended goals in a determined cycle.
Result: Analytical solutions are provided for optimization of the stochastic production-inventory model. Numerical experiments show that inventory level, production rate, and profit over time are based on the optimal initial value of the production rate.
Conclusion: The manufacturer's profit comes from the stages of importing raw materials, processing and producing, storing and supplying items. Finding the initial value of the production rate can make the inventory level and production rate to ensure their desired value and get the target profit within a specified time.

Keywords: Production inventory model, deteriorating items, stochastic optimal control, HJB equation

INTRODUCTION

In commerce, inventory is *a valuable collection of assets* of a manufacturer. By keeping the *optimal stock* levels, the company operates continuously and independently. As illustrated in Figure 1, production-inventory management is *crucial* processes for any business because it can help manufacturers adjust production strategies to ensure business success and *profitability*. Manufacturers want to produce the right amount of goods based on customer demands that generally change over time. In addition, the production rate depends on the quantity of raw materials imported from outside sources. In general, each manufacturer will have the desired production rate and inventory levels targets to guarantee adequate supply to customers and keep businesses running smoothly.

In reality, many deterministic and random factors might affect the production-inventory system. Many items with short life cycles will *often deteriorate during storage* and the original quality will decline *or be lost*, leading to *a small amount of decay*. In a real-life inventory system, the deteriorating inventory is concerned with the marginal value of a commodity caused by damage, obsolescence, rust, humidity, spoilage, etc. The deterioration rate can be equivalent to the maximum useful life of the product. The deteriorating inventory model is widely employed to analyze food

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production, meat, and fast foods with short shelf life. The deteriorating inventory model has appeared for a long time and is becoming a serious *concern* for manufacturers. [Chung & Tsai, 2001] presented the deteriorating model with linear customer demand. [Chen & Lin, 2002] demonstrated the model with a normal distribution on soft life, inventory shortage, and continuous-time demand. Return of goods from the customer also has a significant effect on managing inventory levels. In addition, there will be delays in the supply of raw material *for the production process due to poor supply chain management, typically characterized by an* inability to predict demand. Transportation delays can also increase the related costs, resulting in negative impacts on overall profitability. According to [Hatipoğlu et al., 2022], the cost of flight delays is approximately $ 8.3 billion, and this also causes economic loss in the United States about $ 600 million per year. The impact of supply chain disruption is clearly seen in port congestion at the world's major container *ports* during the Covid-19 pandemic. Many countries have adopted lockdown measures to prevent the disease from spreading. Port congestion occurs due to shortages of maritime participants to handle containers imported into the seaports. The impact of port congestion will lead to difficulty in delivery and significantly to shipping delays and supply chain disruptions. Typically, there are several types of costs associated with inventory management, such as replenishment costs and maintenance costs [Krzyżaniak, 2022]. The economic order quantity (EOQ) is a good approach and highly appreciated method to evaluate total costs for efficient inventory management in the literature. This model mainly is intended to minimize the inventory costs such as ordering cost, holding cost, and shortage cost in business operation. [Jamal et al., 1997] proposed the EOQ inventory model for inventory management. [Wee et al., 2003] developed the EOQ model with a temporary sale price. [Li et al., 2015] used the Hamilton–Jacobi–Bellman (HJB) equation for optimal dynamic pricing in the stochastic inventory system. [Alshamrani, 2013] considered the HJB equation for optimizing the stochastic production–inventory model with deteriorating items. With effective inventory management, businesses would experience higher levels of profit with lower costs, guaranteeing an enhanced competitive advantage over others. Recently, many papers have been presented on the stochastic inventory model summarized in Table 1.

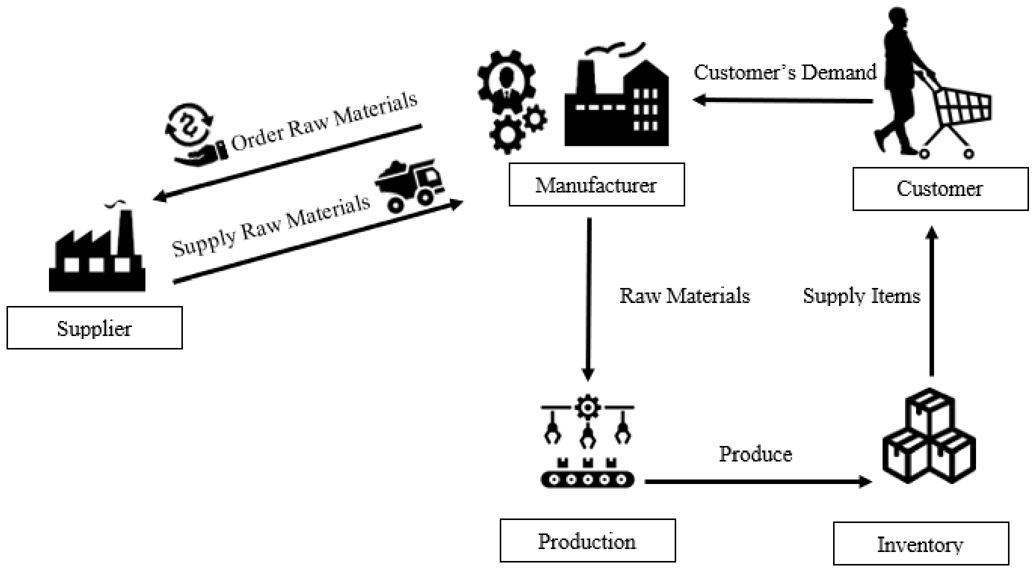

Fig. 1. Generic production–inventory model

Table 1. Literature review of the stochastic inventory model

Article	Deteriorating item	Number of stages in inventory model	Optimization method	Key findings
Li et al. (2015)	No	1	Hamilton-Jacobi-Bellman equation	Dynamic pricing and inventory control for a stochastic inventory system
Alshamrani (2013)	Yes	1	Hamilton-Jacobi-Bellman equation	Optimal expected production rate and expected inventory level
Soni & Suthar (2019)	Yes	3	Two-stage optimization procedure	Optimal price and replenishment cycle of the stochastic demand inventory model
This study	Yes	3	Hamilton-Jacobi-Bellman equation	Optimal initial production rate for the deteriorating inventory model

The main contents of this study are described as follows:

- By considering the deteriorating factor in stochastic production-inventory model, this study extends the model with decreasing coefficient in the production rate.

- The EOQ framework has been employed in the production-inventory model to evaluate costs.

- The optimization problem is analytically solved by the HJB equation, demonstrated by numerical simulations.

This paper is organized as follows. Section 2 provides a problem description in notation. Section 3 presents the production-inventory model and the optimal solution. The article employs the HJB equation to determine the initial production rate to optimize the total profit. Section 4 deals with numerical experiments to demonstrate the feasibility and efficacy of the proposed method. Finally, the conclusions are presented in Section 5.

NOTATIONS AND PROBLEM DEFINITION

This paper will deal with a deteriorating inventory model with a *decrease in supply*. Due to supply chain disruptions, any *delay* in the *receipt* of *raw materials* could affect the costs to order raw materials. When resources cannot be replenished in time, this will result in insufficient inventory level for customer demands, significantly impacting on manufacturer's profits. When there is a shortage of inventory, customers are more likely to cancel orders due to supply issues. Sometimes *customer* retention is less expensive than acquisition. *Rewarding customers* will become a staple of business scheme, by *providing* them with special services and attention, such as discounts, rebates, gifts, etc. In this study, it is assumed that inventory is deteriorating at the beginning of the cycle while customer demand constant. The objective is to find an optimal production-inventory policy to maximize company profit. In addition, this article employs the EOQ framework to evaluate the costs affected by the inventory model. For model development, the *notation* or *symbols are* described in Table 2.

Table 2. Notation of the production-inventory model

Variable	Definition	Unit
$D(t)$	Customer's demand rate at time t	Items/time
$u_1(t)$	Production rate in the interval $(0, t_1)$	Items/time
$u_2(t)$	Production rate in the interval (t_1, t_2)	Items/time
$u_3(t)$	Production rate in the interval (t_2, t_3)	Items/time
$u(t)$	Production rate at time t	Items/time
$I_1(t)$	Inventory level in the interval $(0, t_1)$	Items
$I_2(t)$	Inventory level in the interval (t_1, t_2)	Items
$I_3(t)$	Inventory level in the interval (t_2, t_3)	Items
γ	Decreased coefficient of production rate $0<\gamma<1$	Non-dimensional
u_d	The desired production rate	Items/time
I_d	The desired inventory level	Items
θ	Deteriorating rate of inventory level $0<\theta<1$	Non-dimensional
$dz(t)$	Stochastic variable (Weiner process)	Non-dimensional
σ	Diffusion coefficient	Non-dimensional
o	Ordering cost unit for 1 item	USD
h	Holding cost unit for 1 item	USD
s	Shortage cost unit for 1 item	USD
p	Price unit	USD
α	Increase the coefficient of ordering cost	USD
O	Ordering cost	USD
H	Holding cost	USD
S	Shortage cost	USD
TP	Total profit	USD

MODEL FORMULATION AND SOLUTION APPROACH

With problem descriptions, the behaviors of the inventory model can be categorized in three stages, as shown in Figure 2. Stage 1 is given in the time interval $(0,t_1)$, which is the period prior to inventory problems that cause a delay in the supply of raw materials by the suppliers. Stage 2 is described in the time interval (t_1,t_2). This is the specific period when suppliers are short of raw materials to deliver to manufacturers, and the cost of raw materials could also increase due to competition. The purchasing power of manufacturers will remain unchanged, but the source of raw materials might be decreased. The production rate decreases due to the shortage of production materials, the decreasing coefficient (γ) is used to represent the decrease in the production rate, and the unit price of raw materials will also increase, leading to an increase in ordering cost (O) with the increasing coefficient (α). The last stage is described in the interval (t_2,t_3) when production cannot produce the required number of items; there is a shortage of inventory. At this stage, some customers will continue to wait to receive the goods or try to cancel the orders. The customer cancels orders, leaving the manufacturer lose the opportunity to sell the product.

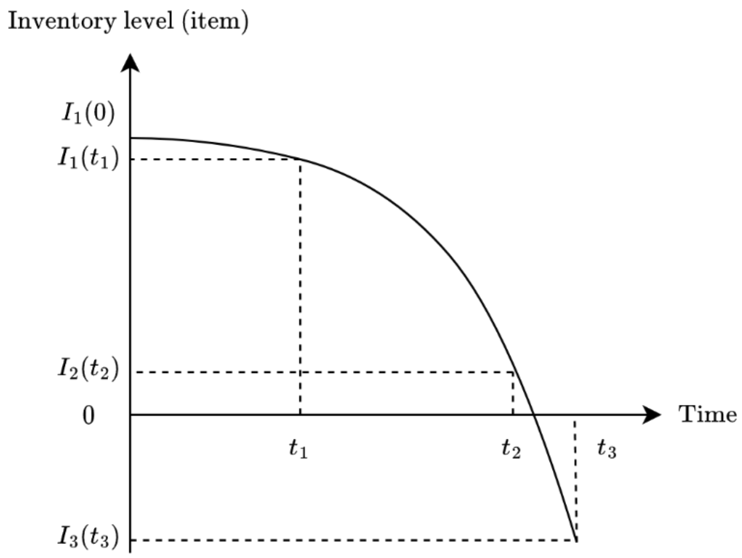

Fig. 2. Pattern of inventory level over time

Several unspecified factors that can influence inventory behavior, such as sales return, inventory spoil, machine breaking down, and human error [Li et al., 2015]. They can be lumped as a Weiner process, $dz(t)$, which is a real-valued *stochastic variable.* The inventory level can be described in terms of three stages:

$$dI = \begin{cases} dI_1 = \left[u(t) - D(t) - \theta I_1(t)\right]dt + \sigma dz(t), & 0 \le t \le t_1 \\ dI_2 = \left[\gamma u(t) - D(t) - \theta I_2(t)\right]dt + \sigma dz(t), & t_1 \le t \le t_2 \\ dI_3 = \left[\gamma u(t) - D(t) - \theta I_3(t)\right]dt + \sigma dz(t), & t_2 \le t \le t_3 \end{cases}$$

(1)

where $u(t)$ is the production rate at the time t and it depends on the inventory level at that time. For the interval $(0,t_1)$, there is no decrease in production so that $u_1(t)$, the production rate at stage 1, is equal to $u(t)$. In case of stage 2, the production rate is $u_2(t) = \gamma u(t)$ with $t \in (t_1,t_2)$ due to the decrease in production. Similar to stage 2, the stage 3 has the production rate $u_3(t) = \gamma u(t)$ with $t \in (t_2,t_3)$. The EOQ framework is used to evaluate the costs in the model. For the production-inventory model, there are two common types of costs: ordering cost (O) and holding cost (H). However, at stage 3, the inventory level is possibly negative. If the inventory goes negative, the manufacturer will lose a portion of the profit, which is called the shortage cost (S). The cost (O) includes costs for ordering raw materials and making the product. Manufacturers need to purchase raw materials from suppliers and the pay transportation cost and operation cost. The ordering cost will be based on the quantities of products, u is production rate and u_d is desired production rate. At the interval (t_1,t_3), there is an event that causes increased transportation costs, leading to an increase in the cost of ordering materials,

$$O=\int_0^{t_1} o\left(u-u_d\right)^2 dt+\int_{t_1}^{t_2} o\alpha\left(\gamma u-u_d\right)^2 dt+\int_{t_2}^{t_3} o\alpha\left(\gamma u-u_d\right)^2 dt \tag{2}$$

Items kept in warehouses *must be carefully stored* and managed to protect them from damage or loss while ensuring original quality. There are also warehouse maintenance costs and equipment maintenance fees. These costs are called holding cost (H) in the EOQ model,

$$H=h\left[\int_0^{t_1}\left(I_1-I_d\right)^2 dt+\int_{t_1}^{t_2}\left(I_2-I_d\right)^2 dt+\int_{t_2}^{t_3}\left(I_3-I_d\right)^2 dt\right] \tag{3}$$

The inventory levels in time intervals $(0,t_1)$, (t_1,t_2), (t_2,t_3) are described as I_1, I_2 and I_3 respectively. I_d is the desired inventory level. The shortage cost (S) occurs when the inventory is not enough for the customer demand *as a consequence of a stockout,*

$$S=\int_{t_2}^{t_3} k\left[s\left(-I_3\right)\right] dt \tag{4}$$

where k is a coefficient that depends on the sign of I_3. If $I_3 \le 0$, k will be equal to 1. Otherwise, k will be 0. The gross profit (TP) for the entire cycle T is given by deducting the costs from the total amount earned. To achieve maximum profitability, the research aims to find the initial value of the production rate so that the total cost incurred is zero to maximize profit. In this case, the revenue achieved will be the desired profit. The cycle T is the total time that will be given by, $T=t_3$. Then, the gross profit is described below,

$$\begin{aligned}
TP &= Desired\ profit+\int_0^{T}\left(-O-H-S\right)dt \\
&= B_1 p_1 I_1\left(t_1\right)+\int_0^{t_1}\left[-o\left(u-u_d\right)^2-h\left(I_1-I_d\right)^2\right]dt \\
&\quad B_2 p_2 I_2\left(t_2\right)+\int_{t_1}^{t_2}\left[pD-o\alpha\left(\gamma u-u_d\right)^2-h\left(I_2-I_d\right)^2\right]dt \\
&\quad B_3 p_3 I_3\left(t_3\right)+\int_{t_2}^{t_3}\left[pD-o\alpha\left(\gamma u-u_d\right)^2-h\left(I_3-I_d\right)^2+ksI_3\right]dt
\end{aligned} \tag{5}$$

where B_1, B_2, and B_3 are the profit rates and p_1, p_2, and p_3 are the price units of items. The objective functions for inventory levels are described in three separate stages:

$$J_1=\max\left\{\int_0^{t_1}\left[-o\left(u-u_d\right)^2-h\left(I_1-I_d\right)^2\right]dt+B_1 p_1 I_1\left(t_1\right)\right\} \tag{6}$$

$$J_2 = \max\left\{\int_{t_1}^{t_2}\left[-o\alpha\left(\gamma u - u_d\right)^2 - h\left(I_2 - I_d\right)^2\right]dt + B_2 p_2 I_2\left(t_2\right)\right\} \tag{7}$$

$$J_3 = \max\left\{\int_{t_2}^{t_3}\left[-o\alpha\left(\gamma u - u_d\right)^2 - h\left(I_3 - I_d\right)^2 + ksI_3\right]dt + B_3 p_3 I_3\left(t_3\right)\right\} \tag{8}$$

Let $V_1\left(I_1, t\right)$ denote the expected value of the objective function J_1 in the interval $\left(0, t_1\right)$ such that it satisfies Hamilton–Jacobi–Bellman (HJB) equation [Sethi & Thompson, 2000] described by,

$$0 = \max_{u(t)}\left\{\left[-o\left(u - u_d\right)^2 - h\left(I_1 - I_d\right)^2\right] + V_t + V_{I_1}\left[u - D - \theta I_1\right] + \frac{1}{2}\sigma^2 V_{I_1 I_1}\right\} \tag{9}$$

where,

$$V_t = \frac{\partial V_1}{\partial t},\ V_{I_1} = \frac{\partial V_1}{\partial I_1},\ V_{I_1 I_1} = \frac{\partial^2 V_1}{\partial {I_1}^2}$$

Taking a partial derivative of equation (9) with respect to u gives,

$$u = \frac{V_{I_1} + 2ou_d}{2o} \tag{10}$$

Substituting equations (10) into (9) yields

$$0 = -o\left(\left(\frac{V_{I_1} + 2ou_d}{2o}\right)^2 - 2u_d\frac{V_{I_1} + 2ou_d}{2o} + {u_d}^2\right) - h\left({I_1}^2 - 2I_d I_1 + {I_d}^2\right)$$
$$+ V_t + V_{I_1}\left[\frac{V_{I_1} + 2ou_d}{2o} - D - \theta I_1\right] + \frac{1}{2}\sigma^2 V_{I_1 I_1} \tag{11}$$

Let us consider the following set of conditions:

$$V\left(I_1, t\right) = Q_1 I_1^2 + R_1 I_1 + M_1 \tag{12}$$

$$V_{I_1} = 2Q_1 I_1 + R_1 \tag{13}$$

$$V_{I_1 I_1} = 2Q_1 \tag{14}$$

$$V_t = \dot{Q}_1 I_1^2 + \dot{R}_1 I_1 + \dot{M}_1 \tag{15}$$

Equation (12) provides the generic form of the expected value $V(I_1,t)$ in stage 1, $t\in(0,t_1)$. Q_1, R_1, and M_1 are variables which will be changed over time in stage 1. is the inventory level at time t of the period $(0,t_1)$. Substituting equations (12), (13), (14), and (15) into (11) gives

$$0=\left(\frac{Q_1^2}{o}-2Q_1\theta-h+\dot{Q}_1\right)I_1^2+\left(\frac{R_1Q_1}{o}+2hI_d+\dot{R}_1-2Q_1D-\theta R_1+2u_dQ_1\right)I_1$$
$$+\frac{R_1^2}{4o}+u_dR_1-hI_d^2+\dot{M}_1-DR_1+\sigma^2Q_1$$
(16)

Equation (16) provides all inventory levels, so that

$$\dot{Q}_1=-\frac{1}{o}Q_1^2+2\theta Q_1+h \qquad (17)$$

$$\dot{R}_1=\left(\theta-\frac{Q_1}{o}\right)R_1+\left(2Q_1D-2Q_1u_d-2hI_d\right) \qquad (18)$$

$$\dot{M}_1=-\frac{R_1^2}{4o}+R_1D-R_1u_d+hI_d^2-\sigma^2Q_1 \qquad (19)$$

At the time $t=t_1$, the moment at the beginning of the decline in production due to the lack of raw materials, the expected value of $V_1(I_1,t)$ at this time can be described by $B_1p_1I_1(t_1)$,

$$\begin{cases}Q(t_1)=0\\ R(t_1)=B_1p_1\\ M(t_1)=0\end{cases} \qquad (20)$$

Equation (17) can be solved as follows:

$$\begin{cases} Q_1 = \dfrac{a_1\left(y_1 - 1\right)}{y_1 - \dfrac{a_1}{b_1}} \\ y_1 = e^{\frac{b_1 - a_1}{o}\left(t_1 - t\right)} \\ a_1 = o\theta - o\sqrt{\theta^2 + \dfrac{h}{o}} \\ b_1 = o\theta + o\sqrt{\theta^2 + \dfrac{h}{o}} \end{cases} \tag{21}$$

In addition, equation (18) can be solved by

$$\begin{aligned} R_1 &= e^{-\int\left(\frac{Q_1}{o} - \theta\right)dt}\left[\int\left(2DQ_1 - 2Q_1 u_d - 2hI_d\right)e^{\int\left(\frac{Q_1}{o} - \theta\right)dt}dt + C_1\right] \\ &= \frac{\sqrt{y_1}}{y_1 + r_1}\left[\frac{\left(4D - 4u_d\right)a_1 o\left(y_1 + 1\right) - 4hI_d o\left(y_1 - r_1\right)}{\left(a_1 - b_1\right)\sqrt{y_1}} + C_1\right] \end{aligned} \tag{22}$$

where

$$\begin{cases} r_1 = -\dfrac{a_1}{b_1} \\ C_1 = \left(1 + r_1\right)B_1 p_1 - \dfrac{\left(8D - 8u_d\right)a_1 o - 4hI_d o\left(1 - r_1\right)}{a_1 - b_1} \end{cases} \tag{23}$$

According to Equation (10), the production rate in stage 1 is described by

$$u_1 = u = \frac{2Q_1 I_1 + R_1 + 2ou_d}{2o} \tag{24}$$

Similarly, the optimal production rates in the intervals $\left(t_1, t_2\right)$ and $\left(t_2, t_3\right)$ will be *discussed in the following.* The boundary conditions at stages 2 and 3 are, respectively, described below

$$\begin{cases} Q_2\left(t_2\right) = 0; \\ R_2\left(t_2\right) = B_2 p_2; \qquad t \in \left(t_1, t_2\right) \\ M_2\left(t_2\right) = 0; \end{cases} \tag{25}$$

$$\begin{cases} Q_3\left(t_3\right) = 0; \\ R_3\left(t_3\right) = B_3 p_3; \qquad t \in \left(t_2, t_3\right) \\ M_3\left(t_3\right) = 0; \end{cases} \tag{26}$$

The optimal production rate in the interval $\left(t_1, t_2\right)$ is described by

$$\begin{cases} u = \dfrac{2Q_2 I_2 + R_2 + 2o\alpha u_d}{2o\alpha\gamma} \\ u_2 = \gamma u = \dfrac{2Q_2 I_2 + R_2 + 2o\alpha u_d}{2o\alpha} \\ Q_2 = \dfrac{a_2\left(y_2 - 1\right)}{y_2 - \dfrac{a_2}{b_2}} \\ R_2 = \dfrac{\sqrt{y_2}}{y_2 + r_2}\left[\dfrac{\left(4D - 4u_d\right)a_2 o\alpha\left(y_2 + 1\right) - 4hI_d o\alpha\left(y_2 - r_2\right)}{\left(a_2 - b_2\right)\sqrt{y_2}} + C_2\right] \end{cases} \tag{27}$$

where

$$\begin{cases} y_2 = e^{\frac{b_2 - a_2}{o\alpha}\left(t_2 - t\right)} \\ a_2 = o\alpha\theta - o\alpha\sqrt{\theta^2 + \dfrac{h}{o\alpha}} \\ b_2 = o\alpha\theta + o\alpha\sqrt{\theta^2 + \dfrac{h}{o\alpha}} \\ r_2 = -\dfrac{a_2}{b_2} \\ C_2 = \left(1 + r_2\right)B_2 p_2 - \dfrac{\left(8D - 8u_d\right)a_2 o\alpha - 4hI_d o\alpha\left(1 - r_2\right)}{a_2 - b_2} \end{cases} \tag{28}$$

Then, the optimal production rate in the interval $\left(t_2, t_3\right)$ is given by

$$\begin{cases} u = \dfrac{2Q_3 I_3 + R_3 + 2o\alpha u_d}{2o\alpha\gamma} \\ u_3 = \gamma u = \dfrac{2Q_3 I_3 + R_3 + 2o\alpha u_d}{2o\alpha} \\ Q_3 = \dfrac{a_3\left(y_3 + 1\right)}{y_3 + \dfrac{a_3}{b_3}} \\ R_3 = \dfrac{\sqrt{y_3}}{y_3 + r_3}\left[\dfrac{\left(4D - 4u_d\right)a_3 o\alpha\left(y_3 + 1\right) - \left(4hI_d o\alpha + 2ks\right)\left(y_3 - r_3\right)}{\left(a_3 - b_3\right)\sqrt{y_3}} + C_3\right] \end{cases} \tag{29}$$

where

$$\begin{cases} y_3 = e^{\frac{b_3 - a_3}{o\alpha}(t_3 - t)} \\ a_3 = o\alpha\theta - o\alpha\sqrt{\theta^2 + \frac{h}{o\alpha}} \\ b_3 = o\alpha\theta + o\alpha\sqrt{\theta^2 + \frac{h}{o\alpha}} \\ r_3 = -\frac{a_3}{b_3} \\ C_3 = (1 + r_3) B_3 p_3 - \frac{(8D - 8u_d) a_3 o\alpha - (4hI_d o\alpha + 2ks)(1 - r_3)}{a_3 - b_3} \end{cases} \tag{30}$$

In this study, it is observed that analytical solutions with the closed forms are provided for the optimization of production-inventory model.

NUMERICAL EXPERIMENT

Numerical simulations are performed to verify the effectiveness of the proposed optimal solutions by controlling production rate and the level of inventory. Numerical analysis is performed using MATLAB environment on Microsoft Windows 10 Pro 64-bit computer, 16GB of RAM, AMD Ryzen 5 5600G processor with Radeon Graphics. Inventory management is an essential component to keep supply chains running smoothly. The experiment test scenarios are based on the stochastic inventory model with the annual cycle with a period of 1 year or 365 days. Manufacturers want to find an optimal production policy to meet the needs of the customer. Assume that the average demand rate is 200 items/day and the current inventory level is 200 items. The inventory level at each month is only 65% of the original balances due to a gradual decline in product quality over time. Production rate describes a manufacturer's ability to produce items over time. A part of the product will serve the demand of customers. The rest will be used to maintain inventory levels. In the numerical experiment, the desired production rate $u_d = 275$ items/day would be greater than the desired inventory level $I_d = 220$ items. For the first day of a period up to 150 days $(0, t_1)$, the dynamic model of the supply chain works with the deteriorating inventory system. For the next 90 days (t_1, t_2), there is an increase in the ordering costs for raw material and a decline in the production rate due to risk factors such as transportation, oil or gas prices, and scarcity of raw materials from suppliers. For the last 125 days (t_2, t_3), if the inventory is not enough for the demand (negative inventory), there will be a shortage cost. The experimental model parameters in this case are listed in Table 3. The parameters selected for numerical analysis are typical values for supply chain inventory management.

Table 3. Experiment parameters

Parameter	Value	Parameter	Value
$D(t)$	200 items/day	θ	0.35
$I(0)$	200 items	o	10 USD/item
u_d	275 items/day	s	30 USD/item
I_d	220 items	h	10 USD/item
γ	0.85	$p_1 = p_2 = p_3$	30 USD/item
α	1.15	$B_1 = B_2 = B_3$	1.5
σ	5		

Based on the above background, the stock levels of inventory in three stages are described in Figure 3. The test results show that the inventory valuation is managed to achieve the desired approximation rate $I_d = 220$ (items). Figure 4 illustrates the production rate, in which the model in three stages can be controlled to achieve the approximation of the target rate $u_d = 275$ (items/day). The manufacturer wants to begin the production rate at $u_1 = 291$ (items/day) to optimize the total profit of stage 1. Similarly, the initial production rates for stages 2 and 3 are $u_2 = 277$ and $u_3 = 277$ (items/day), respectively.

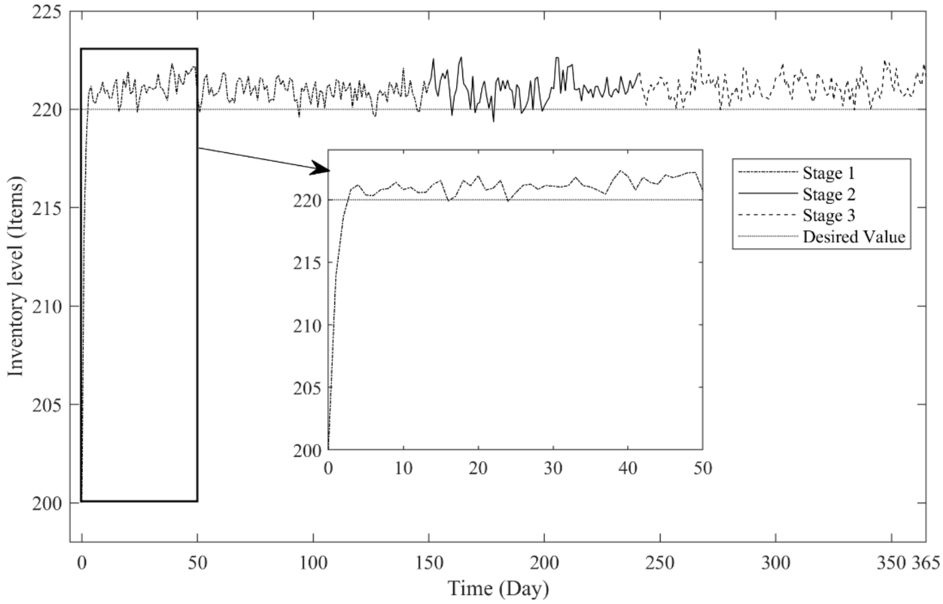

Fig. 3. Stock levels in stochastic inventory management

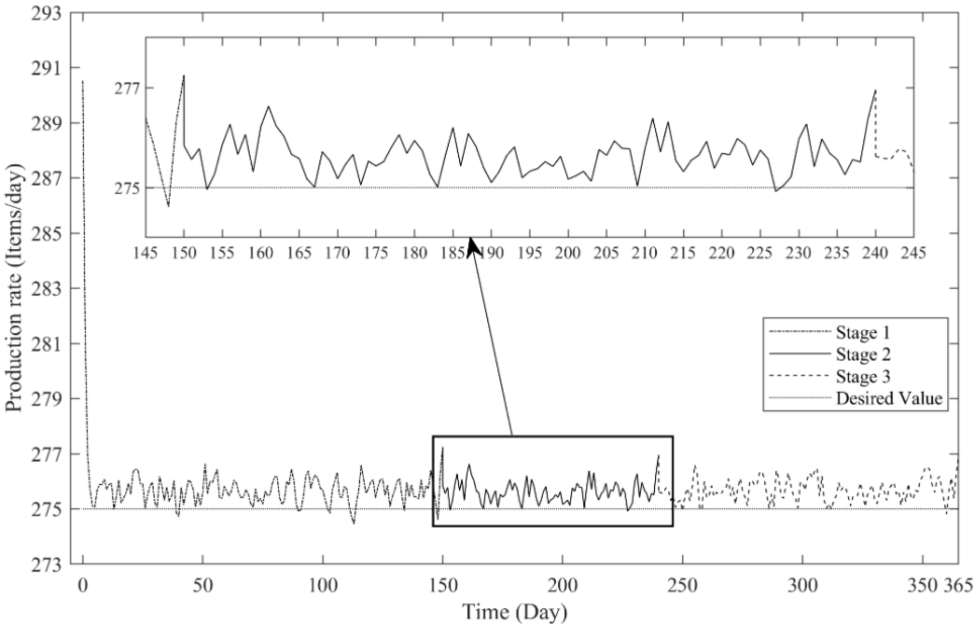

Fig. 4. Production rates of the inventory system

Figure 5 describes the profit of the production-inventory system. Profit depends on the value of the inventory level and the production rate. In this test, the profit rate in three stages is given by $B_1 = B_2 = B_3 = 1.5$. The price units of the items in three stages are $p_1 = p_2 = p_3 = 30$ USD. When the desired inventory level is given by 220 (Items), the desired profit can be given by

$$\text{Desired profit} = B_1 p_1 I_d = 9900 \text{ USD} \quad (31)$$

The values in Figures 3, 4 and 5 cannot be exactly the target rates due to the stochastic factors. However, after optimizing the inventory models, the values do not deviate too much from the target values.

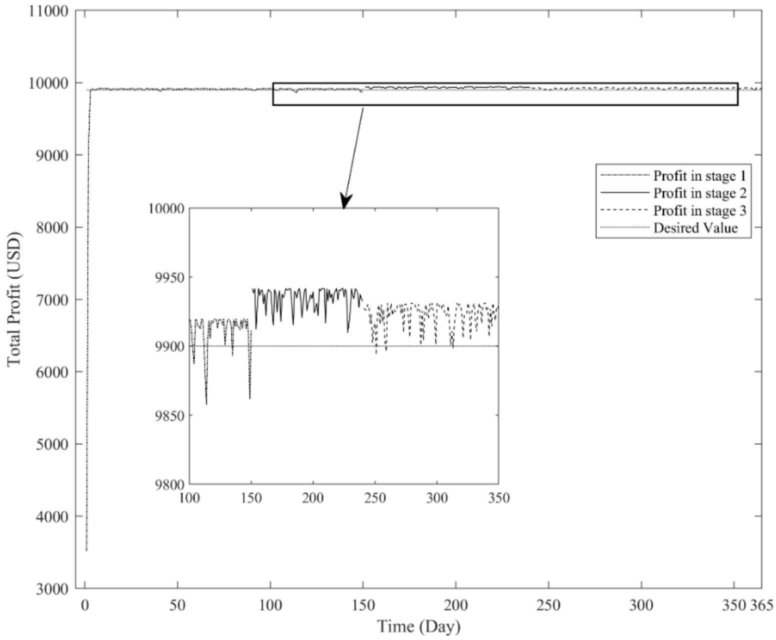

Fig. 5. Total profit in the production-inventory model

CONCLUSION

Efficient inventory management helps manufacturers determine the right production policy to achieve target profits. The manufacturer produces finished goods from raw materials and sells them to retailers or customers to gain *competitive* advantage over others. However, the production-inventory process requires certain costs. The economic order quantity (EOQ) framework with deteriorating item is employed to evaluate the costs in the production inventory model. For solving stochastic *optimal* control *problems*, the study presents the HJB equation to find the initial production rate for the stochastic deterioration model so that the manufacturer can get the desired inventory level, production rate, and profit. Inventory problems and initial production rates at three stages are demonstrated through experiment scenarios. The inventory level, production rate, and the total profit cannot exactly achieve the desired values due to the stochastic factors. However, the numerical experiment shows *that* their *differences* can be negligible by employing a novel inventory management scheme presented in this study. In addition, analytical solutions are provided for the optimization of the production-inventory model. Finally, the efficient inventory management policy will provide the necessary information for many important business decisions.

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ORIGINAL PAPER

CLOSED LOOP SUPPLY CHAINS AND CIRCULAR ECONOMY – THE POSSIBILITIES OF INTERPLAY

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ABSTRACT. Background: The concepts of closed loop supply chain and circular economy are both based on the introduction of circular flow of material goods. Both concepts are becoming increasingly important not only due to the significance of reducing negative environmental impacts, but also due to supply chain disruptions caused by the COVID pandemic and the Russian invasion of Ukraine. The aim of this article is to determine the role of closed loop supply chains in circular economy and to determine the possibilities of interplay regarding practical application of these concepts.
Methods: The research method used in this paper is the review of the existing literature. The reviewed literature is related to the areas of closed loop supply chains and circular economy. The study focuses not only on the possibilities of interplay between these two concepts, but also similarities, differences, and related operational concepts, such as slowing or intensifying loops of flows of material goods.
Results: The results concern the possibilities of interplay between closed loop supply chains and circular economy and possibilities related with building the closed loop supply chains in circular economy. One of such possibilities is building circular networks consisting of closed loop supply chains. It might include collaboration related to reducing the use, reusing, and recycling of material resources.
Conclusions: The main possibility of interplay between closed loop supply chains and circular economy is collaboration between actors of different supply chains aiming at building circular networks. The main research implication is providing a basis for further research related with building closed loop supply chains and circular networks in circular economy.

Keywords: circular economy; circular supply chains; circularity; closed-loop supply chains

INTRODUCTION

This article aims to determine the role of closed loop supply chains in circular economy. Both closed loop supply chains (or circular supply chains) and circular economy share the common purpose of reducing the use of resources by introducing their circular flow. The result of achieving this goal might be reducing the negative environmental impact. However, there are no comprehensive studies regarding the interplay between closed loop supply chains and circular economy.

Building closed loop supply chains is becoming increasingly significant in modern business due to the COVID pandemic and Russian invasion of Ukraine. Both might result in long-term supply chain disruptions. Hence, development of closed loop supply chains might reduce the use of raw materials, limit the dependence on international transport and mitigate the risk of such disruptions.

Closed loop supply chains

Both traditional (linear) supply chains consists of companies collecting natural resources, companies processing natural resources into semi-finished products, components and auxiliary materials, manufacturers of finished products and distribution companies (Witkowski, 2010).

However, the flow of finished goods in a closed-loop supply chain does not end after the usage stage. In a closed-loop supply chain used

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finished goods are transferred back to their manufacturer (or a different company) to recover them. It is called material recovery or end-of-life treatment (Moosmayer *et al.*, 2020, p. 174). If all products, components, semi-products and raw materials can be recovered, there is no need to landfill them.

There are several definitions of closed loop supply chain. According to Guide and Van Wassenhove (2009), closed loop supply chain is “The design and management of a system to maximize value creation over the entire lifecycle of a product with dynamic recovery of value from different types and volumes of returns over time”. Liu et al. (2012) define a circular supply chain as a supply chain "where care is taken of items once they are no longer desired or can no longer be used".

It should be noted, that according to the Guide and Van Wassenhove closed loop supply chain is design and management of a specific system, while according to Liu et al., it is a type of supply chain. On the other hand, Jain et al. (2018) distinguish two perspectives of closed loop supply chain: material perspective and production system perspective.

Taking into account the material perspective, a closed loop supply chain is "a supply chain in which materials are reused and recycled over and over again at the end of their useful life and there are minimal material wastes throughout the supply chain”.

According to the production system perspective, a closed loop supply chain is a production system that "must generate no solid, liquid and gaseous wastes, minimize use of toxic and hazardous chemicals, and run only on renewable energy”. It should be noted, that in some circumstances these two perspectives exclude each other. Reusing and recycling to some extent might generate waste and do not require using renewable energy. On the other hand, generating waste must not be related with emitting it, e.g. if the waste is recycled or converted to energy in-house.

Taking into account the above considerations, the definition of a closed loop supply chain can be following: a supply chain in which material goods are reused or recovered, there is no emission of solid, liquid or gaseous waste, use of toxic and hazardous materials is minimal and only renewable energy is used.

There are several material recovery activities to be distinguished, depending on the type of finished goods. Accordingly, used finished goods might be re-used, refurbished, remanufactured or recycled (Tundys, 2018). The closed loop supply chain scheme is presented in Fig. 1.

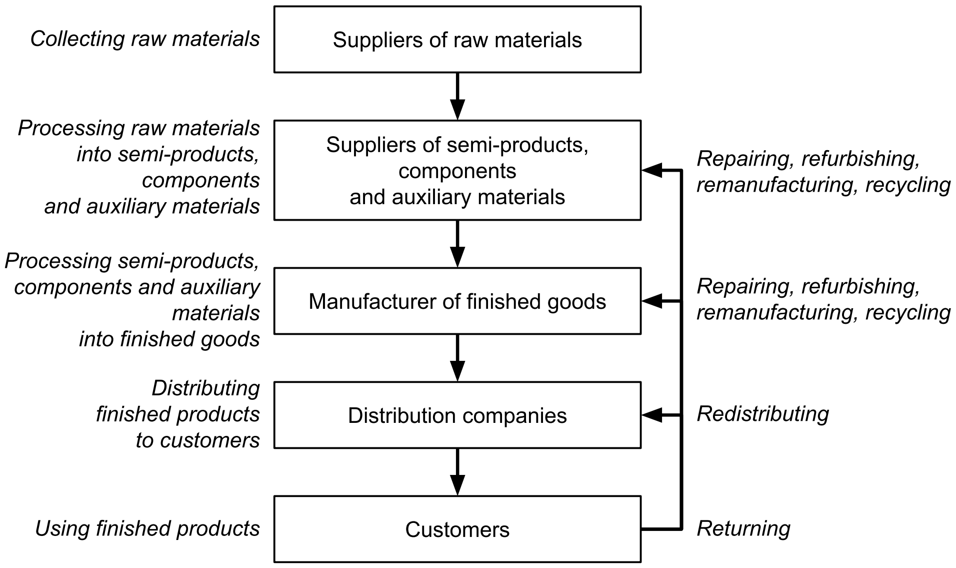

Fig. 1 Closed loop supply chain scheme

Source: own elaboration based on (De Giovanni and Zaccour, 2014; González-Sánchez *et al.*, 2020; Liu *et al.*, 2012).

Geyer and Jackson (2004) described three kinds of reprocessing activities, depending on the type of finished good: product reprocessing (e.g. IT devices, photocopy equipment), component reprocessing (e.g. electronic devices, automotive parts) and materials reprocessing (e.g. paper, glass, aluminium cans). Some of them might involve suppliers of manufacturers of finished goods.

Circular economy

As in the case of traditional supply chain, the flow of material resources in global economy is linear: raw materials are being processed into products that are distributed to end users and then consumed, therefore becoming a waste. Korhonen et al. (2018) describe economy as a growing subsystem of a shrinking parent system (environment). As long as economy is developing in unsustainable way, while natural resources are being depleted, the whole system is approaching a head collision. According to many national and international organizations, such as UNEP (2021) OECD (2021) European Commission (2020), one of possible solution to global environmental problems is introducing circular economy.

Kirchherr et al. (2017) analysed 114 definitions of circular economy and presented their own: "an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes"

On the other hand, Korhonen et al. (2018) proposed a following definition of circular economy: "an economy constructed from societal production-consumption systems that maximizes the service produced from the linear nature-society-nature material and energy throughput flow. This is done by using cyclical materials flows, renewable energy sources and cascading-type energy flows". Visualisation of circular economy is presented in Fig. 2.

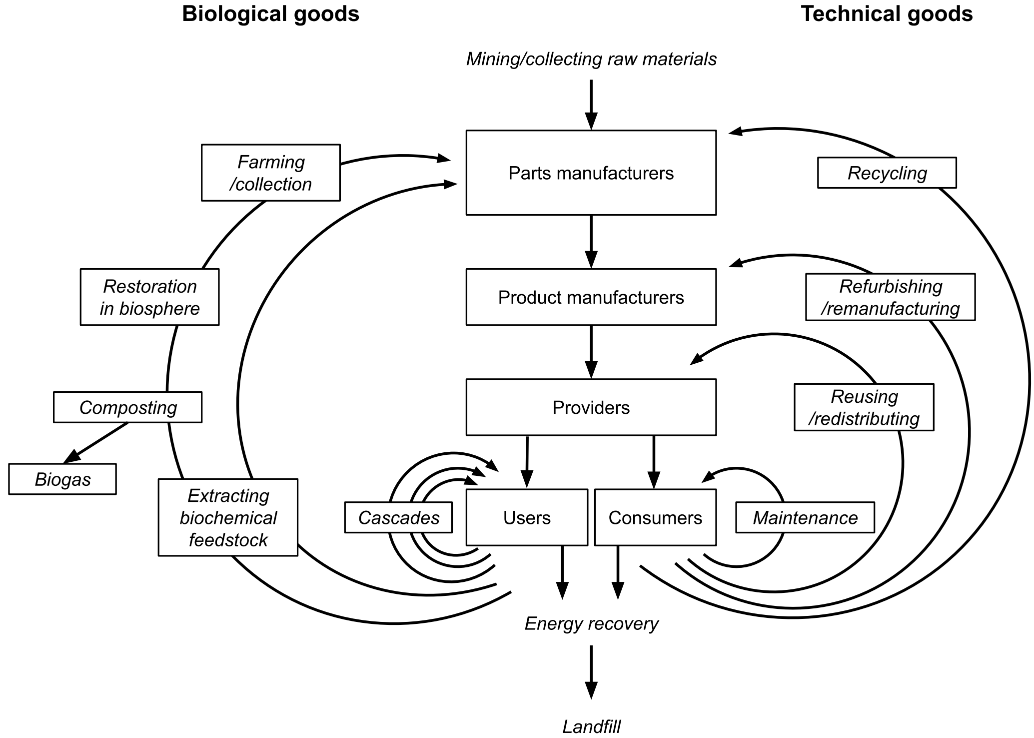

Fig. 2 Circular economy scheme
Source: own elaboration based on (Ellen MacArthur Foundation, 2014).

Similarities, differences and possibilities of interplay between closed loop supply chains and circular economy will be discussed later in this article.

RESEARCH METHODOLOGY

The study consisted of the following stages.

First, the initial literature review was conducted. It was aimed to establish the current state of literature related to areas of closed loop supply chains and circular economy. It included peer-reviewed articles, conference papers and book chapters. Second, the keywords for the main literature review were selected taking into account the results of the initial literature review. Next, the criteria for the literature selection were chosen. Then the main literature review was conducted. In the end, the results were discussed.

The results of the initial literature review are presented in the earlier chapters of this paper. To conduct the main literature review, SCOPUS was chosen as a research database. Based on the results of the initial literature review, the literature selection criteria were chosen.

Since the aim of this article is related to the closed loop supply chains and circular economy, these terms were taken into account. Other included term is circular supply chain.

After completing the list of keywords, the literature review selection criteria were chosen. This choice was based on works of other scholars related to the focal areas, especially Batista et al. (2018, p. 443). The list of criteria is given below:

1. The title, abstract or keywords of the publication contain “closed loop supply chain” or “circular supply chain” and contains “circular economy”.
2. The subject area is Business, Management and Accounting.
3. The language of the publication is English or Polish.
4. Document types taken into account are articles, reviews, books, book chapters and conference papers. Editorials and notes are excluded from the consideration.
5. Only sources in the final publication stage are taken into account. Articles in the press are excluded.
6. The publication is directly related to the area of sharing economy and/or circular supply chains.

The second criterion results from the research approach adopted, which is consideration of the focal concepts from a business perspective. There was no limit to the date of publication. The literature review was conducted in February of 2022. All found publications were in English. The chart describing the number of found publications per year is presented in Fig. 3.

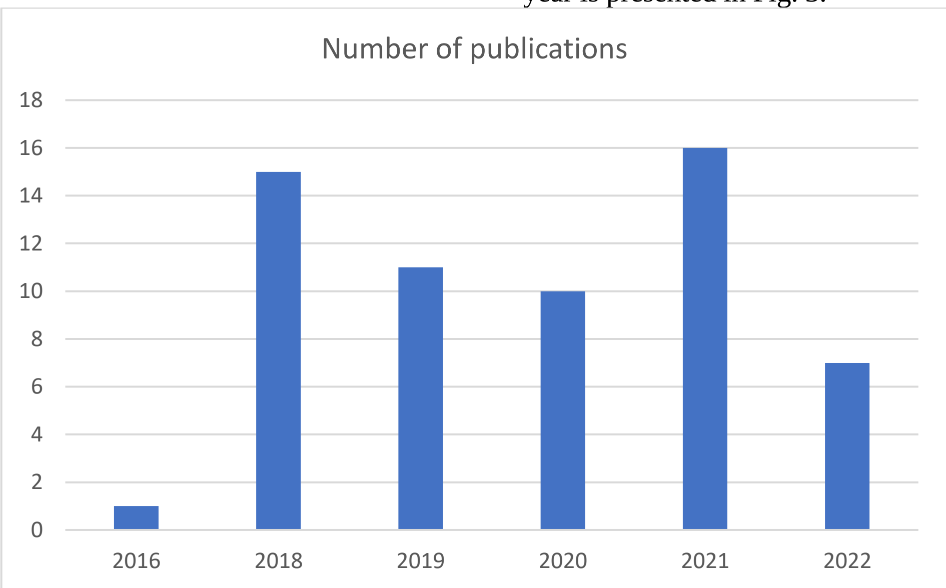

Fig. 3 Number of publications per year

It can be observed, that the number of publications related to the areas of closed loop supply chains and circular economy fluctuates slightly in recent years. However, there is only one publication on this topic older than 2018. It may indicate the growing importance of these topics for modern researchers.

The relevance of reviewed papers varies and they include such topics as collaboration between closed loop supply chains and building circular networks. The most important findings are described and discussed in the next section.

FINDINGS AND DISCUSSION

There are papers focusing on closed loops supply chains with reference to the circular economy (Mangla *et al.*, 2018; Sandvik and Stubbs, 2019). Some scholars describe building closed loop supply chains as a way to introduce circular economy (Kalverkamp and Young, 2019; Koszewska and Bielecki, 2020). However, there is a scarce of sources investigating directly the interplay between closed loop supply chains and circular economy.

Similar to the closed loop supply chain, the key activities related with circular economy are reducing the use, reusing and recycling of material resources (Kirchherr *et al.*, 2017).

As it is shown in Fig. 2, circular economy might be visualized in a relatively similar way as a closed loop supply chain (see: Ellen MacArthur Foundation, 2014). However, the circular economy is an economic system that includes all of its participants (e.g. farmers, product manufacturers, service providers, consumers, etc.). On the other hand, a closed loop supply chain is a group of companies and consumers, related with producing, distributing and using specific product or products (Weele, van, 2014).

Korhonen et al. (2018) based their definition of circular economy on societal production-consumption systems. It should be noted, that societal production-consumption systems include both companies and end-consumers, therefore they can be identified with supply chain actors.

Geissdorfer et al. (2018) described circular business model and listed operational concepts related with closing the loop of supply chain (see:

Table 1). The same concepts are consistent with the concept of circular economy.

Table 1 Characteristics of closed loop supply chain and circular economy

Characteristics	Closed loop supply chain	Circular economy
What is it?	A type of supply chain	A type of economic system
Does it include the circularity of material goods?	**Yes**	**Yes**
Operational concepts	**closing loops, slowing loops, intensifying loops, narrowing loops, dematerialising loops**	**closing loops, slowing loops, intensifying loops, narrowing loops, dematerialising loops**
Key activities	**Reducing the use, reusing and recycling of material resources**	**Reducing the use, reusing and recycling of material resources**
Main driving force	**Business, consumers**	Government, **business, consumers,** NGOs
Participants	Supply chain actors	Economic system actors
Does introducing this concept result in introducing the remaining concept?	Yes (provided, that “economy” can be applied to a single enterprise)	Not necessarily

Similarities are bolded

However, transition to a circular business model is related with several challenges, including customer behaviour related with understanding market for recirculated products, cost of operating circular business model compared to cost savings of product recovery (recoverable value), access to good quality returns and speed of technological progress (van Loon and Van Wassenhove, 2020).

Circular network

Introducing a circular economy concept in a supply chain does not necessarily leads to building a closed loop supply chain. Instead, it might result in adapting circular practices (e.g. recycling) in a facility of one supply chain actor (Leising *et al.*, 2018).

Nevertheless, some scholars study the interplay between closed loop supply chains and circular economy. The example of such interplay is the concept of circular supply chain management, defined by Farooque et al. (2019) as "Circular supply chain management is the integration of circular thinking into the management of the supply chain and its surrounding industrial and natural ecosystems. It systematically restores technical materials and regenerates biological materials toward a zero-waste vision through system-wide innovation in business models and supply chain functions from product/service design to end-of-life and waste management, involving all stakeholders in a product/service lifecycle including parts/product manufacturers, service providers, consumers, and users".

Therefore, circular supply chain management is an application of circular economy in supply chain management (not in a supply chain). It is significant for the focal topic, since a closed loop supply chain can be distinguished from a circular supply chain by the relationship with other supply chains. As Farooque et al. (2019) point out, circular supply chain collaborate with other supply chains in order to recover value from waste to achieve the goal of becoming a zero-waste supply chain.

Hence, the possibility of interplay between concepts of closed loops supply chain and circular economy is building a circular network from closed loop supply chains by collaboration between them, as shown in Fig. 4.

CIRCULAR NETWORK SCHEME

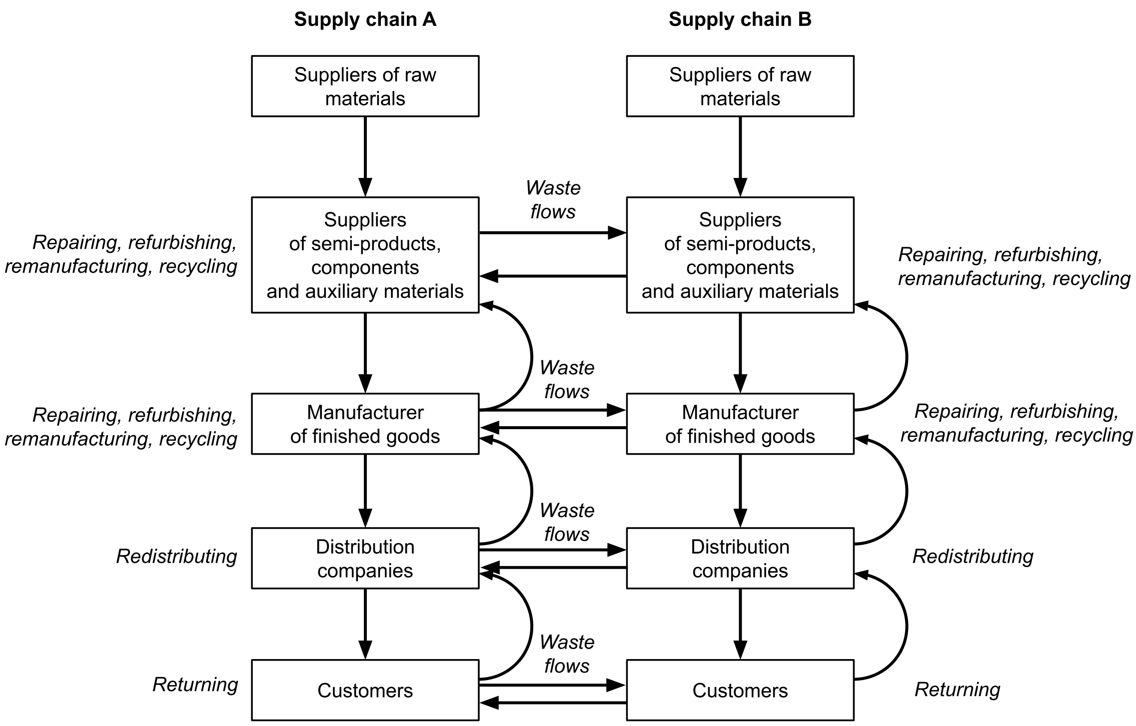

Fig. 4 Circular network scheme
Source: own elaboration based on (Farooque *et al.*, 2019; Leising *et al.*, 2018).

In such network, supply chain actors would collaborate in order to maximize the added value of waste recovery and to avoid landfilling. E.g. furniture manufacturers might collaborate with other furniture manufacturers (hence, actors from different supply chain) by selling wood waste that can be processed into furniture from recycled materials (FURN360, 2017), which might be more profitable on some markets compared to others. Similar possibility was suggested by Kalverkamp and Young (2019).

Other examples of practical application of closed loop supply chain include automotive supply chain (Kalverkamp and Young, 2019; van Loon and Van Wassenhove, 2018), textile supply chain (Sandvik and Stubbs, 2019), electric appliance supply chain (van Loon and Van Wassenhove, 2020), household appliance supply chain (van Loon and Van Wassenhove, 2020).

CONCLUSION

To summarize, the interplay between closed loop supply chain and circular economy is possible in form of collaboration between closed loop supply chains and building circular networks composed of closed loop supply chains. It might result in development of an economic system consisting of companies aiming at maximizing the resource utility and minimizing the emission of waste that cannot be recovered.

Collaboration between closed loop supply chains in order to build circular networks might include environmental cooperation and collaboration with suppliers (Sosnowski, 2019) and conducting environmental supplier evaluation (Sosnowski, 2022).

IMPLICATIONS FOR BUSINESS

The main implication related with focal topic for business is building relationships with business partners. It includes not only suppliers and clients, but also companies with similar profile to ours. Due to the global pandemic and ongoing war between Ukraine and Russia it might be beneficial to seek cooperation opportunities related with material recovery even with direct competitors.

IMPLICATIONS FOR GOVERNMENT

The main implication for government is providing opportunities for both domestic and international cooperation between companies aiming at profitable material recovery. Such opportunities might include simplifying legal regulations regarding trade and transport (including transit) of used products and materials to be recovered.

It might enable building circular networks and stimulate value recovery.

RECOMMENDATIONS FOR FUTURE RESEARCH

The main recommendation for future research is conducting a study regarding building closed loop supply chains taking into account activities related with material recovery. Results of such study might provide insights on determinants of building closed loop supply chain from business perspective. Furthermore, future research should take into account the circumstances of the COVID pandemic and possible supply chain disruption related with Russian invasion of Ukraine.

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ORIGINAL PAPER

DETERMINING THE LOGISTICS MARKET PERFORMANCE OF DEVELOPING COUNTRIES BY ENTROPY AND MABAC METHODS

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ABSTRACT. Background: The levels of logistics market performance of developing countries are published with Agility Emerging Markets Logistics Index (AEMLI) reports. The main purpose of this research is to propose a new model to determine the logistics market performance of developing countries in 2022 and to reorder the developing countries according to their logistics market performance.

Methods: AEMLI indicators have been accepted as the basic criteria for determining the logistics market performance. The importance levels of these criteria have been determined by the Entropy technique. The logistics market performance rankings of developing countries according to the criteria were determined using the Multi-Attributive Border Approximation Area Comparison (MABAC) technique. The data set of 50 developing countries included in the 2022 AEMLI report has been used in the investigation.

Results: According to the proposed new model, the weights of the criteria and logistics market performance rankings of developing countries have been determined. The importance levels of the criteria have been determined as Business Fundamentals (BF), Digital Readiness (DR), International Logistics Opportunities (ILO), and Domestic Logistics Opportunities (DLO), respectively. The ranking based on the new model was compared with the rankings in the 2022 AEMLI report. 21 of the 50 developing countries have improved their rankings. The ranking of 20 countries has been dropped. There is no change in the ranking of 9 countries. Additionally, according to AEMLI, the country with the highest logistics market performance is China, while the country with the best logistics market performance according to the proposed model is the United Arab Emirates (UAE).

Conclusions: Contrary to the literature, Entropy and MABAC techniques were used to rank the logistics market performances of developing countries by making use of AEMLI reports. The issues that countries should focus on in the development of their logistics market performance are shown.

Keywords: Logistics market performance, Developing countries, Entropy, MABAC, MCDM

INTRODUCTION

Logistics and transportation activities are among the important building blocks that enable the realization of global trade [Martí et al., 2014]. Logistics becomes sustainable by creating its own market structure in global trade. Today, global logistics markets are growing and becoming more effective day by day [Doll et al., 2014]. Especially the openness to commercial and logistics development of developing countries makes these countries attractive in terms of logistics market. The geographical, political, cultural, and commercial structure of developing countries plays an active role in the logistics market structure. Therefore, differentiations occur in the logistics market performance of developing countries. This differentiation also changes the impact of logistics performance on international trade [Zaninović et al., 2021]. Furthermore, logistics performance has a significant correlation with macro variables such as global competitiveness [Çemberci et al., 2015], gross domestic product [Uca et al., 2015], corruption [Uca et al., 2016], economic growth [Çelebi et al., 2015].

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Research is carried out to determine and rank the logistics performances of countries. Logistics performance index (LPI) was developed by the World Bank. In the literature, there are many studies that use LPI. The Agility Emerging Markets Logistics Index (AEMLI) was developed to determine the logistics performance of developing countries. AEMLI has been presenting the logistics performance of developing countries on a regular basis every year since 2011. Contrary to LPI, there are few studies using AELMI [Beysenbaev, 2018; Beysenbaev & Dus, 2020; Shestak et al., 2021; Kara, 2022]. The main purpose of this research is to propose a new model, considering the indicators used in the AEMLI reports, which give the logistics market performance and rankings of developing countries. It is also aimed to rank the developing countries of the proposed new model according to their logistics market performances and to compare them with their rankings in AEMLI reports.

Entropy and Multi-Attributive Border Approximation Area Comparison (MABAC) techniques are used to determine the logistics market performance of developing countries. It aims to determine the importance levels of the AELMI indicators based on these techniques and to determine the logistics market performance of developing countries accordingly. For these purposes, in the remainder of the article, a literature review on which MCDM techniques are applied in determining the logistics performance of countries is presented. Then, Entropy and MABAC techniques are explained in the methodology section. In the application part, findings are presented based on the AEMLI data set and indicators. In conclusion, the rankings of the proposed model are compared with the AEMLI rankings.

LİTRETURE REVİEW

Logistics performance is among the main indicators that play an active role in the commercial activities of countries and have a significant correlation with country trade data [Beysanbaev, 2018]. In the literature, efforts are made to determine the logistics performance of countries. Logistics performance index (LPI) and Agility Emerging Markets Logistics Index (AEMLI) are among the indexes developed because of these efforts. LPI is based mainly on survey research. In this context, logistics cost, customs procedures, and investment opportunities of the countries are considered [Martí et al., 2014]. AEMLI is also based on survey-based research. However, it focuses only on the evaluation of the logistics market performance of emerging markets. In this context, *domestic logistics opportunities*, *international logistics opportunities*, *business fundamentals* and *digital readiness* levels of countries are considered (AEMLI, 2022). There are suggestions in the literature that claim that it is necessary to develop LPI [Beysenbaev and Dus, 2020]. At the same time, there are studies in the literature to improve the LPI index [Martí et al., 2017; Rezai et al., 2018]. Additionally, there are steps to develop different indices by using the LPI index [Lu et al., 2019].

Rezai et al. [2018] suggested that LPI scores of countries can be re-determined by determining the importance levels of LPI indicators. In this study, the importance level of the indicators was calculated with the Best Worst method by taking the opinions of 107 experts. There are changes in the LPI scores and rankings of the countries according to the determined importance levels. Criticizing the equal importance of the LPI criteria published by the World Bank, Ulutaş and Karaköy [2019a] suggested that the curvature of the criteria may be different. In this study, the weights were determined using Step-Wise Weight Assessment Ratio Analysis (SWARA) and Criteria Importance Through Intercriteria Correlation (CRITIC) multi-criteria decision making techniques. In addition, the LPI scores of the European Union countries have been redetermined. It has been determined that there are differences between the results obtained and the LPI scores.

Mešić et al. [2022] used LPI criteria to compare the logistics performance of Balkan countries. CRITIC and Measurement Alternatives and Ranking according to Compromise Solution (MARCOS) techniques were used to determine the importance weights of the criteria. According to the findings, the most successful country is Serbia. Martí et al. [2017] determined the efficiency levels of the logistics performance of the countries with the data envelopment analysis method. In this study, three different scenarios were developed. LPI indicators are considered as input and output variables in all scenarios. In the analysis findings, it has been determined that there are differences in the levels of efficiency of logistics performance of the countries.

Yildirim and Mercangöz [2020] discussed the LPI scores published by the World Bank in 2010-2018 with a fuzzy logic approach. LPI indicators were accepted as evaluation criteria. Fuzzy Analytic Hierarchy Process method was used to determine the weights of the criteria. The gray additive ratio assessment technique (ARAS-G) was used to determine the LPI scores and rankings of the countries. A strong correlation was found between both LPI scores. Mercangöz et al. [2020] determined the LPI scores of the member states and candidate countries of the European Union using the gray approach. The LPI scores of selected countries for selected periods were determined using the Complex Proportional Assessment (CORPAS-G) technique. Based on the findings, a strong correlation was found between both LPI scores.

Isik et al. [2020] calculated the LPI scores of 11 Central and Eastern European countries using Statistical Variance and MABAC techniques. Timeliness was determined as the highest level of importance criterion, and infrastructure was determined as the lowest level of importance criterion. As a result of the LPI score calculations of the selected countries, the 3 countries with the highest LPI scores were determined as the Czech Republic, Poland, and Hungary, respectively. Senir [2021] applied the CRITIC and CORPAS methods to determine the LPI scores of the countries of the European Union and Turkey. The weights of export time, and distance, import time and distance criterion were determined. LPI scores and rankings of selected countries were presented.

Çakır [2016] applied CRITIC, simple additive weighting (SAW), and Peters' fuzzy regression methods to determine the levels of logistics performance of OECD countries. The criterion of logistics performance criterion with the highest importance was determined as tracking and tracking. The logistics performance of the lowest importance has been determined as logistics competence. Based on the importance levels of the criteria, the 2014 LPI scores of the OECD countries were determined. Differences were found between the World Bank LPI rankings, and the rankings obtained. Garca et al. [2015] determined the efficiency levels of the DEA and LPI scores of 141 sample countries. The countries with the highest level of LPI activity were Belgium, Germany, Norway, and Luxembourg.

Ozmen [2019] used the Mahalanobis distance (MD) based TODIM technique (an acronym in Portuguese for Interactive and Multicriteria Decision Making) to determine the logistics performance scores of the OECD countries. Two main criteria and nine sub-criteria were used in the study. The main criteria were determined as logistics performance and volume of transport. LPI indicators are included under the main criterion of logistics performance. In the main criterion, the freight, container and passenger volumes of the countries are used. In addition, the results of traditional TODIM and Improved TODIM results were compared. Oğuz et al. [2019] applied the Technique for Order-Preference by Similarity to Ideal Solution (TOPSIS) technique to determine the LPI scores of seven Asian countries. LPI indicators were determined as criteria. Singapore ranked first in the ranking.

Yalçin and Ayaz [2020] applied Fuzzy AHP and Fuzzy TOPSIS techniques to compare the logistics performances of Turkey and neighboring countries. The importance levels of the criteria were determined by Fuzzy AHP. The performance rankings of the countries were carried out with Fuzzy TOPSIS. Turkey ranked first in the logistics performance ranking. Ulutaş and Karaköy [2019b] used LPI indicators as criteria to determine the logistics performance of G20 countries. The Standard Deviation method was used to determine the importance levels of the criteria. The logistics performance rankings of the countries were determined by the Weighted Aggregated Sum Product Assessment (WASPAS) method. The countries with the highest LPI scores are Germany, Japan, United Kingdom, United States, and France, respectively.

As a result of the literature review, it has been determined that LPI indicators are generally used as criteria to determine the logistics performance of countries. Furthermore, it has been understood that various MCDM techniques are used to determine the LPI scores and rankings of the countries. The literature review is presented in the Table 1. The focus of this research is on developing countries and the evaluation of these countries in terms of logistics market performance. For this reason, the Agility Emerging Markets Logistics index indicators and data were used in the research.

Table 1. Literature Review

Authors	Criteria	Methodology	Findings
García et al. (2015)	LPI indicators	DEA	The three countries with the highest level of LPI efficiency are Belgium, Germany, Norway, and Luxembourg.
Çakır (2016)	LPI indicators	CRITIC, SAW, and Peters' fuzzy regression	Based on the importance levels of the criteria, the 2014 LPI scores of the OECD countries were determined.
Martí et al. (2017)	LPI indicators	DEA	The efficiency levels of logistics performance of countries have been determined.
Rezai et al. (2018)	LPI indicators	Best Worst	There have been found to be changes in LPI scores and rankings.
Oğuz et al. (2019)	LPI indicators	TOPSIS	The LPI scores of the Asian country were determined. Singapore is the best according to LPI scores.
Ozmen (2019)	LPI indicators, transportation volume	MD-TODIM	The traditional TODIM and Improved TODIM results were compared.
Ulutaş and Karaköy (2019a)	LPI indicators	SWARA and CRITIC	The LPI scores of countries of the European Union have been determined.
Ulutaş and Karaköy (2019b)	LPI indicators	SD and WASPAS	The countries with the highest LPI scores are Germany, Japan, the United Kingdom, the United States, and France, respectively.
Yildirim and Mercangöz (2020)	LPI indicators	Fuzzy AHP and ARAS-G	There is a strong correlation between LPI scores.
Isik et al. (2020)	LPI indicators	SV and MABAC	The 3 countries with the best LPI scores are the Czech Republic, Poland, and Hungary, respectively.
Mercangöz et al. (2020)	LPI indicators	CORPAS-G	There is a strong correlation between LPI scores.
Yalcı and Ayaz (2020)	LPI indicators	Fuzzy AHP and Fuzzy TOPSIS	Turkey is the best in logistics performance ranking.
Senir (2021)	LPI indicators, Export time and distance, Import time and distance	CRITIC and CORPAS	The LPI scores and ranking of selected countries were calculated according to the determined importance levels.
Mešić et al. (2022)	LPI indicators	CRITIC and MARCOS	The most successful country in terms of logistics performance is Serbia.

METHODOLOGY

The main purpose of this research is to determine the logistics performance of developing countries using Entropy and MABAC techniques. Furthermore, the aim is to reveal the differences in the weights and country rankings by comparing the findings and the AEMLI reports. In this respect, criteria, sampling, entropy technique, and MABAC technical steps are explained in the methodology section. Then it is passed to the application section.

Criteria and Sampling

The 2022 AEMLI report was used to determine and rank the logistics market performances in developing countries. Within the scope of the research, 4 criteria were used [AEMLI, 2022]. These criteria are *Domestic Logistics Opportunities* (DLO), *International Logistics Opportunities* (ILO), *Business Fundamentals* (BF), and *Digital Readiness* (DR). DLO indicates the degree to which developing countries can meet domestic demand in terms of logistics. The ILO indicates the foreign demand capacity and the capacity for cross-border logistics operations of developing countries. BF demonstrates the strength of the business environment and market independence of developing countries. DR shows the digital competence capacity of developing countries in terms of logistics. The sample area of the research consists of 50 developing countries. Entropy technique was used to determine the weights of the criteria and the MABAC method was used to determine the in the logistics market performance of developing countries. The research criteria and the sample area are presented in Table 2.

Table 2. Criteria and Sampling

Analysis	Criteria	Period	Sampling
Entropy and MABAC	Domestic Logistics Opportunities, International Logistics Opportunities, Business Fundamentals, Digital Readiness	2022	50 developing countries

Entropy Technique

The concept of entropy was first introduced by Rudolph Clausius in 1865 as a criterion for disorder in thermodynamics. The concept of entropy was introduced by Shannon in 1948 as an expression of uncertainty. A high entropy value indicates high disorder [Zhang et al., 2011]. In the entropy technique, the weights of the criteria are calculated using the data in the decision matrix. The entropy method is very useful for determining the weights of criteria in a MCDM problem because there is no need to evaluate criteria weights. Instead of evaluation, the weights of the criteria are determined in 5 steps [Wang and Lee, 2009; Erol and Ferrell, 2009; Özdağoğlu et al., 2017].

Step 1. *Creating the decision matrix:* The decision matrix D consisting of m alternatives and n criteria is shown in Eq. (1).

$$D = \begin{bmatrix} x_{11} & \cdots & x_{1j} & \cdots & x_{1n} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

x_{ij} $(i = 1,2,\ldots,m;\ j = 1,2,\ldots,n)$: It is the evaluation of the i^{th} alternative according to the j^{th} criterion.

Step 2. *Normalizing the decision matrix:* To ensure that the criteria values consisting of different units are standard, the normalization process is done with Eq. (2).

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}};\ \forall i,j \quad (2)$$

p_{ij} : The i^{th} alternative is the normalized value of the value it receives according to the j^{th} criterion.

Step 3. *Finding the entropy value:* With the Eq. (3), the entropy values in the [0,1] range of the criteria are found. The k value here is a fixed number and is calculated with Eq. (4).

$$e_{ij} = -k * \sum_{j=1}^{n} p_{ij} * \ln(p_{ij}) \quad (3)$$

$$k = (\ln(m))^{-1} \quad (4)$$

Step 4. *Finding degrees of differentiation:* With the Eq. (5), the degrees of differentiation are calculated by using the entropy values obtained previously.

$$d_j = 1 - e_j \quad (5)$$

Step 5. *Calculation of entropy criterion weights:* As a final step, the weights of the criteria are calculated with Eq. (6).

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (6)$$

MABAC Technique

The MABAC method, which evaluates alternatives because of the calculations made according to the distances of the criteria to the border proximity area, was developed by Pamučar and Ćirović at the research center in the field of defense logistics at the Defense University in Belgrade in 2015 [Pamučar et al., 2018]. In this method, first the distances of the criterion functions for each alternative to the boundary proximity area are calculated. Then the alternatives are ranked, and the optimal choice is made. This sorting process takes place in the following 6 steps [Pamučar and Ćirović, 2015; Božanić, 2016; Gigović, 2017].

Step 1. *Creating the decision matrix:* The decision matrix D consisting of m alternatives and n criteria is shown in Eq. (7).

$$D = \begin{bmatrix} x_{11} & \cdots & x_{1j} & \cdots & x_{1n} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix} \quad (7)$$

x_{ij} $(i = 1, 2, \dots, m;\ j = 1, 2, \dots, n)$: It is the evaluation of the i^{th} alternative according to the j^{th} criterion.

Step 2. *Normalizing the decision matrix:* Normalization is done to ensure that the criteria values consisting of different units are standard. In this process, Eq. (8) is used for maximization oriented criteria (benefit) and Eq. (9) for minimization-oriented criteria (cost).

$$n_{ij} = \frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \quad (8)$$

$$n_{ij} = \frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \quad (9)$$

x_i^+ are the maximum values of the columns in the normalized decision matrix. x_i^- are the minimum values in the columns of the normalized decision matrix. The normalized decision matrix is shown in Eq. (10).

$$N = \begin{bmatrix} n_{11} & \cdots & n_{1j} & \cdots & n_{1n} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ n_{i1} & \cdots & n_{ij} & \cdots & n_{in} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ n_{m1} & \cdots & n_{mj} & \cdots & n_{mn} \end{bmatrix} \quad (10)$$

Step 3. *Weighting of decision matrix:* The decision matrix is weighted with the help of Eq. (11) by using normalized decision matrix elements and criterion weight values.

$$v_{ij} = w_i * (n_{ij} + 1) \quad (11)$$

Step 4. *Creating the boundary proximity matrix:* With the Eq. 12, the border closeness values of each criterion are calculated. As a result, the boundary proximity field matrix in Eq. 13 is obtained.

$$g_i = \left(\prod_{j=1}^{m} v_{ij}\right)^{\frac{1}{m}} \quad (12)$$

$$G = [g_1 \quad g_2 \quad \cdots \quad g_n] \quad (13)$$

Step 5. *Calculating the distances of the decision alternatives to the boundary proximity area:* As a result of the operations in Eq. 14, the distances of each value in the decision matrix from the boundary proximity area are calculated.

$$Q = V - G = \begin{bmatrix} v_{11} - g_1 & \cdots & q_{1j} - g_j & \cdots & q_{1n} - g_n \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ q_{i1} - g_1 & \cdots & q_{ij} - g_j & \cdots & q_{in} - g_n \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ q_{m1} - g_1 & \cdots & q_{mj} - g_j & \cdots & q_{mn} - g_n \end{bmatrix} = \begin{bmatrix} q_{11} & \cdots & q_{1j} & \cdots & q_{1n} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ q_{i1} & \cdots & q_{ij} & \cdots & q_{in} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ q_{m1} & \cdots & q_{mj} & \cdots & q_{mn} \end{bmatrix} \quad (14)$$

Step 6. *Determining the status of decision alternatives according to boundary proximity area and ranking the alternatives:* The decision alternatives (A_i) are either in the Boundary Proximity Field (G) or the Lower Affinity Field (G^-) or the Upper Affinity Field (Eq. (15)). The more q_{ij} values are in the Upper Affinity Field, the more likely that the alternative is to be the best alternative (Ayçin and Çakın, 2019).

$$A_i \in \begin{cases} G^+ \ if \ q_{ij} > 0 \\ G \ if \ q_{ij} = 0 \\ G^- \ if \ q_{ij} < 0 \end{cases} \quad (15)$$

With the Eq. (16), the criteria functions belonging to each alternative are calculated, and thus the ranking of the alternatives is made.

$$S_i = \sum_{j=1}^{n} q_{ij} \quad (16)$$

APPLICATION

In this study a total of 50 alternatives (m) and 4 criteria (n) were determined, which was conducted to determine the levels of development of the logistics market in developing countries. The study data set is given in Table 3. The weights of the criteria were calculated using the entropy method. Then, the alternatives were listed using the MABAC method.

Entropy Technique Findings

The 5 steps of the entropy technique were performed in order.

Step 1: The decision matrix consisting of 50 alternatives and 4 criteria is shown in Table 3.

Table 3. Data Set

Country	DLO	ILO	BF	DR	Country	DLO	ILO	BF	DR
China	8,54	9,75	7,06	7,25	Peru	4,7	5,1	4,57	4,52
India	8,01	7,23	5,96	6,74	Pakistan	5,03	4,58	4,33	5,1
UAE	5,58	5,73	9,2	8,63	Kenya	4,55	4,61	4,92	5,43
Malaysia	5,32	5,92	8,19	7,35	Ukraine	4,79	4,97	4,46	4,64
Indonesia	6,34	5,95	5,93	6,47	Iran	5,13	4,23	4,3	5,19
Saudi Arabia	5,35	5,51	8,16	7,07	Argentina	4,86	4,61	3,92	5,03
Qatar	5,79	4,89	7,96	6,52	Ghana	4,57	4,42	4,62	5,14
Thailand	5,13	6,01	5,82	6,54	Sri Lanka	4,49	4,72	4,36	4,82
Mexico	5,54	6,4	5,13	5,4	Nigeria	5,18	4,28	3,53	4,81
Turkey	5,28	5,87	5,87	5,96	Lebanon	4,76	4,6	4,13	4,33
Vietnam	5,02	6,01	5,48	5,75	Tunisia	4,58	4,48	5,03	4,06
Chile	4,87	5,17	7,17	6,14	Algeria	4,84	4,22	4,99	3,96
Russia	5,2	5,67	5,51	5,89	Ecuador	4,49	4,63	4,66	3,75
Oman	4,92	4,89	7,26	5,69	Bangladesh	4,99	4,38	3,44	4,38
Bahrain	4,99	4,68	7,3	5,16	Cambodia	4,4	4,47	4,22	4,34
Brazil	5,5	5,43	3,95	5,58	Paraguay	4,39	4,46	4,23	4,38
Kuwait	5,02	4,57	6,18	5,92	Tanzania	4,56	4,09	4,72	4,14
Philippines	5	5,25	4,38	5,99	Uganda	4,37	4,39	3,88	4,07
Jordan	4,86	4,73	6,7	4,97	Bolivia	4,42	4,46	3,58	3,1
Morocco	4,59	5	6,81	4,34	Ethiopia	4,36	4,36	3,15	3,42
Egypt	5,13	4,65	5,51	5	Mozambique	4,19	4,4	1,41	2,91
Kazakhstan	4,67	4,7	6,2	4,93	Angola	4,3	4,26	1,02	2,8
Uruguay	4,78	4,41	6,08	5,21	Venezuela	4,45	3,86	0,45	3,62
South Africa	4,69	4,95	5	5,17	Myanmar	4,4	4,25	0,69	1,83
Colombia	4,69	5,02	4,52	4,9	Libya	4,4	2,2	0,6	1,64

Step 2: The normalized decision matrix calculated with Eq. (2) is shown in Table 4.

Steps 3-4-5: The entropy values of the criteria were found with Eq. (3), the degree of differentiation with Eq. (5) and the weights of the entropy criteria with Eq. (6) are shown in Table 5.

Table 4. Normalized Decision Matrix

Country	DLO	ILO	BF	DR	Country	DLO	ILO	BF	DR
China	0,034159	0,039407	0,028636	0,029002	Peru	0,018799	0,020613	0,018537	0,018081
India	0,032039	0,029222	0,024175	0,026962	Pakistan	0,020119	0,018511	0,017563	0,020402
UAE	0,022319	0,023159	0,037316	0,034523	Kenya	0,018199	0,018632	0,019956	0,021722
Malaysia	0,021279	0,023927	0,03322	0,029402	Ukraine	0,019159	0,020087	0,01809	0,018561
Indonesia	0,025359	0,024048	0,024053	0,025882	Iran	0,020519	0,017096	0,017441	0,020762
Saudi Arabia	0,021399	0,02227	0,033098	0,028282	Argentina	0,019439	0,018632	0,0159	0,020122
Qatar	0,023159	0,019764	0,032287	0,026082	Ghana	0,018279	0,017864	0,018739	0,020562
Thailand	0,020519	0,024291	0,023607	0,026162	Sri Lanka	0,017959	0,019077	0,017685	0,019282
Mexico	0,022159	0,025867	0,020808	0,021602	Nigeria	0,020719	0,017299	0,014318	0,019242
Turkey	0,021119	0,023725	0,02381	0,023842	Lebanon	0,019039	0,018592	0,016752	0,017321
Vietnam	0,020079	0,024291	0,022228	0,023002	Tunisia	0,018319	0,018107	0,020402	0,016241
Chile	0,019479	0,020896	0,029083	0,024562	Algeria	0,019359	0,017056	0,02024	0,015841
Russia	0,020799	0,022916	0,022349	0,023562	Ecuador	0,017959	0,018713	0,018902	0,015001
Oman	0,019679	0,019764	0,029448	0,022762	Bangladesh	0,019959	0,017703	0,013953	0,017521
Bahrain	0,019959	0,018915	0,02961	0,020642	Cambodia	0,017599	0,018066	0,017117	0,017361
Brazil	0,021999	0,021946	0,016022	0,022322	Paraguay	0,017559	0,018026	0,017157	0,017521
Kuwait	0,020079	0,018471	0,025067	0,023682	Tanzania	0,018239	0,016531	0,019145	0,016561
Philippines	0,019999	0,021219	0,017766	0,023962	Uganda	0,017479	0,017743	0,015738	0,016281
Jordan	0,019439	0,019117	0,027176	0,019882	Bolivia	0,017679	0,018026	0,014521	0,012401
Morocco	0,018359	0,020209	0,027622	0,017361	Ethiopia	0,017439	0,017622	0,012777	0,013681
Egypt	0,020519	0,018794	0,022349	0,020002	Mozambique	0,016759	0,017784	0,005719	0,011641
Kazakhstan	0,018679	0,018996	0,025148	0,019722	Angola	0,017199	0,017218	0,004137	0,011201
Uruguay	0,019119	0,017824	0,024661	0,020842	Venezuela	0,017799	0,015601	0,001825	0,014481
South Africa	0,018759	0,020006	0,020281	0,020682	Myanmar	0,017599	0,017177	0,002799	0,007321
Colombia	0,018759	0,020289	0,018334	0,019602	Libya	0,017599	0,008892	0,002434	0,006561

Table 5. Entropy Values, Differentiation Degrees, and Criterion Weights

	DLO	ILO	BF	DR
e_i	0,997153	0,994877	0,976636	0,990184
d_j	0,002847	0,005123	0,023364	0,009816
w_j	0,069182	0,124499	0,567777	0,238542
e_i	0,997153	0,994877	0,976636	0,990184

MABAC Technique Findings

The 6 steps of the MABAC technique were completed in order.

Step 1: The decision matrix is the same as in Table 3.

Table 6. Normalized Decision Matrix with MABAC Method

Country	DLO	ILO	BF	DR	Country	DLO	ILO	BF	DR
China	1	1	0,755429	0,802575	Peru	0,117241	0,384106	0,470857	0,412017
India	0,878161	0,666225	0,629714	0,729614	Pakistan	0,193103	0,315232	0,443429	0,494993
UAE	0,31954	0,46755	1	1	Kenya	0,082759	0,319205	0,510857	0,542203
Malaysia	0,25977	0,492715	0,884571	0,816881	Ukraine	0,137931	0,366887	0,458286	0,429185
Indonesia	0,494253	0,496689	0,626286	0,690987	Iran	0,216092	0,268874	0,44	0,507868
Saudi Arabia	0,266667	0,438411	0,881143	0,776824	Argentina	0,154023	0,319205	0,396571	0,484979
Qatar	0,367816	0,356291	0,858286	0,69814	Ghana	0,087356	0,29404	0,476571	0,500715
Thailand	0,216092	0,504636	0,613714	0,701001	Sri Lanka	0,068966	0,333775	0,446857	0,454936
Mexico	0,310345	0,556291	0,534857	0,537911	Nigeria	0,227586	0,275497	0,352	0,453505
Turkey	0,250575	0,486093	0,619429	0,618026	Lebanon	0,131034	0,317881	0,420571	0,384835
Vietnam	0,190805	0,504636	0,574857	0,587983	Tunisia	0,089655	0,301987	0,523429	0,346209
Chile	0,156322	0,393377	0,768	0,643777	Algeria	0,149425	0,26755	0,518857	0,331903
Russia	0,232184	0,459603	0,578286	0,608011	Ecuador	0,068966	0,321854	0,481143	0,30186
Oman	0,167816	0,356291	0,778286	0,579399	Bangladesh	0,183908	0,288742	0,341714	0,391989
Bahrain	0,183908	0,328477	0,782857	0,503577	Cambodia	0,048276	0,300662	0,430857	0,386266
Brazil	0,301149	0,427815	0,4	0,563662	Paraguay	0,045977	0,299338	0,432	0,391989
Kuwait	0,190805	0,313907	0,654857	0,612303	Tanzania	0,085057	0,250331	0,488	0,357654
Philippines	0,186207	0,403974	0,449143	0,622318	Uganda	0,041379	0,290066	0,392	0,347639
Jordan	0,154023	0,335099	0,714286	0,476395	Bolivia	0,052874	0,299338	0,357714	0,20887
Morocco	0,091954	0,370861	0,726857	0,386266	Ethiopia	0,03908	0,286093	0,308571	0,254649
Egypt	0,216092	0,324503	0,578286	0,480687	Mozambique	0	0,291391	0,109714	0,181688
Kazakhstan	0,110345	0,331126	0,657143	0,470672	Angola	0,025287	0,272848	0,065143	0,165951
Uruguay	0,135632	0,292715	0,643429	0,51073	Venezuela	0,05977	0,219868	0	0,283262
South Africa	0,114943	0,364238	0,52	0,505007	Myanmar	0,048276	0,271523	0,027429	0,027182
Colombia	0,114943	0,37351	0,465143	0,466381	Libya	0,048276	0	0,017143	0

Step 2: Since all criteria are maximization oriented, the decision matrix was normalized as shown in Table 6 using Eq. (8).

Step 3: With Eq. (11), the weighted decision matrix in Table 7 was obtained. The weights of the criteria in Eq. (11) were calculated with Eq. (6).

Step 4: With Eq. (12), the border proximity area values for each criterion were calculated, and the border proximity area matrix is shown in Table 8.

Table 7. Weighted Decision Matrix

Country	DLO	ILO	BF	DR	Country	DLO	ILO	BF	DR
China	0,123444	0,222147	0,889216	0,383623	Peru	0,068958	0,153738	0,745066	0,300505
India	0,115924	0,185074	0,825535	0,368095	Pakistan	0,073641	0,146088	0,731172	0,318163
UAE	0,081445	0,163006	1,013104	0,425639	Kenya	0,06683	0,146529	0,765328	0,328211
Malaysia	0,077756	0,165801	0,954633	0,386667	Ukraine	0,070235	0,151825	0,738697	0,304158
Indonesia	0,092228	0,166243	0,823798	0,359875	Iran	0,07506	0,140938	0,729435	0,320904
Saudi Arabia	0,078181	0,159769	0,952897	0,378143	Argentina	0,071229	0,146529	0,707436	0,316032
Qatar	0,084424	0,150648	0,941318	0,361397	Ghana	0,067114	0,143734	0,74796	0,319381
Thailand	0,07506	0,167125	0,81743	0,362006	Sri Lanka	0,065979	0,148147	0,732908	0,309638
Mexico	0,080877	0,172863	0,777485	0,327297	Nigeria	0,075769	0,141674	0,684858	0,309334
Turkey	0,077188	0,165066	0,820325	0,344347	Lebanon	0,06981	0,146382	0,719593	0,29472
Vietnam	0,073499	0,167125	0,797747	0,337953	Tunisia	0,067256	0,144616	0,771696	0,286499
Chile	0,071371	0,154767	0,895584	0,349828	Algeria	0,070945	0,140791	0,76938	0,283455
Russia	0,076053	0,162123	0,799484	0,342216	Ecuador	0,065979	0,146823	0,750276	0,277061
Oman	0,07208	0,150648	0,900794	0,336127	Bangladesh	0,073073	0,143145	0,679648	0,296242
Bahrain	0,073073	0,147559	0,90311	0,31999	Cambodia	0,064702	0,144469	0,724803	0,295024
Brazil	0,08031	0,158593	0,709173	0,332778	Paraguay	0,06456	0,144322	0,725382	0,296242
Kuwait	0,073499	0,14594	0,838271	0,343129	Tanzania	0,066972	0,138879	0,753749	0,288935
Philippines	0,073215	0,155944	0,734066	0,345261	Uganda	0,064276	0,143292	0,70512	0,286804
Jordan	0,071229	0,148294	0,868375	0,314205	Bolivia	0,064986	0,144322	0,687753	0,257271
Morocco	0,067398	0,152266	0,874743	0,295024	Ethiopia	0,064134	0,142851	0,662859	0,267014
Egypt	0,07506	0,147117	0,799484	0,315119	Mozambique	0,061722	0,143439	0,562128	0,251486
Kazakhstan	0,068533	0,147853	0,839429	0,312988	Angola	0,063283	0,14138	0,53955	0,248137
Uruguay	0,070094	0,143587	0,832482	0,321512	Venezuela	0,065411	0,135495	0,506552	0,273103
South Africa	0,068817	0,151531	0,769959	0,320295	Myanmar	0,064702	0,141233	0,520446	0,218604
Colombia	0,068817	0,152561	0,742171	0,312074	Libya	0,064702	0,111074	0,515236	0,212819

Table 8. Boundary Proximity Matrix

	DLO	ILO	BF	DR
g_i	0,072527	0,150816	0,757273	0,312347

Step 5: The distances of each value in the decision matrix to the boundary proximity area were calculated by performing the operations in Eq. (14). These values are given in Table 9.

Step 6: As a result of the values obtained with Eq. (16), the alternatives are ranked. The ranking of developing countries is given in Table 10.

RESULTS AND CONCLUSION

The levels of the logistics market performance of developing countries are presented in the AELMI reports. The main purpose of this research is to recalculate the logistics market performances of countries using Entropy and MABAC techniques. It is also the comparison of the scores obtained with the data in the AELMI reports. In this context, 2022 logistics market performance data for developing countries were obtained from AELMI reports. Afterwards, the Entropy technique was applied to determine the importance levels of the four basic criteria. Considering the weights of the criteria, the criterion with the highest level of importance is the BF (0. 567777). The other weights of other criteria are DR (0.238542), ILO (0.124499), and DLO (0.069182), respectively. When the criteria weights are compared, the weight of the DR is about half of the BF. The weight of the ILO is about half that of the DR. The weight of the DLO is about half of the ILO. According to these findings, it can be said that BF is by far the most important factor in determining the levels of the logistics market performance of specific countries. This indicates that developing countries should turn to the BF compared to other criteria to increase their logistics market performance. To increase the scores of the BF of the countries, the following points should be developed: (i) Ensuring stability and controlling inflation levels, (ii) Increasing the country's market accessibility level and ensuring local stability, (iii) Reducing domestic crime and violence, (iv) Correct implementation of credit and debt dynamics, (v) Improving the fight against corruption, (vi) and establishing the legal regulatory environment. According to the weights of other criteria, developing countries should focus on the level of accessibility to the international logistics market rather than national logistics markets. In addition, what is more important than focusing on nations and international markets is that countries develop efforts to improve their digital capabilities.

Table 9. Distances of Decision Alternatives to Boundary Proximity Area

Country	DLO	ILO	BF	DR	Country	DLO	ILO	BF	DR
China	0,050917	0,071332	0,131943	0,071276	Peru	-0,00357	0,002922	-0,01221	-0,01184
India	0,043397	0,034258	0,068262	0,055748	Pakistan	0,001114	-0,00473	-0,0261	0,005816
UAE	0,008918	0,012191	0,255831	0,113291	Kenya	-0,0057	-0,00429	0,008055	0,015863
Malaysia	0,005229	0,014986	0,19736	0,07432	Ukraine	-0,00229	0,00101	-0,01858	-0,00819
Indonesia	0,019702	0,015427	0,066525	0,047528	Iran	0,002533	-0,00988	-0,02784	0,008556
Saudi Arabia	0,005654	0,008954	0,195624	0,065795	Argentina	-0,0013	-0,00429	-0,04984	0,003685
Qatar	0,011898	-0,00017	0,184045	0,04905	Ghana	-0,00541	-0,00708	-0,00931	0,007034
Thailand	0,002533	0,01631	0,060157	0,049659	Sri Lanka	-0,00655	-0,00267	-0,02436	-0,00271
Mexico	0,00835	0,022047	0,020212	0,01495	Nigeria	0,003242	-0,00914	-0,07241	-0,00301
Turkey	0,004661	0,01425	0,063052	0,032	Lebanon	-0,00272	-0,00443	-0,03768	-0,01763
Vietnam	0,000972	0,01631	0,040474	0,025606	Tunisia	-0,00527	-0,0062	0,014423	-0,02585
Chile	-0,00116	0,003952	0,138311	0,03748	Algeria	-0,00158	-0,01002	0,012107	-0,02889
Russia	0,003526	0,011308	0,042211	0,029869	Ecuador	-0,00655	-0,00399	-0,007	-0,03529
Oman	-0,00045	-0,00017	0,143521	0,023779	Bangladesh	0,000546	-0,00767	-0,07763	-0,01611
Bahrain	0,000546	-0,00326	0,145837	0,007643	Cambodia	-0,00783	-0,00635	-0,03247	-0,01732
Brazil	0,007783	0,007777	-0,0481	0,02043	Paraguay	-0,00797	-0,00649	-0,03189	-0,01611
Kuwait	0,000972	-0,00488	0,080998	0,030782	Tanzania	-0,00555	-0,01194	-0,00352	-0,02341
Philippines	0,000688	0,005129	-0,02321	0,032913	Uganda	-0,00825	-0,00752	-0,05215	-0,02554
Jordan	-0,0013	-0,00252	0,111102	0,001858	Bolivia	-0,00754	-0,00649	-0,06952	-0,05508
Morocco	-0,00513	0,001451	0,11747	-0,01732	Ethiopia	-0,00839	-0,00796	-0,09441	-0,04533
Egypt	0,002533	-0,0037	0,042211	0,002772	Mozambique	-0,0108	-0,00738	-0,19515	-0,06086
Kazakhstan	-0,00399	-0,00296	0,082156	0,00064	Angola	-0,00924	-0,00944	-0,21772	-0,06421
Uruguay	-0,00243	-0,00723	0,075209	0,009165	Venezuela	-0,00712	-0,01532	-0,25072	-0,03924
South Africa	-0,00371	0,000715	0,012686	0,007947	Myanmar	-0,00783	-0,00958	-0,23683	-0,09374
Colombia	-0,00371	0,001745	-0,0151	-0,00027	Libya	-0,00783	-0,03974	-0,24204	-0,09953

Table 10. Ranking of Developing Countries

AEMLI Ranking	Country	S_i	Proposed Model Ranking	AEMLI Ranking	Country	S_i	Proposed Model Ranking
1	China	0,325467	2	26	Peru	-0,0247	30
2	India	0,201665	6	27	Pakistan	-0,0239	29
3	UAE	0,390231	1	28	Kenya	0,013935	24
4	Malaysia	0,291895	3	29	Ukraine	-0,02805	32
5	Indonesia	0,149181	10	30	Iran	-0,02663	31
6	Saudi Arabia	0,276027	4	31	Argentina	-0,05174	36
7	Qatar	0,244825	5	32	Ghana	-0,01477	26
8	Thailand	0,128659	11	33	Sri Lanka	-0,03629	34
9	Mexico	0,06556	20	34	Nigeria	-0,08133	41
10	Turkey	0,113963	12	35	Lebanon	-0,06246	39
11	Vietnam	0,083362	17	36	Tunisia	-0,0229	28
12	Chile	0,178587	7	37	Algeria	-0,02839	33
13	Russia	0,086913	16	38	Ecuador	-0,05282	37
14	Oman	0,166686	8	39	Bangladesh	-0,10085	43
15	Bahrain	0,150769	9	40	Cambodia	-0,06396	40
16	Brazil	-0,01211	25	41	Paraguay	-0,06246	38
17	Kuwait	0,107877	14	42	Tanzania	-0,04443	35
18	Philippines	0,015524	23	43	Uganda	-0,09347	42
19	Jordan	0,109141	13	44	Bolivia	-0,13863	44
20	Morocco	0,096469	15	45	Ethiopia	-0,1561	45
21	Egypt	0,043817	21	46	Mozambique	-0,27419	46
22	Kazakhstan	0,07584	18	47	Angola	-0,30061	47
23	Uruguay	0,074712	19	48	Venezuela	-0,3124	48
24	South Africa	0,017638	22	49	Myanmar	-0,34798	49
25	Colombia	-0,01734	27	50	Libya	-0,38913	50

When the country rankings determined by the MABAC method are compared with the rankings presented in the AELMI 2022 report, changes are observed in the country rankings. Countries that have increased their ranking according to their position in the new proposed ranking are UAE, Malaysia, Saudi Arabia, Qatar, Chile, Oman, Bahrain, Kuwait, Jordan, Morocco, Kazakhstan, Uruguay, South Africa, Kenya, Ghana, Tunisia, Algeria, Ecuador, Paraguay, Tanzania, and It is Uganda. The countries whose rankings decreased are China, India, Indonesia, Thailand, Mexico, Turkey, Vietnam, Russia, Philippines, Colombia, Peru, Pakistan, Ukraine, Iran, Argentina, Sri Lanka, Nigeria, Lebanon, and Bangladesh. The countries whose ranking has not changed are Egypt, Cambodia, Bolivia, Ethiopia, Mozambique, Angola, Venezuela, Myanmar, and Libya. The country with the highest-ranking increase is Mexico. The countries that fell the most in the ranking were Oman, Bahrain, Jordan, Ghana, and Tunisia. Additionally, according to the proposed new model, the country with the highest logistics market performance is UAE, and the lowest country is Libya.

In the literature, it is known that there are differences in the logistics performance rankings of countries as a result of research on logistics performance indexes with various MCDM techniques [García et al. 2015; Çakır, 2016; Martí et al., 2017; Rezai et al., 2018; Oğuz et al., 2019; Ozmen, 2019; Yildirim and Mercangöz, 2020; Yalçin and Ayaz, 2020; Mešić et al., 2022]. With this research, it has been proven that there are changes in the logistics market performance rankings of developing countries. At this point, the results of the research and the results obtained in the literature have been determined to show parallelism. It is recommended that researchers identify datasets from different periods of AEMLI reports with different MCDM techniques and compare the results obtained with these research results.

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ORIGINAL PAPER

SUPPLY CHAIN MATURITY MODELS: A COMPARATIVE REVIEW

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ABSTRACT. **Background:** Due to the high potential to gain competitive advantage in today's global market, supply chains play a critical role in the current industry. Understanding maturity and its features in the context of the supply chain can help companies achieve higher levels of performance. To assess and measure supply chains, a wide variety of supply chain maturity models have been developed to help companies analyze the existing state in the supply chain, allowing for the achievement of higher levels of maturity and providing guidance in the development of an improvement roadmap.
Methods: The review spans from the early 1990s to 2021 and examines research carried out and published in the literature, including papers on conference proceedings, articles in journals, and technical reports. The previous models, stages, dimensions (areas/elements), and methods are included in this review. Research gaps are also noted, analyzed, and discussed.
Results: The purpose of this study is to perform a comparative analysis of supply chain maturity models to explore the special characteristics of the studied models, which help to identify the differences and similarities between each other, and also to present the various focus areas related to the supply chain. The results show the existence of a large variety of models with a trend to the customs of models for specific area of supply chain. We also identified that most of the models have similar maturity level names and number since they are developed based on previously existing maturity models. The results of this paper are meant to serve as a reference guide for a detailed understanding of documented supply chain maturity models and help practitioners to seek better alignment in regards to supply chain maturity models characteristics.
Conclusions: Supply chains play an important role in the market rivalry nowadays. Understanding maturity and its components in the context of supply chain management can help companies perform at higher levels. Despite the high number of maturity models developed in the field of supply chain, the result of this review shows that there is a need for new studies to fill the gaps in the existing work and to take into consideration the complexity faced in the management of supply chain networks.

Keywords: supply chain management; SCM; maturity models; performance

INTRODUCTION

Today, supply chain is becoming a crucial component of the organization's performance measurement and has attracted considerable interest from academics and professionals [Azman Daud and Suhaiza Zailani 2011]. Gunasekaran, Patel [2001] and McGaughy [2004] have discussed the critical role of metrics and measures in an organization's success due to direct impact on strategic, tactical, and operational planning and control [Azman Daud and Suhaiza Zailani 2011]. In addition, "the revolution of SCM in the last decade has proved that an increasing number of companies seek to enhance performance beyond their own boundaries" [Azman Daud and Suhaiza Zailani 2011].

"Maturity model aims to aid companies to benchmark the maturity of their operations and assumes that companies pass through a number of maturity levels before reaching high stages" [Nentland 2008]. "Maturity models have been developed within a wide range of disciplines. However, only a few models are targeting supply chain management" [Nentland 2008, Lockamy and McCormack 2004, Netland et al. 2007, Srai and Gregory 2005]. "The concept of maturity in supply chain network derives from the understanding that networks have life cycles that can be clearly defined, managed, measured and controlled throughout the time" [Fraser et

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al. 2002]. When there is a high level of maturity, it leads to high performance, costs saving, and increased efficiency in achieving outlined objectives [Fraser et al. 2002, Lockamy and McCormack 2004, McCormack et al. 2008]. Companies are better prepared to deal with changes in the supply chain environment by developing mature supply chain operations. [Lahti et al. 2008]. SCM processes are evaluated using maturity models, which also help businesses in identifying areas for improvement. [McCormack et al. 2003, Lahti et al. 2008]. In recent years, more studies have focused on examining supply chain management procedures and trying to enhance their effectiveness using supply chain maturity methodologies [Cheshmberah and Beheshtikia 2020]. By responding to the following research question, our objective is to gain an overview of existing supply chain maturity models: – "What kind of maturity models has already been developed to assess the maturity of supply chain"? and "How the supply chain maturity models differ from each other?" To answer these questions, this article reviews what kind of supply chain maturity models are currently offered in the literature by conducting a literature review on supply chain maturity models.

This paper is structured as follows: in Section 2, we present the research methodology, in Section 3 we highlight the theoretical background of supply chain maturity models, then in Section 4 we discuss the summary of different developed supply chain maturity models, including an overview of the characteristics of the main model. The supply chain maturity discussion is covered in Section 5, and the study is concluded in Section 6.

RESEARCH METHODOLOGY

Using a systematic review of the literature, we searched in several databases with the following key words: "supply chain management" AND "maturity models". The papers were selected based on the topic and abstract. Furthermore, papers that were excluded from this study did not address the following attributes: they did not define the traits of maturity models (dimensions, scope, levels), (2) did not present a new model but quote an existing model. The study also obtained other additional papers from references from the earlier articles extracted. Only 49 relevant papers are used for the comparative analysis of supply chain maturity models. Figure 1 shows the distribution of selected articles by database and publication type.

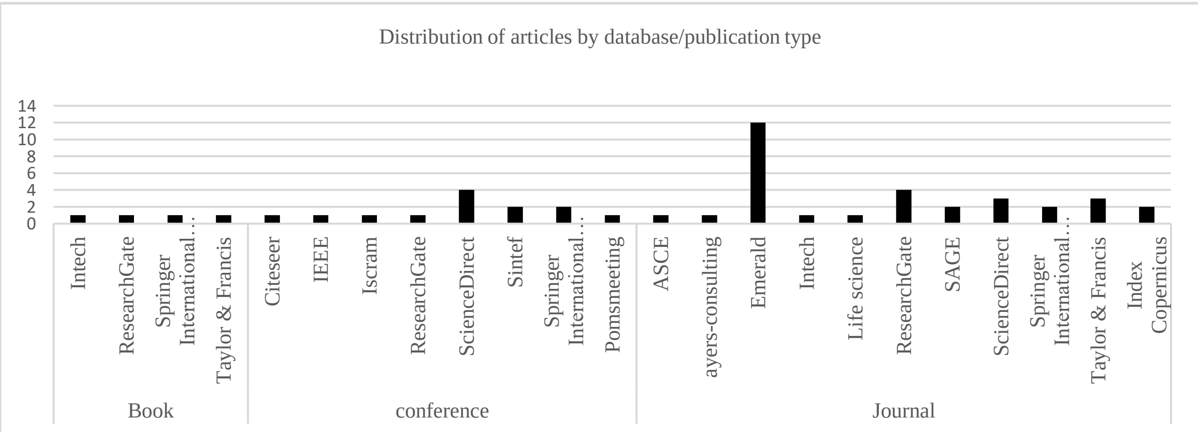

Fig.1. Distribution of articles by database/publication type.

The majority of the articles were found in the Emerald database (24%, 12 articles), Science direct (14%, 7 articles) and ResearchGate (12%, 6 articles), with the remainder being split between 19 different databases. In relation to the breakdown of the papers reviewed by publishing type, as shown the articles were drawn from a variety of publications, with published journals accounting for the majority (64%, 32 articles), 26% from conference proceeding (13 articles), with the remainder 10% (5 articles) from books and other sources (technical report, unpublished theses).

THEORETICAL BACKGROUND

"The literal meaning of the word maturity is ripeness, which means the evolution from initial to more advanced state" [Lahti et al. 2009]. "The basic idea behind this is that the subject may pass through several intermediate states on the way to maturity" [Lahti et al. 2009]. Furthermore, "maturity implies that the processes are well understood, supported by documentation and training, is consistently applied in projects throughout the organization and is continually being monitored and improved by its users" [Lahti et al. 2009, Fraser et al. 2002].

"Maturity models are rooted in the field of quality management, where Crosby's Quality Management Maturity Grid was a pioneering work" [Fraser et al. 2002]. Since then, numerous different forms of maturity models have been created within various fields. The Capability Maturity Model (CMM), which depicts stages in the usage of information technology, is the most well-known use of the maturity model concept in information technology and software development. "Technology, innovation, R&D effectiveness, collaboration, dependability, quality management, product design, knowledge management, and service operations are more examples of disciplines where maturity models have been developed" [Netland et al. 2007]. Later, in 2000, the CMM was upgraded to Capability Maturity Model Integration (CMMI). "The CMMI is a process improvement approach that provides organizations with the essential elements of effective processes" [Lahti et al. 2009]. "It can be used to guide process improvement across a project, a division, or an entire organization" [Lahti et al. 2009]. Although several types of maturity model of SCM have been published, they all have in common the fact that they define a number of dimensions or process areas at various stages of maturity and provide a description of typical performance. When a maturity level is reached, it is expressed at that level. While the number of levels varies depending on the maturity model, the most immature state is represented by the lowest level, and the highest level represents the completely developed state. Dimensions illustrate various aspects of maturity and subdimensions give a deeper view. Furthermore, different typologies were proposed by Fraser et al. [2002]. First, the activities requested for each level are described in maturity grids. Second, in Likert-like questionnaires, respondents must rate the organization's performance across multiple dimensions to assess maturity. The hybrid category combines answers with maturity descriptions [Lahti et al. 2009].

OVERVIEW OF SUPPLY CHAIN MATURITY MODELS

Continuous improvement is acknowledged as a key element for firms to flourish in today's competitive business environment. "Flexible, efficient and matured supply chains guide the business to maintain competitiveness and maximize customer and shareholder value" [Lahti et al. 2009]. In this section, we present an overview of supply chain maturity models. The descriptions of the models are presented in chronological order:

Table 1. Overview of the supply chain maturity models.

Reserachers	Year	Approach
Stevens	1989	Management of material flow must be evaluated from three perspectives: strategic, tactical, and operational—in order for an integrated supply chain. At all levels, it is necessary to coordinate and harmonize the utilization of resources such as people, facilities, money, and systems.
Poirier	1999	Based on a thorough model with four levels of maturity that a company develops through as it works to advance to the advanced stages of supply chain optimization, the company evaluates its current maturity stage.
McCormack	2001	This model states that supply chain management maturity progresses through five stages, with the ultimate objective of having a fully expanded organization with complete integration of operations between businesses, their clients and their trading partners. Within a specific supply chain, more functions and businesses are included with each additional step.
Poirier and Bauer	2001	A corporation increases its supply chain effort to a position where e-commerce features are introduced, absorbed, and advantageously used as a full network communication system is described by the proposed model, which is made up of five levels.
Stonich and Moncrieff	2001	The enabling practices that will lead to performance gains are defined by the maturity model. The SCOR model serves as the basis for the supply chain management maturity model's dimensions (plan, source, make, deliver and overall)
Ayers and Malmberg	2002	a four-stage model for reevaluating your supply chain's capacity to provide affordable customer service and competitive advantage
Ayers	2004	Based on a thorough model with five stages and the operational dimensions organization, process, and systems, the company evaluates its current maturity stage.
Handfield and straight	2004	Using a paradigm that ranges from Ad Hoc through Defined, Linked, Integrated, and Extended to gauge the maturity of procurement practices. Each of these components is evaluated at the level of the business process, categorizing it as a strategic, team-based, or operational (daily) process.
Lockamy and McCormack	2004	The "business process maturity" of a supply chain is described in the model. utilizes the Supply Chain Council's SCOR framework and, like the majority of other maturity models, draws inspiration from the Quality Maturity Grid and the Capability Maturity Model. The maturity of the supply chain management process is provided by the model for improved supply chain performance.
Leem and Yoon	2004	Because customer satisfaction is based on how a software product and its service are perceived collectively, the maturity model of software customer satisfaction takes into account both software products and related services. The degree to which customer opinions regarding software products and services are gathered and reflected determines the maturity levels of software customer satisfaction.
IBM	2005	The model that was created, which is in line with the degree of supply chain integration, served as a foundation for maturity level assessments and the goal of creating an "On Demand Supply Chain". Static supply chain, functional excellence, horizontal integration, external participation, and demand-based supply chain are the five tiers that make up the model.
Lapide	2005	This model should be used as a diagnostic tool for helping a company improve its sales and operation planning processes based on four defined maturity stages
PRTM management consultant	2005	The four processes of the Supply Chain Operations Reference model: plan, source, make, and deliver—as well as what is referred to as "overall" SCM practices, which direct the strategy and connect the processes, are individually evaluated according to their level of capability using this model.
Aberdeen Group	2006	presented an approach for determining the level of supply chain visibility under the name "Roadmap for the Visibility of Supply Chain." "Shipment tracking capabilities," "supply chain disruption management," and "supply chain improvement" are the three levels at which this model evaluates the supply chain maturity level.
Jaklic et al.	2006	presented a supply chain maturity model with five levels. In this model, the SCOR framework and the Lockamy and McCormack model are combined in this model. This paradigm has the following levels: Ad hoc, Defined, Linked, Integrated, and Extended.
Netland et al.	2007	The author recommended using the EFQM Excellence Model to assess the level of supply chain maturity. The SCM-CMM model is defined as having

		five maturity levels: the following: primary, defined, extended, networked, and ad hoc (contingency)
Pache and Spalanzani	2007	Five maturity levels—intra-organizational, inter-organizational, extended inter-organizational, multi-chain, and social—have been proposed as influencing interorganizational connections.
McCormack et al.	2008	The approach uses the business process maturity model and the supply chain operation reference model to identify the supply chain management actions that could enhance a company's competitive supply chain performance.
Garcia Reyes and Giachetti	2008	The various dimensions of the supply chain (suppliers, production, inventories, customers, human resources, information systems, and performance measurement systems), as well as different abstraction levels, are all covered by the model, which offers a roadmap for business improvement. In general, it offers practical techniques to improve enterprises.
Lahti	2009	Functional emphasis, internal integration, external integration, and cross-enterprise collaboration were the four stages of the model. This study created a questionnaire to evaluate the practices of the supply chain players, as well as the maturity of various sectors of the supply chain process.
Vics	2010	The CPFR business model is made up of 4 maturity stages namely: Unlinked- Basic- Collaborative- Strategic aims to reach integrated business planning.
Gupta and Handfield	2011	Model based on 5 maturity levels：Ad-hoc- Defined -Managed -Leveraged Optimized
Meng et al.	2011	The model follows the capability maturity principle and defines four maturity levels of the relationships in the construction supply chain. It is composed of 24 assessment criteria in eight categories at each of the four maturity levels. The maturity is evaluated through a series of expert interviews.
Accenture Company	2012	Set of the four supply chain maturity stages, from discrete decision making along the chain to a value-driven supply chain. These actions include demand-driven supply chains, value-driven supply chains, supply chains focused on tasks and business units, and supply chains focused on efficiency and cost.
Hameri et al.	2013	Six steps form the concept, the first three of which are regional and deal with initial sourcing, chain organization, and expansion. The following three steps deal with global and multinational operations, chain redesign, and lean supply chain management.
Reefke et al.	2014	The "SSCM maturity model," which has six maturity stages, offers guidance for the growth of more advanced SC sustainability. A description, set of objectives, and prerequisites are given for each level. A cyclical, multistep method to maturity advancement is used to support this paradigm.
Wagner et al.	2014	Creates a comprehensive S&OP maturity model that companies can use to evaluate their internal S&OP procedures and outlines the steps necessary to adopt an integrated S&OP strategy in order to achieve a more aligned company.
Fischer et al.	2016	This approach has been designed to assess the supply chain flexibility's maturity (SCF). Each of the five (5) maturity levels—collaboration, information technology, information flow, internal flexibility, and performance measurement, that the researchers found incorporates these five (5) characteristics.
Ho et al.	2016	Considered a framework built on the Capability Maturity Model Integration (CMMI) methodology as a diagnostic tool to assess current organizational collaboration practices, as well as a road map for directing enterprises to higher degrees of supply chain collaboration.
Mendes JR et al.	2016	Framework to help businesses evaluate their current demand-driven process maturity level and provide a road map for setting SC plans to advance to higher degrees of maturity
Tontini et al.	2016	Small and medium-sized businesses can use this useful tool to evaluate their own maturity in procurement and supply management. The maturity of the following four macroprocesses is assessed by this instrument: (1) Materials management, (2) Purchase process, (3) Supplier evaluation process, and (4) Procurement planning process.

Rudnicka	2017	The major objective of the proposed maturity model is to help companies self-evaluate their current strategy and identify any potential gaps that need to be filled to support sustainability.
Sartori and Frederico	2017	Taking into account the maturity of supply chain management, three categories were discussed and determined. These include the supply chain structure (collaboration, strategic focus, responsiveness, and environmental resources), the business process and management components (process management, technology and tools, performance assessment, and risk and project management).
Asdecker and Felch	2018	The concept consists of five maturation stages that are applied to three dimensions: basic digitization, cross-departmental digitization, horizontal and vertical digitization, full digitization, and optimal full digitization (order processing, warehousing and shipping). Three to seven elements make up each dimension. The high degree of information makes it easier to create a particular development path for a supply chain and allows for detailed evaluations of the maturity outcomes.
Szłapka and Stachowiak	2018	In order to categorize businesses into five types, criteria were defined using the Logistics 4.0 Model. The three aspects of logistics1 listed below serve as the basis for this classification: (1) Management; (2) Material Flow; (3) Information Flow
Gustafsson et al.	2019	a maturity model for product fitting in retail supply chains has been developed, with three levels of digitization and potential results for each level being stated. In fact, digital product fitting is a growing operational approach in the retail industry that uses digital models of both customers and products to match product supply to customer needs. The three levels mentioned are volumenta, virtusize, and corpus.
Yahyaoui et al.	2019	The suggested model's goals are to first determine the SC maturity level of SMEs in the automotive industry and then to provide them with assistance in creating a roadmap for supply chain progress.
Grest et al.	2020	recommending a supply chain maturity model tailored especially for the humanitarian industry. The model, which takes the shape of a two-dimensional matrix, intends to: 1) objectify one organization's situation with respect to its transformation journey; and 2) provide a roadmap for the subsequent improvement areas to focus on.
Caiado et al.	2021	a fresh methodology that takes into account the intricacy of how OSCM perceives the extent of digitalization is proposed to evaluate the I4.0 maturity of manufacturing organizations. The main focus is on determining the best way to gauge the readiness of manufacturing enterprises for digitalization.

All of the models described are essentially similar, with the exception of the observed supply chain subject areas and number of maturity stages. It is critical to remember that companies should move through the stages of those models in order, building on the practices they have built at each level. To be considered mature for a specific maturity level, a corporation must be effectively implementing most of the practices of that stage.

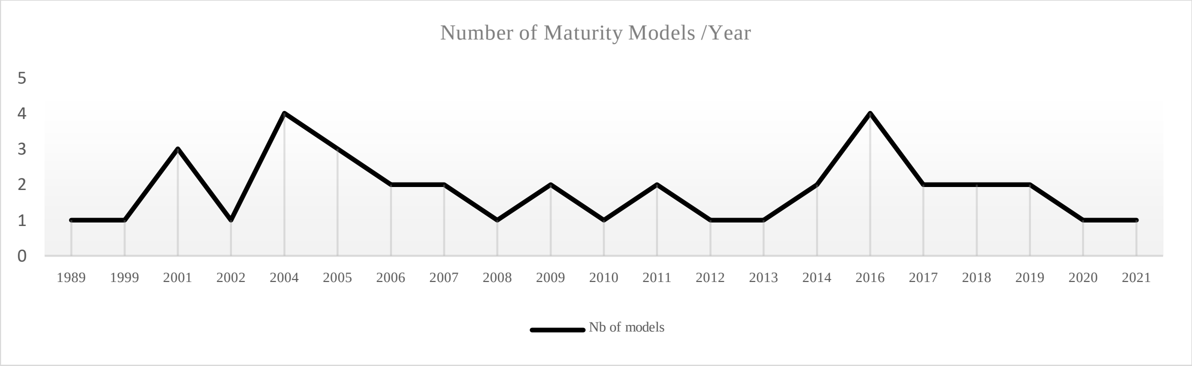

Fig.2. Number of SCMM developed per year.

Figure 2 shows the distribution of supply chain maturity models obtained by publication year. The number of models remains steady, except for two noticeable peaks in 2004 and 2016. We were unable to pinpoint the main cause of this study's findings in 2004 and 2016.

Supply Chain Maturity Levels

One of the main criteria of the listed models is maturity levels, which differ from model to another. In the table below, we identified for each model the number and name of maturity levels.

Table 2. Supply chain maturity levels.

Author's	**Year**	**Number of maturity levels**	**1**	**2**	**3**	**4**	**5**	**6**
Stevens	1989	4	Baseline	Functional	Internal Integration	External integration		
Poirier	1999	4	sourcing & logistics	internal excellence	network construction	industry leader		
Poirier and Bauer	2001	5	Enterprise integration	corporate excellence	partner collaboration	Value chain collaboration	Full network connectivity	
Stonich and Moncrieff	2001	4	Functional focus	Internal integration	External integration	Cross Enterprise collaboration		
McCormack	2001	5	Ad hoc	Defined	Linked	Integrated	Extended	
Ayers and Malmberg	2002	4	Infrastructure	Cost Reduction	Collaboration	Strategic		
Handfield and straight	2004	4	Basic Beginnings	Moderate Development	Limited Integration	Fully Integrated Supply Chains		
Ayers	2004	5	Dysfunctional	Infrastructure	Cost reduction	Collaboration	Strategic Contribution	
Lockamy and McCormack	2004	5	Ad hoc	Defined	Linked	Integrated	Extended	
Leem and Yoon	2004	4	Initial	Ready-made	Tailored	Customer oriented		
PRTM management consultant	2005	4	Functional focus	Internal integration	External integration	Cross Enterprise collaboration		
IBM	2005	5	Static	Functional	Horizontal Integration	External collaboration	On-Demand SC	
Lapide	2005	4	Marginal	Rudimentary	Classic	Ideal		
The Aberdeen Group	2006	3	Shipment tracking capability	supply chain disruption management	supply chain improvement			
Jaklic et al	2006	5	Ad hoc	Defined	Linked	Integrated	Extended	
Pache and Spalanzani	2007	5	Intra-organizational	Inter-organizational	Extended inter-organizational	Multichain Maturity	Social Maturity	
Netland et al	2007	5	Ad hoc (contingency	Primary	defined	Extended	Networked	
McCormack et al	2008	5	Ad hoc	Defined	Linked	Integrated	Extended	
Garcia Reyes and Giachetti	2008	5	Undefined	Defined	Manageable	Collaborative	Leading	
Lahti	2009	4	functional focus	internal integration	external integration	cross-enterprise collaboration		
Vics	2010	4	Unlinked	Basic	Collaborative	Strategic		

Meng et al	2011	4	Price competition	Quality competition	Project partnering	Strategic partnering/alliance		
Gupta and Handfield	2011	5	Ad-hoc	Defined	Managed	Leveraged	Optimized	
Accenture Company	2012	4	Focused on function	focused on efficiency	demand driven supply	Value driven supply		
Hameri et al	2013	6	Startup	systemization	Explosion	Restructuring	Integration	Focused chains
Reefke et al	2014	6	Unaware & non-compliant	ad hoc & basic compliance	Defined & compliance	Linked & exceeds compliance	Integrated & proactive	extended & sustainability leadership
Wagner et al	2014	6	Undeveloped	Rudimentary	Reactive	Consistent	Integrated	Proactive
Ho et al	2016	5	Initial	managed	defined	quantitatively managed	Optimizing	
Tontini et al	2016	4	Level 1	Level 2	Level 3	Level 4		
Fischer et al	2016	5	No flexibility	Intra-firm flexibility	Reactive flexibility	Proactive flexibility	Paradigmatic flexibility	
Mendes JR et al	2016	5	Basic Push Operation	Optimized push	Hybrid push-pull	Advanced demand driven pull	Optimized demand-driven pull	
Rudnicka	2017	5	Poor	Sufficient	Good	Very good	Excellent	
Sartori and Frederico	2017	3	Initial	Intermediate	Advanced			
Szłapka and Stachowiak	2018	5	Ignoring	Defining	Adopting	Managing	Integrated	
Asdecker and Felch	2018	5	basic digitization	cross department digitization	horizontal and vertical digitization	full digitization	optimized full digitization	
Yahyaoui et al	2019	3	Effective	efficiency SC	excellence SC			
Gustafsson et al	2019	3	Corpus	virtusize	volumenta			
Grest et al	2020	4	Elementary	Intermediate	advanced	Proficient		
Caiado et al	2021	5	Nonexistent	Conceptual	Managed	Advanced	Self-optimized)	

Maturity models use a variety of terms to describe different stages of maturity. The various terminologies for maturity levels are shown in Table 2. Regarding the number of maturity levels, we observed that the majority of models are based on five levels (46%), followed by the usage of four levels (36%) and by the usage of three levels (10%) and only few models used six levels (8%).

Supply Chain Maturity Dimensions

The most important dimensions mentioned in the published studies are shown in Figure 3. The dimensions highlighted in the following picture can serve as a basis for the creation of supply chain management maturity models. These dimensions provide a global perspective for supply chain management.

- The characteristics of each of the dimensions are as follows:
- Planning is related to multiple steps including demand planning, supply planning and operation planning.
- Costs are affected by the level of costs and inventory in the supply chain.
- Customers are related to the level of customer satisfaction as well as the attention provided to customers within the chain management.
- Processes deal with formalizing, integrating, and structuring the chain's processes.

- Technology and tools are highly supporting supply chain management, for example, information systems and statistical techniques for demand forecasting.
- Collaboration refers to communication and other joint chain endeavors, such as product creation and planning, as well as the sharing of information, profits, and resources among chain participants.
- Management is related to the quality of supply chain project management, risk management, and supply chain management training and awareness.
- Performance: The extent of performance measures in the supply chain is related to performance measurement.
- Strategic focus is the term used to describe the strategic objectives set for supply chain management by the focal company and its other participants.
- Resources are linked to the types of resources used in the supply chain, being they common (needed for execution of processes within the chain) and competitive (generate competitive advantage and are difficult to be employed by competing chains due to their differential);
- Environment refers to refers to legal concerns and credit incentives that promote the supply chain's optimal performance.
- Supply involves sourcing raw materials, services, managing contracts, and relationships with suppliers.
- Demand seeks to balance meeting client demands with maintaining adequate inventory levels.
- The organization outlines how certain activities are directed to achieve the goals of an organization.
- Storage and distribution cover a wide range of tasks and procedures, including inventory management, warehousing, supply chain management, and logistics.

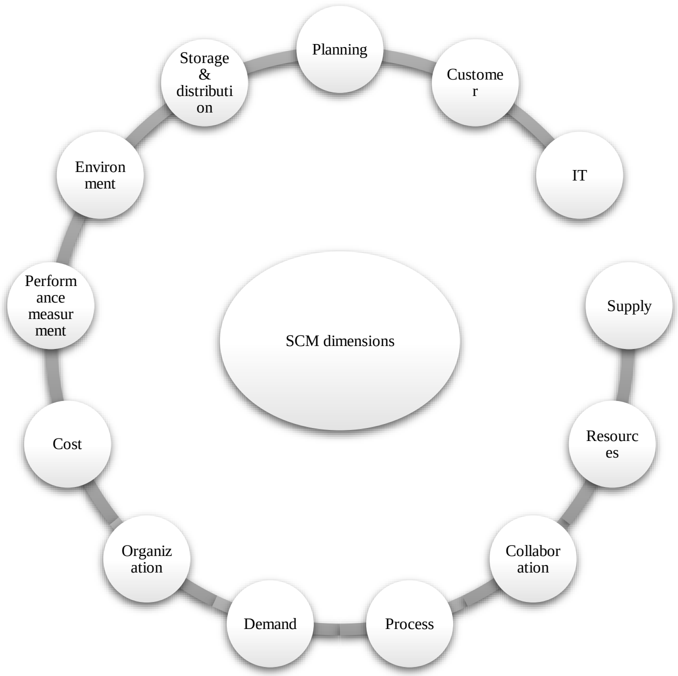

Fig. 3. Supply chain maturity dimensions.

Supply Chain Maturity Focus Areas

The review of the literature reveals that there are various methods for evaluating the maturity of SCM. Table 3 shows the focus area on SCM maturity issues based on the maturity models.

The scope of supply chain maturity models covers various areas of the supply chain; some models have contemplated supply chain management (SCM), demand driven supply chain (DDSC), supply chain optimization, supply chain integration (SCI), supply chain collaboration (SCC), and supply chain process management. In certain studies, the supply chain's flexibility, sustainability, visibility, and leanness were given special consideration; other models place a premium on the customer and the cost.

DISCUSSION

Reviewing the available supply chain models in the literature shows that the number of maturity levels varies from model to model. For most of these models, the number of levels is determined at random and is dependent on the author's ability to locate the appropriate labels or illustrative language that distinguishes the levels. Some of the studies models are basically similar, only the name of maturity levels and subject area of supply chain are varying, this can be explained by the fact that these models were created by adapting or enhancing previous maturity models.

The literature review provides evidence that most maturity models offer little guidance on particular actions that should be taken to raise maturity levels. The absence of orientation and information in the majority maturity models was emphasized by [Poeppelbuss et al. 2011] (p. 519): "academic articles often present new MMs as a rough sketch that would not suffice for practical application. Thus far, academics often fall short in providing detailed guidelines and helpful (software-based or on-line) toolkits to support the practical adoption of models developed in academia", this can be improved by establishing precise criteria that enable users to identify their present maturity stage and recognize a roadmap to the next stage.

We also noticed that some models were developed to serve specific type of organizations; therefore, their application in different organizations or industries is not as successful. Furthermore, only a few models used scientific guidelines to develop maturity models, implying that most of the models studied were developed based on the author's practical experience of the author. As a result, most models lack a theoretical foundation.

CONCLUSION

Supply chains play an important role in the market rivalry nowadays. Understanding maturity and its components in the context of supply chain management can help companies perform at higher levels. A supply chain maturity model is a methodology for the definition, measurement, management, and control of business processes. A higher level of maturity denotes an organization's superior performance [Poirier 2006].

It is acknowledged that continual monitoring and improvement are necessary for a company to succeed in the cutting-edge business world of today. Supply chains that are adaptable, effective, and mature help businesses stay competitive and maximize customer and shareholder value [Lalwani and Mason 2006].

Table 3. Supply chain maturity areas.

Reseracher/Focus area	Cost	Customer satisfaction	Demand driven supply chain	Lean supply chain	Procurement and supply manamegent	Delivery process	S&OP	Supply chain 4.0	Supply chain collaboration	Supply chain flexibility	Supply chain integration	Supply chain managment	supply chain managment	supply chain optimization	supply chain process management	supply chain sustainaibility	supply chain visibility
Stevens 1989											*						
Poirier 1999														*			
McCormack 2001													*				
Poirier and Bauer 2001														*			
Stonich and Moncrieff 2001													*				
Ayers and Malmberg 2002	*	*											*				
Ayers 2004												*					
Handfield and straight 2004					*												
Leem and Yoon 2004		*															
Lockamy and McCormack 2004															*		
IBM 2005			*														
Lapide 2005							*										
PRTM management consultant 2005												*					
Aberdeen Group 2006																	*
Jaklic et al 2006															*		
Netland et al 2007													*				
Pache and Spalanzani 2007																*	
McCormack et al 2008															*		
Garcia Reyes and Giachetti 2008															*		
Lahti 2009												*					
Vics 2010									*								
Gupta and Handfield 2011															*		
Meng et al 2011												*					
Accenture Company 2012	*																
Hameri et al 2013				*													
Reefke et al 2014																*	
Wagner et al 2014							*										
Fischer et al 2016										*							
Ho et al 2016									*								
Mendes JR et al 2016			*														
Tontini et al 2016					*												
Rudnicka 2017																*	
Sartori and Frederico 2017													*				
Asdecker and Felch 2018						*											
Szłapka and Stachowiak 2018								*									
Gustafsson et al 2019												*					
Yahyaoui et al 2019												*					
Grest et al 2020												*					
Caiado et al 2021								*									

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The state of the art maturity models in supply chain was analyzed. 49 articles (published from 1998 to 2021) were selected from the Science direct, Emerald Insight, and Research Gate databases. Despite the growing interest in supply chain maturity models as evidenced by the number of recently published, efforts to summarize the state-of-the-art in Supply chain maturity models have so far been rather limited, which emphasizes the importance of investigating this research area. This research contributes to a comprehensive review, analysis, and synthesis of the MM literature. Various issues associated with MMs (i.e., research objectives, maturity levels, and focus/scope of models) are explored to reveal the differences and similarities between each model and to contribute to the evolution and significance of this multidimensional area. The results of this paper are meant to serve as a reference guide for a detailed understanding of documented supply chain maturity models and help practitioners to seek better alignment in regards to supply chain maturity models characteristics.

The present study has some limitations, considering that maturity models developed by practitioners and consultants are often difficult to access using scientific databases, the art of state was performed through various databases to identify all possible relevant papers, but it is certain that some research papers were missed. To fill this gap, more comprehensive research is required using other sources of information, such as magazines and organizations' internal documents.

Organizations seek models and tools to help improve their supply chain operations. There are numerous models that might be used to achieve the required benefits. Despite numerous attempts to enhance and broaden individual performance evaluation into firms' suppliers, distributors, and customers of firms, there is currently no supply chain maturity model capable of managing the normal complexity faced in the management of supply chain networks. Future research could be considered to expand the analysis of supply chain maturity models including other characteristics such as the typology, architecture, and application area of the model.

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ORIGINAL PAPER

IMPROVEMENT OF MULTIMODAL TRANSPORTATION BASED ON LOGISTIC PRINCIPLES

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ABSTRACT. Relevance of the study: As the experience of advanced countries shows, the development of the economy in our country, in particular, in the transportation services market, is associated with the development of interaction between all types of transport. Thus, in modern conditions, for the growth of the role of railway transport, multimodal transportation, which is important for the interaction of Ukraine with the countries of Europe and the East, is becoming important and will also help minimize costs and preserve the environment. Therefore, the issues of evaluating the introduction of multimodal transportation with logistic principles are discussed in the article. It is shown how to determine the marginal substitution rate in the conveyance type while using various modes of transport, based on the utility function and transportation costs.
Purpose of the study: The purpose of the article is to develop measures to improve the functioning of parts in multimodal freight delivery routes by minimizing transportation costs, taking into account quality indicators. For this purpose, the following tasks have been set and are being solved: to develop a model for evaluating the efficiency of using different modes of transport with optimal costs; to choose a method for estimating the optimal delivery route and freight volumes; to evaluate the efficiency of transportation technology based on a qualimetric indicator.
Approaches: An approach to a comprehensive evaluation of the effect from the activities of transport enterprises in multimodal transportation based on cost optimization, with the qualimetric indicator, and aimed at maximizing the satisfaction of shippers' requirements is offered when determining the route of such transportation parameters as the cost and the quality of freight delivery.
Results: The results of the theoretical generalization and analysis of approaches to the formalization of the functioning process in multimodal transportation systems for the delivery of goods by rail and road modes of transport are presented in the article. **The significance of the results.** The materials in the article are of practical value for employees of transport and logistics companies and enterprises, scientists, and pedagogical workers to improve their professional level.

Keywords: multimodal transportation, railway transport, principles of logistics and qualimetry, vehicle

INTRODUCTION

Transport plays a significant role in the world economy, uniting cities, countries, and continents, contributing to the development of countries as a whole and their entry into the world market. The development of transport infrastructure contributes to the economic, social, and political component of the country's life spheres.

In modern conditions, there is a drop in the volume of transportation by rail, primarily due to the martial law in our country, as well as a drop in industrial output, a decrease in domestic demand due to a decrease in purchasing ability.

Even under such conditions, according to the State Statistics Service of Ukraine, most of the freight transportation, domestic and international, is carried by rail (State Statistics Service of Ukraine, 2022). Consequently, rail transport remains as the leading transport for

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mass cargo transportation due to its reliability, competitiveness, and efficiency for long-distance transportation (Krasheninin and Shapatina, 2016).

Currently, the development of the transport system is increasingly correlated with the mutually beneficial interaction between different modes of transport, with a special place being occupied by multimodal transportation. This mode of freight transportation is carried out on the basis of a multimodal transportation agreement, while a single transportation document (document of multimodal transportation of cargo) is used throughout the route. The geography of Ukraine, which is located at the intersection of international transport corridors and is a connecting link between the European countries and the east, does play the important role.

The processes of globalization in the Ukrainian economy set the task to use rationally using the potential of the economic and geographical position, the effective implementation of which will contribute to obtain economic benefits from participation in international transportation, as well as to create new influence mechanisms on the world economic processes. The main trends in the development of the freight transport organization on the world's railways are associated with the expanded use of specialized rolling stock and the increase in transportation in mixed schemes (multimodal, intermodal, piggyback and bimodal transportation) mainly in international traffic. Multimodal transportation, as world experience shows, is one of the most promising areas for expanding the range of transport services.

Multimodal transportation is carried out with the participation of two or more modes of transport, while competing modes of transport, the main ones being road and rail, are combined in a single delivery chain, using their strengths. Therefore, we ensure a constant influx of new customers, which is a lifeline for the Ukrainian railway industry, because several international transport corridors pass through its territory.

In recent years, the policy of JSC "Ukrzaliznytsia" has been striving to increase the role of multimodal transportation, which will contribute to the interaction of Ukraine with the countries of the European Union. Recently, the role of multimodal transportation with Asian countries has increased. The number of multimodal runs, namely container trains, that passed in 2021 along the routes of international rail freight transportation China - Europe, increased by 22% compared to the previous year, up to 15 thousand trains. The number of container trains on the China-Western European countries, which runs through the territory of Ukraine, has also increased significantly (the transportation of containers on China-Europe rail routes increased by 66% in 2021, 2022).

To increase the efficiency of freight transportation, it is advisable to have a mutually beneficial combination of rail and road modes of transport, that is, to carry out multimodal transportation.

ANALYSIS OF THE LITERATURE AND STATEMENT OF THE PROBLEM

The introduction and study of the organization of multimodal transportation has a significant place in the domestic and foreign literature, where a wide range of issues is considered.

The experience of some countries confirms the economic efficiency of multimodal freight transport. Thus, the multimodal transport system is considered from the standpoint of its components, purpose, characteristics of the freight transportation organization, as well as the composition of the participants in this system. The main feature of the multimodal transport system is the integrity and consistency of all the processes for the delivery of goods.

It is noted in the articles (Krasheninin and Shapatina, 2021), (Fan et al., 2019) that multimodal transportation ensures the safety and security of goods, delivering them door-to-door, but its main disadvantage is the long time frame for loading and dispatching freights. In scientific developments, the mathematical rationale of such a transportation technology is not fully considered.

In the study (Müller et al., 2021) the main attention is paid to the technological aspect of multimodal transportation based on an intelligent system, but the choice of a fright delivery route as one of the components of this transportation is not substantiated. The article (Wronka, 2017) notes the sustainability of laying new routes for container trains in the Europe-Asia direction, in the work (Lin, 2019) the methods for choosing the optimal route for freight delivery are determined, while taking into account the impact of carbon dioxide emissions on the environment, however, the criterion of delivery time is not paid attention.

The article (Gremm, 2018) considers a multimodal transport system, compares the cost component in the interaction of transport modes, but does not determine the role of each transport mode in saving transportation costs.

Studies (Kos et al., 2017), (Hao, Yue, 2016) consider the evaluation of effectiveness in interaction between various modes of transport according to the criteria of transportation cost and time, but do not take into account risks and do not substantiate the number of indicators that determine effectiveness at various methods of interaction between vehicles.

It should be noted that the problems of transport technology interaction based on the reduction of transportation costs, taking into account the quality indicator, are still given insufficient attention.

The issues of defining measures to improve the processes of optimizing parts in multimodal freight delivery routes by minimizing transportation costs, taking into account quality indicators based on the principles of logistics and qualimetry remain topical.

THE STUDY OF MUTUALLY BENEFICIAL INTERACTION OF DIFFERENT TRANSPORT TECHNOLOGIES

The introduction of multimodal transportation poses new challenges for the strategic development of the Ukrainian transport industry, which requires the development of new approaches to the development of transport technologies.

Currently, one of the major challenges for rail transport is to strike a balance between an unpredictable market and making consistent profits by providing new services to customers. Ensuring highly efficient and profitable operation of the industry, its successful operation in the transport services market, due to the uncertainty and dynamism of its development, poses many challenges for the railway. They include forecasting market situations and choosing the optimal strategy, taking into account the possible behavior of transport product consumers in a competitive market environment. It is the basis for carrying out activities to attract customers to the railway transport, planning the need for transportation resources, and income that the railway can receive from the transportation of goods.

Models of the behavior of the transport system and consumers of transport product in market and especially conflict situations, built on the basis of market research, can become an effective tool for solving these difficult tasks.

With all the differences of mathematical models describing market processes, in terms of economic content, problem setting, and methodological approaches, they are united by one common goal - to determine the best strategy for the behavior of both the carrier and the client in the transport product sales market. It makes it possible to build a transport policy taking into account the interests of cargo owners and, ultimately, to increase the volume of transportation and improve the economic situation of the railway.

Depending on the state of the market environment, the processes occurring in the transport market can be described by different models: dynamic based on differential equations, probabilistic, and built on expert systems. As the analysis of foreign experience shows, it is possible that the behavior of market entities in a competitive transport environment is well described by models using game theory methods. This method is based on an intuitive idea of the optimal value, that is, the obtained optimal value is not unique, the solution of the problem will differ depending on the conditions (Panchenko and Rezunenko, 2015, P.2).

In addition, analytical models using mathematical programming methods, in particular linear programming, have become widely used to reflect fairly stable stationary processes. The solution of the linear programming problem occurs when optimizing for a certain indicator if an objective function and restrictions are available.

Recently, attempts have been made to describe the functioning of the market environment under conditions of pronounced uncertainty by the methods of artificial intelligence theory using expert systems. This system can process, apply, and improve the acquired knowledge and skills, has learning capability (Savchenko and Synelnikov, 2017).

Multimodal transportation is a complex transport and logistic process that provides the rationale for an effective way to implement the transport process, determining the optimal route, the role of each transport, organizing the interaction between certain modes of transport and cargo transshipment points, processing the necessary documents, taking into account various risk factors, etc. Therefore, it should be noted that this type of transportation is one of the most difficult methods of transportation in the organizational aspect.

With that in mind, let us consider the following model, which takes into account a complex of market situations and allows us to evaluate which combination of several interchangeable modes of transport the consumer will choose as optimal for him.

Using this model, it is possible to solve optimization problems related to the search for a certain equilibrium point for market processes under the conditions of a compromise between opposing trends and subjects of the transport market. With it, one can predict the motivation of the potential customers actions and set up a predicted marketing policy.

This is the so-called consumer model, which characterizes the expediency of interchangeability of one transport mode with another in terms of providing multimodal transportation (Panchenko and Rezunenko, 2015, P.1).

Figure 1 shows a graphical interpretation of the substitution of transport modes, which demonstrates a curve U that reflects the utility function of transport modes for the consumer of its services. The ordinate axes x_1 and x_2 represent the interchangeable modes of transport and their services, which can be obtained from the chosen mode of transportation, and the ratio x_1 / x_2 shows the marginal rate of substitution of one transport mode by another, and the shaded area, the admissible substitution zone.

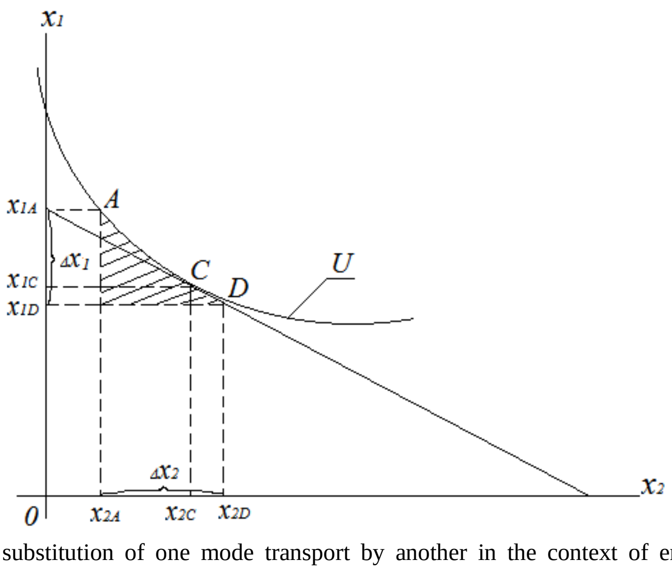

Fig. 1 Graphical interpretation of substitution of one mode transport by another in the context of ensuring multimodal transportation

Mutual substitution of transport modes makes sense only on the section AD of the utility function curve. Marginal substitution is possible only with the consumer interests of the market entity.

The segment Ox_{2A} characterizes the minimum amount of consumer interests from vehicles x_2, which the consumer cannot refuse, and Ox_{1D} – the minimum amount of consumer interests from services necessary for the consumer x_1.

When replacing one mode of transport with another, the consumer should take into account their resource capabilities. They are estimated by the so-called budget constraint, which is the sum of goods and services prices and transport tariffs on numerical values of interchangeable and complementary utility. On the graph, this is a straight line that affects the curved utility function at the equilibrium point C.

Moreover, this point should be in the allowable substitution zone and should characterize the position of the consumer's economic equilibrium in terms of the best substitution of transport modes for accepting prices and tariffs. It also shows a kind of compromise for opposing tendencies in the processes of replacing one mode of transport with another in order to obtain the maximum economic benefit for the consumer. The slope ratio of the direct budget constraint to the y-axis is numerically equal to the ratio of the prices which are considered as tariffs for the modes of transport to each other. From an economic point of view, the budget constraint shows how to distribute freights between two modes of transport within a divided amount of money.

The curve describing the utility function reflects the possible combinations of two economic services that provide the same benefit to the consumer and is a graphical interpretation of the maximized (or minimized) objective function. Moreover, the coordinates of the equilibrium point represent the optimal solution to the problem of substitution, for example, railway transport for automobile transport or vice versa.

Having obtained on the basis of marketing research the numerical characteristics of the potential client behavior motivation, it is possible to determine the specific type of objective function and calculate the parameters that will characterize his possible actions. Figure 1 shows the combined use of transport modes at the equilibrium point x_{2C} and the corresponding level of substitutable services x_{1C}. The value of these coordinates with the adopted pricing policy shows the optimal combination for the consumer of using road and rail transport when transporting freights.

As can be seen from the consideration of this model, for the consumer, first of all, it is important to realize their interests in the conditions of monetary restrictions. But for vehicles, to satisfy the conditions of competitiveness, it is necessary to ensure the minimum costs for their operation. From the point of view of operating costs, it implies the choice of the optimal route of movement, which reduces the cost of energy carriers. In addition, the carrier receives its profit from the volume of the transported cargos. In addition, the faster transportation is completed, the more vehicles can offer their services. That is, to evaluate the efficiency of vehicles, the following main aspects should be taken into account: the optimal route, the maximum load, and the maximum delivery speed of the freight or services to the client.

To solve multidimensional problems related to the evaluation of the behavior in the transport market, linear programming methods are effective. When different types of freight using some transport schemes, the application of graphic-analytical methods, due to their features, becomes practically impossible. Meanwhile, the algorithms of the classical resource allocation problem, formulated in terms of linear programming, have practically no restrictions on solving a multidimensional distribution problem (Panchenko and Rezunenko, 2015, P.1).

Let us formulate such a problem on the interests of transport consumers. Let us assume that from several methods of the delivery of finished products, the sender must choose their optimal combination, which ensures the minimum total cost of transportation. Natural restrictions are imposed on the volume of traffic, determined by the railway contacts with the sender. In addition, the sender's resources to pay for tariffs are also limited. In this case, the solution is resolved into such a distribution of traffic volumes by modes of transport, in which the objective function expressing costs by tariffs will have a minimum value.

In the event of a conflict situation associated with a drop in the income of the railway, it becomes necessary to increase the level of the tariff for transportation, then the total profit of the railway may increase. However, if the level of tariffs is reduced, then the volume of traffic and the total profit will increase slightly. Consequently, with a decrease in the total profit of the railway with an increase in tariffs, it is advisable to reduce the level of tariffs for transportation.

Thus, the ideology of interchangeability of each transport mode in the chain of freight delivery using multimodal technology is clear.

THE RESULTS ON DETERMINING THE LEVEL OF EXPENSES FOR TRANSPORTATION TECHNOLOGIES

The most important indicator that influences the choice of delivery method is transportation costs. At the same time, an important role is assigned to the choice of the delivery route and the volume of freight transported. When determining the route of transport, methods such as the Dijkstra’s algorithm, the salesman problem, the ant colony algorithm, the transportation problem, the genetic algorithm, etc. are used.

Dijkstra's algorithm is used to find the shortest path from one point of the graph to another. Dijkstra's classical algorithm can only be applied to graphs without edges of negative length. When solving the salesman problem, a criterion for choosing the best route is selected, it is either the shortest or the cheapest, or a combination of criteria and the corresponding distance and cost matrices. The ant colony algorithm is one of the efficient polynomial algorithms to obtain an approximate solution to the salesman problem. The specified salesman problem and the ant algorithm are heuristic, when solving them, not the most efficient route is found, but an approximate solution, however, due to the number of the algorithm repetitions, a more accurate result can be obtained (Denardo, 2003).

The solution of the transport problem belongs to the problems of linear programming. The solution of the transport problem is to find the optimal plan for transporting the uniform goods from points of production to points of consumption, the efficiency is evaluated by the criterion of the lowest cost of transportation (Panchenko and Rezunenko, 2015, p.1). The search for a solution according to the genetic algorithm occurs with the help of "crossing" and a similar natural selection process. The disadvantage of this method is the necessity to know the background, the gene pool (Oudani et al., 2014).

So, the cost of freight delivery is largely dependent on the choice of the optimal parts of the multimodal route in the freight supply chain. Therefore, one of the tasks to determine the cost indicator for multimodal transportation is to establish the optimal transportation route.

When choosing a mode of transport for the corresponding transport technology of transport in paper (Panchenko et al., 2017) the methods of theoretical qualimetry are used and the transport work is determined expressed in trans. A variety of vehicles does not allow one to estimate their properties in their entirety, so for different modes of transport the range of using technical characteristics is different, therefore, for an objective evaluation of transport technology, a qualimetric indicator is used, taking into account costs in conventional units.

Then, in the implementation of multimodal transportation, we will determine the indicator corresponding to the cost of transportation, taking into account the qualimetric component:

$$C(S_i) = \sum_{i=1}^{a} \sum_{j=1}^{b} \sum_{k=1}^{B} \delta_i C_i \to \min, \qquad (1)$$

де $a = \sum a_i$ – departure and destination points;

$b = \sum b_j$ – number of transport types involved in multimodal transportation;

$B = \sum B_k$ – mass of freight delivered by various transport types, t;

S_i – route for the freight delivery by various transport types, km;

δ_i – value of transport types, $\sum \delta_i = 1$;

C_i – indicator of the level of costs for transportation technologies with the qualimetric component, conventional units/tran.

When choosing the transport components in the multimodal freight delivery, the following factors are taken into account: transportation cost, delivery time, frequency of shipments, reliability of compliance with the freight delivery schedule, ability to transport various loads, ability to deliver freight anywhere in the territory (Kysly et al., 2010). According to the above factors, the most competitive variants for freight delivery are railway and road transport.

Therefore, we will consider freight delivery only by ground modes of transport. Let there be a set of freight delivery routes S_i from point a_1 to point a_2 by various types of transport. According to the put task, there are three possible variants to freight delivery: railway transport,, road transport and multimodal transportation. At the same time, part of the freight in a certain volume ΔB_i in places a_i (Fig. 2).

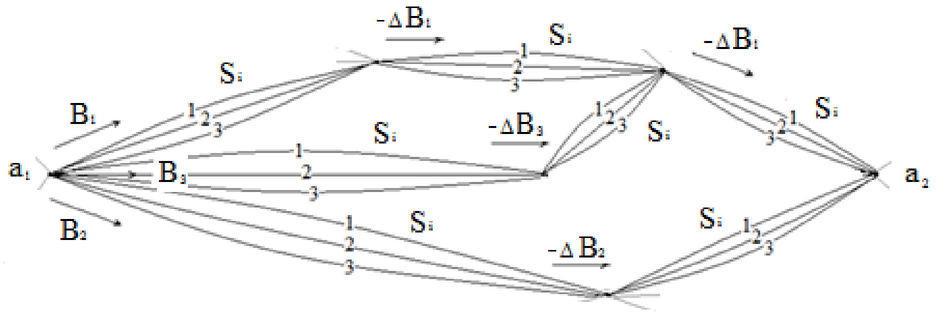

Fig. 2. Example of a random choice of the freight delivery route from point a_1 to point a_2 with different technologies: 1- by railway; 2-by road; 3-by multimodal

Taking into account the above, the formula was transformed for multimodal transportation with the participation of road and rail transport.

$$C(S_i) = \sum_j \sum_i \delta_i \frac{z_i}{A_i \cdot \prod_{i=1}^{m} \lambda_i} \rightarrow \min, \qquad (2)$$

де j – variable corresponding to the freight transportation route;

i – variable corresponding to the transport type, $i = \overline{1,n}$;

S_i – route for the freight delivery by various transport types, km;

δ_i – value of transport types, $\sum \delta_i = 1$;

z_i – transportation costs, conventional units;

A_i – beneficial effect of the transport operation, tran;

$\prod_{i=1}^{m} \lambda_i$ – coefficients reflecting the commercial return, reserve of dynamic properties, the ratio of vehicle maintenance costs over the service life to its cost, time reduction under technological operations, competitiveness and reliability of the vehicle.

Moreover, the beneficial effect is estimated as follows:

$$A_i = B_i \cdot v_i^2 \cdot S_i \to \max, \quad (3)$$

де B_i – mass of freight delivered by various transport types, t;

v_i – speed movement of the vehicle, km/h;

S_i – route for the freight delivery by various transport types, km.

The coefficients $\prod_{i=1}^{m} \lambda_i$ determined accordingly:

coefficient of commercial return λ_{1i}

$$\lambda_{1i} = \frac{p_i}{m_i}, \quad (4)$$

де p_i – load capability of a transport vehicle, t;

m_i – weight of the transport vehicle in the loaded state, t.

coefficient of reserve of dynamic properties λ_{2i}

$$\lambda_{2i} = \left(\frac{v_{max\,i}}{v_{p_i}}\right)^2, \quad (5)$$

v_{max_i} – maximum speed of the transport vehicle with freight, km/h;

v_{p_i} –calculated speed of a transport vehicle, km/h;

coefficient that takes into account the ratio of vehicle maintenance costs for the life cycle to its value λ_{3i}

$$\lambda_{3i} = \frac{k_{v_i}}{c_{v_i}} \quad (6)$$

де k_{v_i} – costs on maintenance of transport vehicles during the service life, UAH.;

c_{v_i} – transport vehicle cost, UAH.

coefficient that takes into account the reduction of time under technological operations λ_{4i}

$$\lambda_{4i} = 1 - \frac{r_i}{t_i}, \quad (7)$$

де r_i – increase in the value of time under technological operations by various technologies, h.

t_i – time value under technological operations using the basic technology, h.

The coefficient of competitiveness λ_{5i} and reliability of the vehicle λ_{6i} is determined in accordance with (Puzankov and Chetvergov, 2003), (Vasilevsky and Podzharenko, 2010), (Shapatina, 2013), (Lavrukhin et al., 2017).

Then the indicator that corresponds to transportation costs, taking into account the qualitative component for multimodal transportation, is determined.

$$C(S_i) = \sum_j \sum_i \delta_i \frac{z_i \cdot \left(1 - \frac{r_i}{t_i}\right)}{B_i v_i^2 S_i \cdot \frac{p_i}{m_i} \cdot \left(\frac{v_{max\,i}}{v_{p_i}}\right)^2 \cdot \frac{k_{v_i}}{c_i} \cdot \lambda_{5i} \cdot \lambda_{6i}} \to \min. \quad (8)$$

Under such limits:

$$\begin{cases} B_i > 0; S_i > 0; \\ \sum \delta_i = 1; \delta_i \geq 0; \\ S_1 \leq S_{ts}; S_2 \leq S_r; \\ S_1 + S_2 + S_3 \leq S_{dp}; \\ 0 < v_{p_i} \leq v_i \leq v_{max}. \end{cases} \quad (9)$$

де B_i – mass of freight delivered by various types of transport, t;

S_i – route for the freight delivery by various transport types, km.

δ_i – value of transport types;

S_1 – route for the freight delivery by rail transport, km;

S_{ts} – distance to the technical station, km;

S_2 – route for the freight delivery by road transport, km;

S_r – distance to the gas station or service station, km;

S_3 – route for the freight delivery by multimodal transport, km;

S_{dp} – distance to the destination point, km;

v_{p_i} – calculated speed of a transport vehicle, km/h;

v_i – vehicle speed movement, km/h;

v_{max_i} – maximum speed of the transport vehicle with cargo, km / h.

It should be noted that to determine the possible B_i and v_i it is necessary to take into account the value of the estimated lift and adjust them accordingly (Rules of grade computations for train service, 1985). In practice, for this, two masses of the composition B_2 and B_3, which are smaller than the critical mass B_1 at the calculated lift, must be set. For them, specific accelerating forces are calculated and a graph is constructed $v_i(S_i)$.

At the end of the largest (estimated) rise, the speeds v_2 and v_3 are obtained. Curves are constructed based on known values of composition masses and speeds $B_i(v_i)$ (Fig. 3).

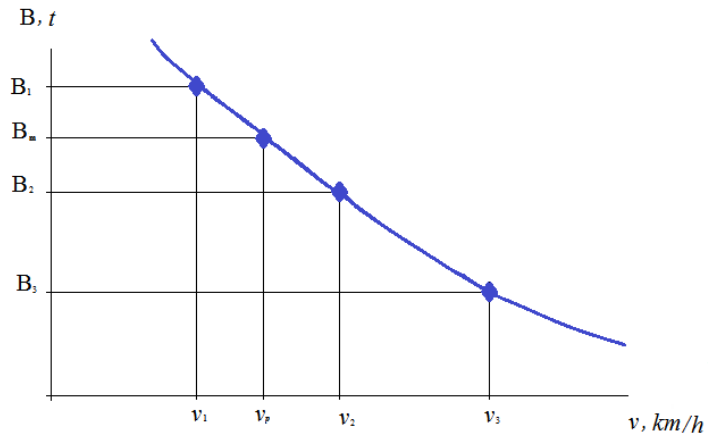

Fig. 3 Determination of the mass of the composition on the critical slope

Using this graph, determine the desired mass of the composition B_m at the computed speed v_p.

In general terms, the solution of this problem can be reduced to a linear programming problem or a dynamic programming problem. If the constraints have a nonlinear dependence, then dynamic programming with constraints that have a linear dependence will use the linear programming method.

It should be noted that the solution of the problem has a multifactorial influence of various factors on the performance of the problem. In analytical form, individual problems can be reduced to a solution to determine the optimal path. But in general, the formalization of such a solution is theoretically difficult to achieve; therefore, this problem is solved using optimization methods according to the structural diagram shown in Figure 4.

The possibility of limiting the volume of freight involves traction calculations. As part of these calculations, the estimated mass of a train or other vehicle, the average technical speed of the delivery of the freight to the place of unloading or transshipment point to another vehicle is determined. On the basis of the above method, the following graphical dependencies were obtained (Figure 5).

Using this nomogram, it is easy for the carrier operator to identify alternative vehicles to provide transportation for customers. Maneuvering these data, it is possible to correct routes, evaluate the critical mass of freight, and limit the speed of obtaining the minimum cost for transportation.

According to the above, when choosing the technology of freight transportation, the importance of each component of the qualitative indicator should be taken into account in any time period when making decisions, the implementation of the choice of the type of transport is shown in Fig. 6.

The results of determining the level of transportation costs by various transport technologies, taking into account the qualimetric component, are shown in Figure 7.

From the dependencies presented, it is possible to choose the optimal technology for freight transport to different delivery routes and a combination of transport types.

Thus, based on the analysis performed, it is shown that the efficiency is affected by the choice of a vehicle, taking into account the range of the optimal values of carrying capacity and the zone of transportation distance based on determining the optimal value of the qualimetric indicator.

In this formulation, the basic principles of logistics are implemented: a systematic approach (coverage of all logistic chains); individualization (adaptation to specific conditions); humanization (modern working conditions and exclusion of harmful effects on the environment); reduction of total transportation costs in market conditions; development of service at the modern level with flexibility, reliability.

So, the main criterion for choosing a route is transportation costs. When solving certain transport problems, it is often necessary to take into account some additional restrictions that were not encountered when considering simple variants of these problems. Recently, transport services have been paying attention to additional criteria, which include, for example, the possibility of receiving an order within a clearly defined time frame, high-quality information support for the order fulfillment process, etc.

Based on the optimal multimodal route obtained in the freight supply chain, cost calculations are made for various technologies of freight delivery, which depends not only on the route, but also on the volume and class of load (Congli and Yixiang, 2016).

Thus, the combination of two transport modes for the multimodal transportation organization will provide the necessary level of quality for the delivery and storage of goods, cost savings, and an increase in the competitiveness of rail transportation. Therefore, for multimodal transport, the cost is calculated taking into account delivery by train, which reduces costs by up to 50% and becomes especially beneficial when transporting bulk freight (Islam D.M.Z., 2014).

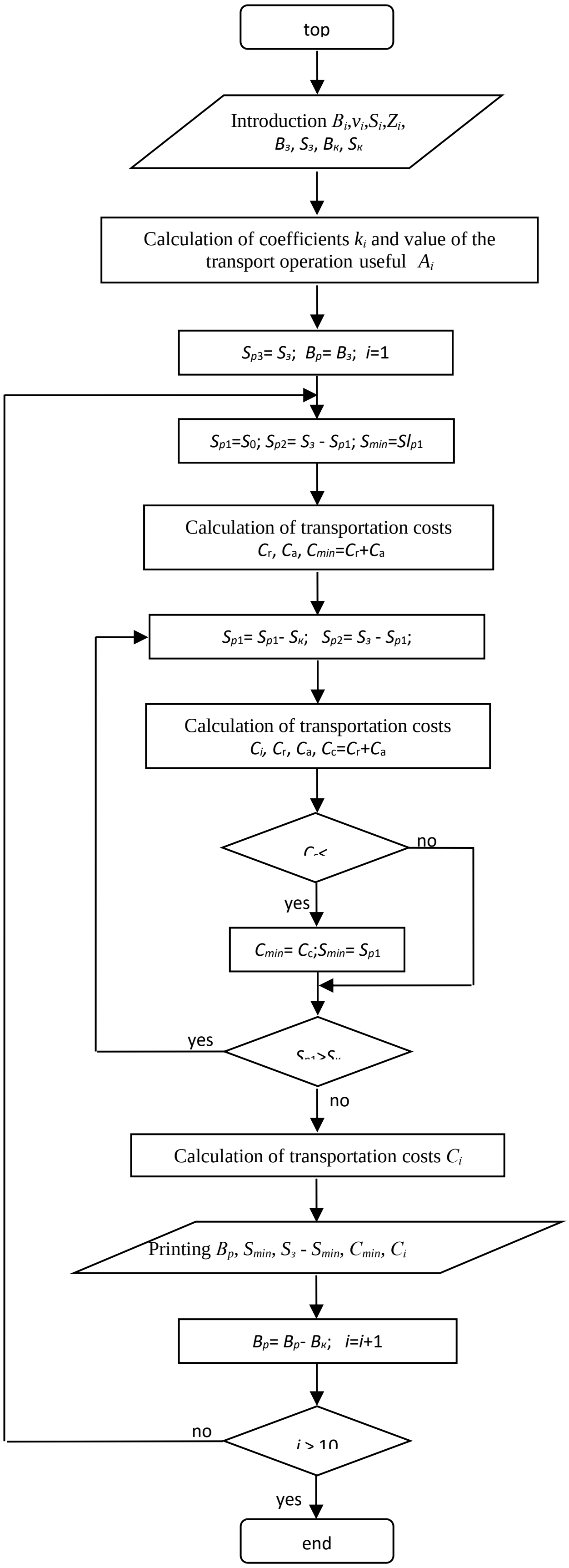

Fig. 4. Structural diagram of the transport technology selection algorithm

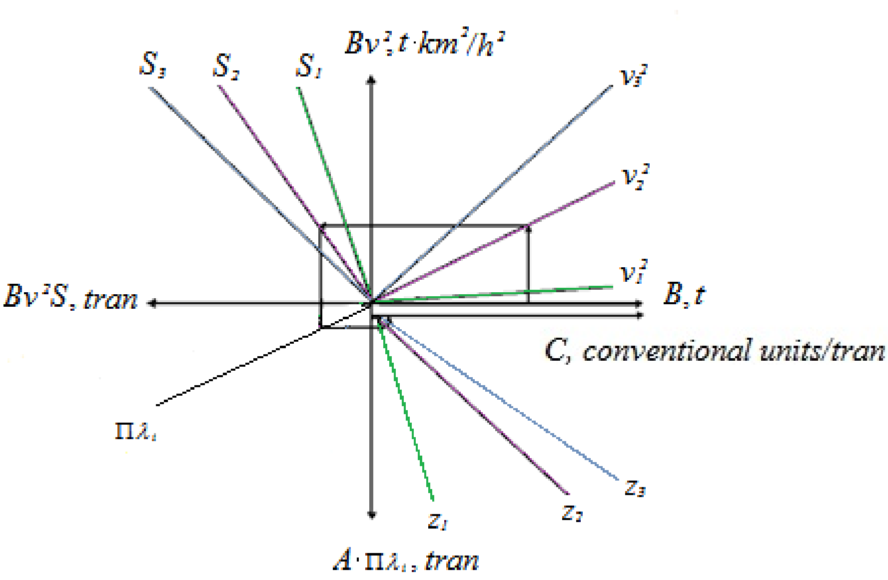

Fig. 5 Nomogram for determining the cost indicator with the qualimetric component

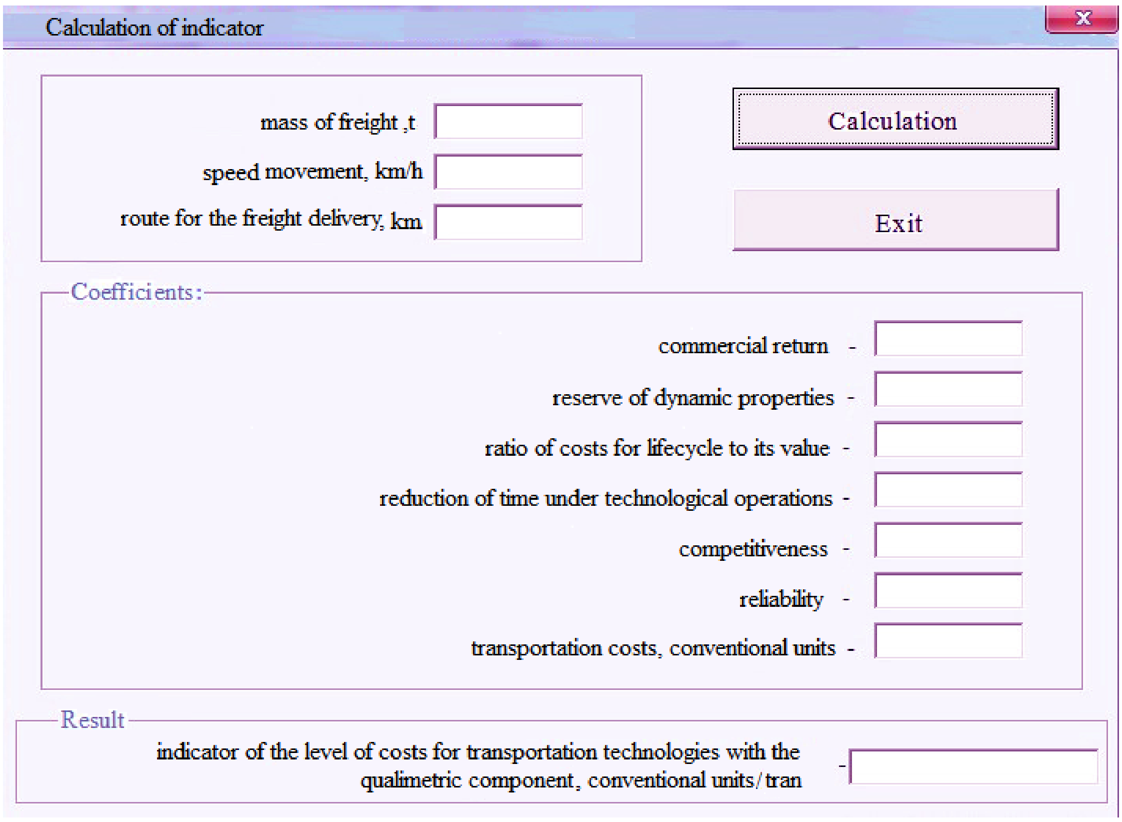

Fig. 6 Implementation of the choice of transportation type taking into account the qualimetric component

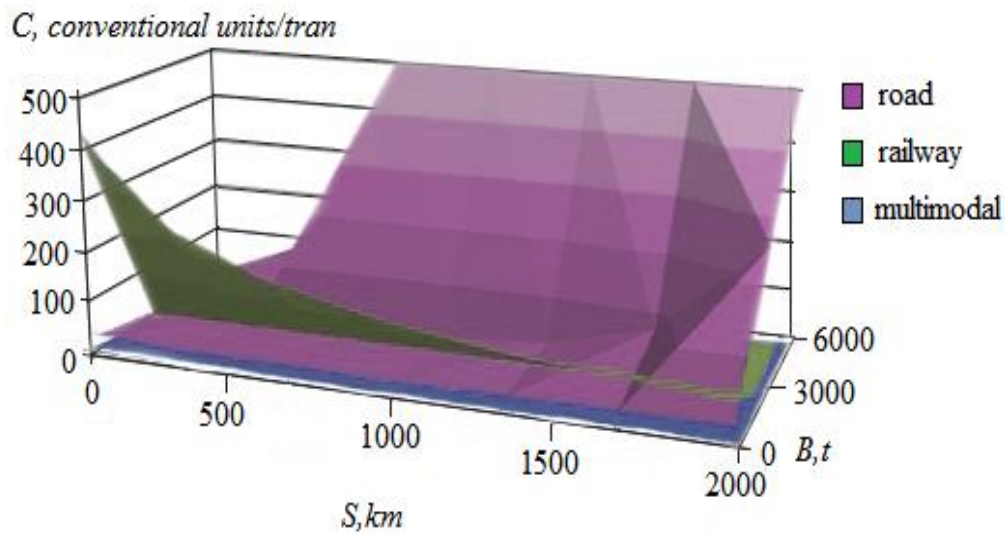

Fig. 7 Determining the level of transportation costs by various transport technologies taking into account the qualimetric component

DISCUSSION

Traditionally, in our country, railway transport occupies a dominant place in transporting large volumes of goods by land, and its work is estimated in terms of gross tons per kilometers. At the same time, the work of maritime transport is estimated by the size of the displacement, i.e., dead weight. However, in a competitive environment, the dominance of one transport mode is almost impossible. Especially when the demand for door-to-door delivery of goods is growing, the combination of transport modes in a single transportation chain becomes important.

It should be noted that the generally accepted criteria used to evaluate the operation of various transport modes do not provide an objective assessment of the transport efficiency, whereas they do not take into account an important factor for users as speed. At the same time, in some studies, attempts were made to take into account the freight delivery speed on the basis of the transport movement unit as a product of the main transport process indicators: the load weight, the distance of transportation, and the speed of freight traffic (Grebenikov et al., 1998). However, this indicator does not fully provide an objective performance evaluation of transport operation, therefore, in the study (Andrianov and Lopatin, 1983), a criterion for evaluating transport work was offered in the form of the so-called “tran” with the dimension tkm^3/h^2. ‘Tran’ consists of three components: the weight of the transported load, its transportation distance, and the speed square of the freight traffic.

This set of parameters characterizes the essence of the energy of mass transfer, that is, the kinetic energy of movement, equivalent to the work of transfering the load over a certain distance. As can be seen from the dimension of this unit, the dominant factor in the evaluation of transport operation is the speed factor (speed squared), which forms the basis of the transportation intensification process. That is, the unit ‘tran’ reflects and considers the known laws of nature, according to which work is spent overcoming the resistance forces that change according to quadratic laws of movement speed (Andrianov and Lopatin, 1983).

As world experience shows, in modern conditions, a significant number of freight owners have demanded from the carrier, first of all, to speed up delivery and not necessarily to minimize operating costs, which also shows the importance of taking into account the speed indicator when evaluating transport services. This is also evidenced by the need to solve the problem of improving multimodal transportation technology based on cost optimization, taking into account the qualimetric indicator aimed at maximizing the satisfaction of shippers when determining the route of such transportation parameters as the cost and quality of freight delivery, which are different in nature.

In addition, the results of the study on improving the functioning of the parts of multimodal freight delivery routes by minimizing transportation costs, with qualitative indicators, allow making decisions on the choice of freight transportation technology at a specific point in time, considering the importance of each criterion component (Fig. 5, 6).

The offered qualimetric indicator, with costs in conventional units, has the main advantage over the existing ones (Hanssen et al., 2012), (Steadie et al., 2014), (Mindur, 2021), (Pshinko et al., 2022), while it is systemic in nature, takes into account the integrity and consistency of all freight delivery processes, and evaluates the complexity of vehicle level indicators that have influence on the freight transportation efficiency.

In addition, this indicator can be used both to evaluate the performance of the interaction between road and rail transport, and for other modes of transport due to its complex nature. Its interpretation in graphical form has a convenient visualization in the form of a nomogram.

In the context of changing markets for transport services, it is a necessity to modernize service elements along the entire length of the supply chain. The main task of railway transport in these conditions is to balance the unpredictability of situations in the transport service market (Primachenko et al., 2022).

The current state of infrastructure, the necessity for effective development and coordination of railway, road, and maritime transport requires the continued development of the state transport network. At the same time, the state and degree of using the capacities and infrastructure of these transport modes indicates the presence of contradictions and inconsistencies, which worsen the transport service quality and reduce their work efficiency.

As a result of these tasks diversity, namely: for railway transport, which is one of the largest consumers of energy resources, the priority direction for the development of the industry is the introduction of resource-saving technologies, for road transport – ensuring the mobility of transportation, for maritime transport – the provision of quality services. Therefore, the improvement and development of the national transport potential requires the modernization of infrastructure, increasing the efficiency of transportation technologies in order to increase competitiveness and adapt to European transport standards.

The availability of multifunctional rolling stock is gaining momentum in the world. In particular, in the countries of western Europe and Japan, transportation by hybrid trains or tram-trains designed for both urban and railway traffic has become widespread. In our country, hybrid rolling stock is gradually developed in urban transport as a separate experience. The introduction of such rolling stock will help to prevent the threat of the disappearance of energy supply, reduce emissions of harmful substances into the environment, and ensure resource saving.

As the practice of world experience shows, the main measures to improve the functioning of transport based on logistic principles are real-time supply chain management, the selection and provision of the optimal route for freight delivery, the application of modern vehicles, which is just possible to implement on the specific 'tran" criterion .

Since real-time supply chain management technology allows one to receive data on the vehicles movement, weather conditions in a certain area, the state of roads or access roads, it will help to select the optimal delivery route, reduce time costs, and use energy resources efficiently based on the principle of consistency.

The primary task to improve freight delivery quality remains the task of ensuring the reliability and safety of transportation with the optimal route, which is reflected in additional coefficients introduced to evaluate the quality of transport service.

A promising direction for improving the efficiency of the transport industry is the implementation of transportation based on autonomous vehicles, which provides freight transportation without a driver, thereby reducing the influence of the "human" factor. Such a direction as the freight delivery by aircraft, for example heavy-duty quadrocopters, is gaining currency, the path of which will be selected over existing tracks and other infrastructure elements, ensuring the transportation of both goods and people (China tested a flying taxi drone with a pilot inside, 2022). A promising direction in the development of the logistic transport infrastructure is the introduction of robotics in warehouse operations, while providing access to any hard-to-reach places and having an extended inspection area. This measure allows to significantly increase the efficiency and speed of warehouse processes, ensuring the development of services at a modern level, at flexibility and reliability, also based on the “tran” indicator.

The introduction of such an indicator allows to track possible delays at the points of changing the transport mode and on the lines in dynamics, depending on the arrival time of the freight at a given point on the route, and also determines the optimal route not only by the criterion of costs, but also by the criterion of the transportation duration taking into account the qualimetric indicator.

Thus, to evaluate the quality of the transport technology, the following tasks were solved:

- a criterion for choosing the mode of transport for each section on the route has been formed;

- the optimal route for the freight delivery was determined;

- The value of the quality criterion of transport technology is determined on the basis of the developed algorithm, and a graphical dependence is built, interprets the effectiveness of the interaction between modes of transport for freight traffic.

The criterion for choosing a transport technology based on a qualimetric evaluation takes into account the freight transportation volume, the freight delivery speed, the route distance, the time spent on the moving, downtime during technological procedures, variable freight traffic in different periods of the year. Separately, within the framework of traction calculations, the task of estimating the maximum weight of the train and the average speed of traffic is performed, and based on linear or dynamic programming, the optimal route for the delivery is modeled, the mode of transport is selected, and the interaction between the transport modes is determined. At the same time, restrictions that may arise in case of traffic disruptions due to emergency situations and during repair work are taken into account. Based on the introduction of automated freight traffic management technology, a freight transportation route is selected, considering the network tension and the likelihood of vehicle failure, which will allow the change of route quickly and improve the quality and meet the demands of transportation.

Thus, the implementation of the task to improve the transportation management quality involves determining the optimal route for the freight delivery, searching for the optimal interaction of the transport modes including in particular multimodal transportation. The introduction of modern transport infrastructure technologies based on logistic principles will improve transport operations in general, reduce the impact of crisis situations on the economy, and ensure resource saving.

The resulting procedure for evaluating the quality of transportation management can complement traditional approaches to the formation of transport technologies, including new vehicles. The developed transport technology evaluation procedure can be used for non-discriminatory access to infrastructure.

CONCLUSIONS

The application of the models concerned in the railway marketing services will allow them to evaluate in advance the possible customers’ behavior in the transport service market and to take proactive measures to attract freights to the rail transport more effectively.

Therefore:

1. The model for evaluating the efficiency of using different modes of transport with optimal costs has been formed.

2. As a method for estimating the optimal delivery route and traffic volume, depending on the nature of the constraints, a linear or dynamic programming method is chosen.

The essence of economic efficiency lies in cost savings when designing multimodal freight delivery routes, which are carried out continuously and jointly by different modes of transport, which occur by reducing the time across the entire logistic network for freight delivery at the lowest cost and high quality of services performed for consumers based on a qualimetric indicator. The competitive advantage of the transport multimodality principle is that services are provided by only one carrier, while providing door-to-door delivery, thus becoming less costly and more efficient than when each of the carriers tries to maximize its profit on its own separate site in the logistic product supply chain.

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ORIGINAL PAPER

SUSTAINABLE SUPPLY CHAINS MODELING

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ABSTRACT. Background: Although existing studies have highlighted the importance of modeling sustainable supply chains, there is a scarcity of research that integrates environmental, social, and economic dimensions simultaneously. Accordingly, this paper aims to explore the possibilities of creating and modeling sustainable supply chains in the trefoil of economic, environmental, and social sustainability.

Methods: For creating and modeling optimal sustainable supply chains, we used the mathematical method of dynamic programming. The method of dynamic programming was chosen for the reason that dynamic programming represents a set of special mathematical methods that serve to optimize multi-stage or multi-phase processes.

Results: Minimum costs of the supply chain in the given example are achieved when the problem is solved from an economic perspective or from the perspective of total costs. Solving the problem from an ecological or social perspective increases the costs of the supply chain compared to optimal solutions, by 16.05% if the problem is solved from an ecological perspective and by 14.31% if the problem is solved from a social perspective.

Conclusions: Contemporary sustainable **s**upply chains are forced to include in their logistics network only those participants who can satisfy the principles of integral sustainability, i.e. respecting the economic, ecological and social dimensions.

Key words: supply chains, sustainable development, economic sustainability, ecological sustainability, social sustainability, dynamic programming

INTRODUCTION

"Slowbalisation" [Kandil, Battaïa and Hammami 2020], the COVID-19 crisis [Pupavac, Maršanić and Krpan 2021] and finally the war in Ukraine and the inflation associated with it put supply chain management at the forefront of scientists and logisticians around the world again. This management should be based on the principles of sustainability. Sustainability for the 21st century integrates environmental, social and economic dimensions [Govindan, Jafarian and Nourbakhsh 2015]. Global supply chains as open, dispersed, complex, dynamic, and stochastic systems [Zelenika and Pupavac 2008] are in a state of constant transformation and less and less security. New approaches to supply chain modelling put more focus on security and resilience. Managers are increasingly concerned that supply chains should be robust, not just efficient. The costs of such approach would fall on taxpayers, companies, and consumers.

In order to carry out this transformation in an efficient way, it seems appropriate to investigate the possibilities of creating and modelling sustainable supply chains in the framework of economic, ecological, and social sustainability. The scientific contribution of this work comes from the fact that it simultaneously optimizes the supply chain from different aspects of strong sustainability. According to the defined problem and goal of the investigation, a scientific question was set: Does ignoring any dimension of sustainability in the optimization of supply chains can result in unfavourable solutions, i.e., higher costs in the execution of supply chain activities? In order to achieve the aim and purpose of the research and to find answers to the scientific question, numerous scientific methods

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were applied, among which the analysis and synthesis method, the comparative method and the dynamic programming method stand out.

THEORETHICAL FRAMEWORK AND RESEARCH PROBLEM

Supply chains connect producers, processors, and suppliers, through traders and intermediaries (freight forwarder, agents, distributors, and carriers) with customers. Inside the supply chain, constant flows of information, products, and money take place. A typical supply chain is a network [Joshi 2022]. By analyzing individual stages in the execution of the business venture of supply chains and their participants, it is possible to determine some of the more important features of supply chains, such as: 1) every participant in the supply chain, apart from their own, should be guided by the common interest of the supply chain and, by rationalizing their operations, contribute to the rationalization of the operations of the entire supply chain; 2) supply chains can have different numbers of participants, different sizes and economic strengths; 3) participants within the supply chain can be permanent, occasional, or temporary; 4) supply chain participants can be local, national, regional, and/or global, 5) a supply chain is only as strong as its weakest link (participant); 6) the work of participants within the logistics chain must be synchronized and coordinated with market requirements.

An efficiently created supply chain is one that delivers the required product (service) to the right place, at the right time, in the right quantity, and at the right price. The profitability of the supply chain is determined from the function of the total profit that is shared between all active participants in the supply chain. Creating a supply chain starts with choosing the appropriate strategy: global, pan-European, regional, national, local. After that, it is necessary to make the optimal choice of supply chain participants and work on their competitive performance. Disruptions in supply chains caused by the COVID-19 crisis and the war in Ukraine have forced global supply chain leaders to change the paradigm of creating supply chains. Namely, an increasing number of managers of global supply chains decide on at least two suppliers of raw materials, on increasing stocks within the supply chain, regionalization of supply chains, and nearshoring. Nearshoring is a tactic that allows companies to move their operations to the closest country [Diaz 2021]. Therefore, the key challenges for supply chain managers are to create an effective and efficient supply chain network that will be robust enough to recover from any disruption and that also needs to have enough vigilance to provide the same sustainability in a disruption state. Adapting to these unanticipated disturbances, supply chain systems could abandon their sustainability goals.

Many scientists have investigated the modeling of sustainable supply chains in recent works [Mota 2018; Panigrahi, Bahinipati and Jain, 2019, Ghadimi, Wang and Lim, 2019, Zimon, Tyan and Sroufe 2019, Hoffa-Dabrowska and Grzybowska 2021]. Analysis of the literature demonstrates that the effectiveness of the supply chain is assessed not only in terms of business, but also in terms of its effects on the environment and the social system [Kot 2018]. According to Pagell and Shevcehenko [2014], a sustainable supply chain had “no harm on social or environmental systems while maintaining economic viability.” The supply chain is entirely sustainable, it will not have a negative impact on social or ecological systems, and it will generate long-term profits [Niño-Amézquita, Legotin and Barbakov 2017, Yang and Černevičiūtė, 2017, Abdel-Basset et al. 2020]. Mari, Lee and Memon [2014] point out that "increasing regulations for carbon and waste management are forcing firms to consider their supply chains from ecological and social objectives". Sustainable supply chains should be based on sustainable practices such as ethical sourcing, green purchasing, environmental purchasing, and logistics social responsibility [Agrawal et al. 2015, Ghadimi et al. 2017, Sarkis and Zhu, 2017].

DATA AND METHODOLOGY

Let’s say that for a product to be manufactured and delivered at the demand location within the supply chain, certain production and logistic activities need to be done and which can be classified into five phases (I-V): x_1 (procurement of raw materials), x_2 (production), x_3 (warehousing and land transport), x_4, (maritime transport), x_5 (selling), and for which within the global logistic system it is possible to engage 23 different participants: f_1, f_2, f_3...,f_{23}. A logistic operator is familiar with the engagement schedule of participants within the supply chain in carrying out single phases of the logistic undertaking (cf. Table 1).

Table 1. Production phases within the supply chain and potential supply chain participants

Phases of logistic process	Potential supply chain participants	Costs of each phase within the supply chain (in 000 €)			
1	2	3			
		Economic	Environmental	Social	Total
I. Delivery of raw materials Incoterms EXW - Ex Works	f_1 – Russia f_2 – Finland f_3 – Egypt	**10** 12 14	(35×0.03)=1.05 (25×0.03)=**0.75** (40×0.03)=1.20	(5)=2.5 (1)=**0** (10)=7	13.55 **12.75** 22.20
II. Production	f_4 – Czech f_5 – Romania f_6 – Poland f_7 – Slovakia	32 **22** 26 24	(32×0.03)=0.96 (40×0.03)=1.2 (25×0.03)=**0.75** (30×0.03)=0.9	(1)=**0** (10)=11 (5)=6.5 (5)=6	32.96 34.20 33.25 **30.90**
III. Warehousing and land carriage (railway operator, road transport operator)	f_8 – national railway operator f_9 – ABC Logistics	**6** 7	(0.7×0.03)=**0.021** (4.5×0.03)=0.135	(1)=**0** (5)=1.75	**6.021** 8.885
IV. Sea shipping (ship operators)	f_{10} - Global Alliance f_{11} - Grand Alliance f_{12} - Maersk-Sealand	8 **6** 9	(31.2×0.03)=0.936 (30.0×0.03)=**0.9** (33.0×0.03)=0.99	(5)=2 (5)=**1.5** (5)=2.25	10.936 **8.40** 12.24
V. Distribution (distributors in North America)	f_{13} – East Coast f_{14} – West Coast f_{15} – Canada	10 **9** 12	(2.8×0.03)=**0.084** (3.1×0.03)=0.093 (3.5×0.03)=0.105	(5)=2.5 (5)=**2.25** (5)=3.0	12.584 **11.343** 15.105
I., II.	f_{16} – Austria	30	(65×0.03)=1.95	(5)=7.5	39.45
II., III.	f_{17} – Switzerland	36	(40×0.03)=1,2	(1)=0	37.20
I., II., III.	f_{18} – GB	42	(75×0.03)=2.25	(5)=10.5	54.75
II., III., IV.	f_{19} – Croatia	40	(60×0.03)=1.8	(5)=10	51.80
III., IV., V.	f_{20} – Germany	28	(28×0.03)=0.84	(1)=0	28.84
III., IV.	f_{21} – Italy	22	(30×0.03)=0.9	(5)=5.5	28.40
IV., V	f_{22} – USA f_{23} – USA	20 18	(25×0.03)=0.75 (22×0.03)=0.66	(5)=5 (5)=4.5	25.75 **23.16**

Source: Own work

The assumption is that the supply chain produces and delivers 100 tons of goods per month. Economic, environmental, and social costs are arbitrarily estimated. Economic costs are the cost price of each stage within the supply chain. Environmental costs refer to pollution of rivers, air, environment, waste, and are expressed in monetary units in such a way that their cost is estimated at 30 EUR/t CO_2. The ecological costs of transport were estimated so that the CO_2 emission of truck transport is 150 g-CO_2/tkm, sea transport 39 g-CO_2/tkm and rail transport 20 g-CO_2/tkm [Niwa, 2009]. Social costs are estimated as a percentage of economic costs depending on whether there is a high (10), medium (5) or low (1) risk of unacceptable business behaviour within any supply chain participant. Unacceptable business behaviour means poor working conditions for employees, the use of child labour, or the practice of forced labour within the supply chain. If the public becomes aware of the practice of unacceptable behaviour within any participant in the supply chain, it can have adverse effects throughout the supply chain. Thus, the social costs were estimated for the existence of a high risk of unacceptable behaviour at 50% of the economic costs, the existence of a medium risk at 25%, and the existence of a low risk without costs for the respective supply chain participant.

Accordingly, in the continuation of this scientific discussion, using the mathematical method of dynamic programming, the supply chain was optimized from an economic, ecological, and social point of view, and the supply chain was optimized taking into account all three points of view, that is, from the point of view of total costs. The method of dynamic programming was chosen for the reason that dynamic programming represents a set of special mathematical methods that serve to optimize multi-stage or multi-phase processes. A large number of different problems from supply chain management can be presented in the form of multi-stage processes, which can be solved by applying the dynamic programming method.

MATHEMATICAL MODEL

It is possible to present the described production process within the supply chain by means of mathematical relations in the following way:

$x_i f_j = 1, i = 1, 2, ..., n; \quad j = 1, 2, ..., m$

if in the production phase within the global logistic chain x_i services of a potential logistic chain participant f_j are used.

$$\left(\sum_{i=1}^{k-(r-1)} x_{i+r-1}\right) f_j = k-(r-1), k \epsilon [1,n], r \epsilon [1,n]\ k > r, j = 1,2,\dots,m \qquad (1)$$

if in the k-(r-1) of the production phases within the global logistic chain and specifically from r, including the production phases r and k, services of a potential logistic participant f_j are used.

$x_i f_j = 0, \quad i = 1, 2, ..., n; \quad j = 1, 2, ..., m$

if for the production phase x_i services of a potential logistic participant f_j are not used.

Except for the aforementioned, the following requirements arising from the very nature of the problem should be taken into account.

$$\sum_{i=1}^{n} (x_i = n)$$

This means that the selected logistic production process within the global logistic chain has to be complete, i.e., it has to comprise all n phases.

$f_j = 1, j = 1, 2, ..., m,$

if in the selected logistic process the services of a potential global logistic chain participant f_j are used, and

$f_j = 0, j = 1, 2, ..., m,$

if in the selected logistic process the services of a potential global logistic chain participant f_j are not used.

Based on the data in Table 1 it is evident that some of the potential global logistic chain stakeholders could be engaged in several production phases within the logistic chain. Such conditions can be defined with the pair (x_i, f_j), $i = 1,2, ..., n; j = 1,2, ..., m$, which means that with this pair it can be defined whether during a single phase of the execution of the logistic process a potential participant f_j will be engaged or if his engagement is not possible in the given phase. If the potential participants in the logistic chain f_j, $j = 1,2, ..., m$ are allocated to every phase of the execution of the logistic process x_i, $i = 1,2, ..., n$, all possible conditions of the services production within the logistic chain will be obtained that can be marked with L.

Now, the optimal selection of participants can be set in the following way: from all *m* possible (potential) supply chain participants, those meeting all requested requirements are to be selected so that the criterion function

$$z^* = \sum_{(x_i, f_j) \in L} c(x_i, f_j) \quad (2)$$

with restrictions:

$x_i f_j \leq 1, i = 1, 2, ..., n; j = 1, 2. ..., m,$

$$\left(\sum_{i=1}^{k-(r-1)} x_{i+r-1}\right) f_j \leq k - (r-1), k \epsilon [1, n], k > r, j = 1,2, \ldots, m \quad (3)$$

$$\sum_{i=1}^{n} x_i = n$$

$f_j = \{^0_1 \; j = 1,2, ..., m.$

assumes maximum or minimum value. For the criterion function, the following can be taken: production costs within the logistic chain, time needed for executing production within the logistic chain, engagement of capacities needed for executing production within the logistic chain, engagement of people needed for production within the logistic chain (...).

Taking into account specific features of logistic processes and in order to bring the goods to the delivery point by appropriate transport means without unnecessary retentions and execution of additional logistic activities, it seems appropriate to describe the logistic process with the oriented network. Such networks are quite suitable for modelling practical logistic problems where solving the problem comes down to defining an extreme (shortest or longest) way.

In the oriented network G = (N, L), whose set of nodes N = $\{1,2,\ldots,n\}$, and branches (i, j) ∈ L, where is always $i < j$, based on the optimality principle, to define the shortest way between two nodes, for example 1 and n, it is possible to write the following recursive equation.

$$f(j) = \min_i \{f(i) + c_{ij}\} \; j = 2,3, ..., n \quad (4)$$

whereby

$f(1) = 0.$

RESARCH RESULT AND DISCUSION

Based on the data from Table 1, it is evident that in order to design an optimal network from an economic, ecological, social, or total cost aspect, it is not necessary to consider all potential participants, but only some of them. Thus, for example, in the second phase of the supply chain, out of four potential producers, namely f4 from Greece, f5 from Romania, f6 from Poland, and f7 from Slovakia with different production costs, the producers with the lowest costs will be selected. Thus, producer f2 will be selected from the economic point of view, producer f3 from the environmental point of view, f1 from the social point of view, and producer f4 will be selected from the point of view of total costs (economic, ecological, and social). With such an approach, it is possible to eliminate non-competitive participants in the supply chain, depending on the point of view from which the optimization is approached: economic, ecological, social or from the point of view of total costs. Once the non-competitive potential participants of the supply chain are eliminated, it is possible to approach the design of the appropriate supply chain network and to solve the problem thus posed.

The following shows the supply chain network from an economic point of view (cf. figure 1) and the supply chain network from the point of view of environmental costs (cf. figure 2).

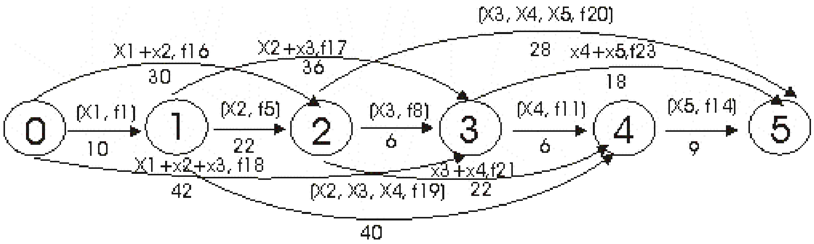

Fig. 1. Logistic network of potential qualified global supply chain participants from economic aspects
Source: Own work

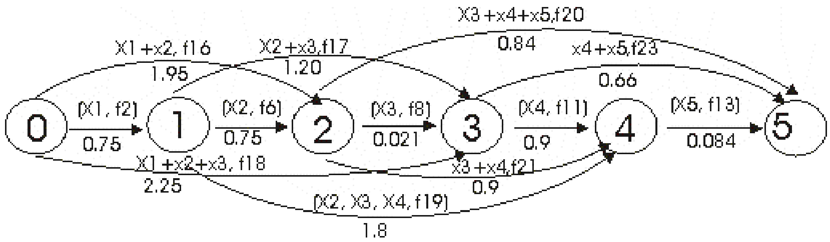

Fig. 2. Logistic network of potential qualified global supply chain participants from ecological aspects

Source: Own work

Above every branch of the logistic network (cf. *Figure 1* and *Figure 2*) a logistic chain phase is entered, as well as potential participants for carrying out a certain activity within the global logistic chain, and under the branches of the logistic network costs for carrying out a certain phase within the logistic chain are entered.

In the following, the problem of the shortest path in the network is solved from an economic point of view by applying the dynamic programming method. Other problems were solved according to the same principle, and the description of their solution is omitted. By applying the recursive expression, the following is obtained.

f(0) = 0 i f(1) = 10, and then

$$f(2) = \min \begin{cases} f(0) + c(x1 + x2, f16 = 0 + 30 \\ f(1) + c(x2, f5 = 10 + 22 \end{cases} \}=30$$

$$f(3) = \min \begin{cases} f(0) + c(x1 + x2 + x3, f16 = 0 + 42 \\ f(1) + c(x2 + x3, f17 = 10 + 36 \\ f(2) + c(x3, f8) = 30 + 6 \end{cases} \} = 36$$

$$f(4) = \min \begin{cases} f(0) + \infty = 0 + \infty = \infty \\ f(1) + c(x2 + x3 + x4, f19) = 10 + 40 \\ f(2) + c(x3 + x4, f21) = 30 + 22 \\ f(3) + c(x4, f11) = 36 + 6 = 42 \end{cases} \}=42$$

and finally

$$f(5) = \min \begin{cases} f(0) + \infty = 0 + \infty = \infty \\ f(1) + \infty = 10 + \infty = \infty \\ f(2) + c(x3 + x4 + x5, f20 = 30 + 28\} = 51 \\ f(3) + c(x4 + x5, f13) = 36 + 18 \\ f(4) + c(x5, f14) = 42 + 9 \end{cases}$$

which means that the length of the shortest way p*, i.e. the minimum value of the function of the target z* = d(p*) = 51, and this way is p* = (**0,2,3,4,5**). It means that in the global supply chain in the first and second execution phase the participant f_{16} will be involved, in the third phase the participant f_8, and in the fourth phase within the global supply chain the participant f_{11} will be involved and in the last phase the participant f_{14}. These active participants form a supply chain that will ensure the execution of the business venture at minimal economic costs in the amount of €51,000. The optimal supply chain formed from an economic point of view will have its associated ecological (€2,964) and social costs (€11,250), and the total costs of the supply chain formed from an economic point of view will amount to €65,214. An overview of other optimal solutions is given in Table 2.

Table 2. Overview of optimal solutions

Optimization by aspects	Optimal way on network	Supply chain participants	Economic costs (000 €)	Environmental costs (000 €)	Social costs (000 €)	Min total costs (000 €)
Economic	0,2,3,4,5	f16,f8,f11,f14	51	2.964	11.25	65.214
Environmental	0,1,2,3,5	f2,f6,f8,f23	62	2.181	11.5	75.681
Social	0,1,2,5	f2,f4,f20	72	2.55	0	74.55
Total costs	0,2,3,4,5	f16,f8,f11,f14	51	2.964	11.25	65.214

Source: Own work

Based on the data in Table 2, it is clear that the minimum costs of the supply chain in this example are achieved when the problem is solved from an economic perspective or from the perspective of total costs. The reasons for this should be the high economic costs within the supply chain, which highlights the importance of economic sustainability. Solving the mentioned problem from an ecological or social perspective increases the costs of the supply chain compared to optimal solutions by 16.05% if the problem is solved from an ecological perspective and by 14.31% if the problem is solved from a social perspective. It is also evident that it is possible to form a supply chain without social costs. The importance of optimizing supply chains is also confirmed by the data in Table 3, which contains an overview of the most unfavorable solutions. From experience, the most unfavorable solutions were obtained by solving the functions at their maximum.

Table 3. Overview of the most unfavorable solutions from experience

Solution by aspects	Way on network	Supply chain participants	Economic costs (000 €)	Environmental costs (000 €)	Social costs (000 €)	Max total costs (000 €)
Economic	0,1,2,4,5	f3,f,4,f21,f15	80	3.165	15,5	98.665
Environmental	0,2,3,4,5	F16,f9,f12,f15	58	3.645	14.5	76.145
Social	0,1,2,4,5	f3,f5,f21,f15	70	3.405	26.5	99.905
Total costs	0,1,2,4,5	f3,f,5,f21,f15	70	3.405	26.5	99.905

Source: Own work

Based on the data from Table 3, it is clear that the most unfavorable solution obtained when the function is solved at its maximum is 51.97% higher than the optimal solution from the perspective of total costs. The optimal supply chain optimized only from the economic perspective is more favorable by 51.29%, from the ecological perspective by 0.06%, and from the social point of view by 34.01%. Also, from Table 3, it is clear that all optimal solutions obtained are more favorable according to any criterion of sustainability than those solutions that ignore sustainability from any perspective, thus proving the set hypothesis.

CONCLUSION

Supply chains for the 21st century are forced to include in their logistics network only those participants who can satisfy the principles of integral sustainability, i.e. respecting the economic, ecological and social dimensions. Such an approach emphasizes that supply chains do not have only one goal, the creation of economic value, but that it is necessary that they emphasize the creation of ecological and social value as their priority goals. This means that the supply chain network should be cleaned as much as possible of those participants who cannot meet the requirements of integral sustainability. Participants in the supply chain who are unable to meet these requirements can seriously impair its competitiveness or, due to non-compliance with environmental and/or social requirements, contaminate the entire supply chain network. In order to ensure the competitiveness of the supply chain and avoid possible scandals, it is necessary to create and optimize a sustainable supply chain. The results obtained point to the conclusion that all optimal solutions obtained according to any criterion of sustainability are more favorable than those solutions that ignore sustainability from any perspective. The implications of this approach are to create robust and efficient supply chains. The main shortcoming of this work stems from the fact that the creation and modeling of a sustainable supply chain were dominated by an economic perspective. In future research, all three components of sustainability should be treated equally.

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ORIGINAL PAPER

AN ANALYTICAL HIERARCHY PROCESS-BASED DECISION MAKING FOR SUSTAINABLE MEDICAL DEVICES DEVELOPMENT

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ABSTRACT. Background: The medical device industry needs to be sustainable and should consider the safest, trusted quality and accessibility for use when they are required for patient diagnostic procedures. This study is conducted to identify the factors influencing sustainable development of medical devices.

Methods: The analytical hierarchy process (AHP) is being adopted to prioritize the influencing factors. Based on the classified criteria, the alternative factors are evaluated and compared with each other using AHP to make an optimal selection.

Results: The findings show that there are six main factors and seventeen sub-factors in this study that can support the development of sustainable medical devices. This study provides useful information for the medical device supplier to improve their current and future product design toward sustainable medical device development.

Conclusions: This study adds to the understanding of sustainable medical device development and its consequences on the intention to use from the consumer's perspective.

Keywords: medical device, new product development, sustainability, product management, analytical hierarchy process (AHP)

INTRODUCTION

The healthcare industry has evolved and has integrated various sectors that offer products and services to treat patient diseases effectively and in real time. The healthcare industry is considered one of the major sectors that incur a huge amount of expenditure. This is because this sector offers a modern treatment approach with the adoption of technological advancement. To achieve that, the process involved several areas such as medical device supplies, pharmaceuticals, and related medical technology. Currently, the healthcare industry is also constantly transforming into a sophisticated system through the use of modernised innovation technology [Bulatnikov & Constantin 2021]. Advances in medical technology are offering companies a great opportunity to introduce new innovative products to the market. At the same time, the quality of products and services has become the primary concern for medical device companies, which have been operating in an increasingly competitive environment.

Each medical device company has a different standard in defining product quality because many development processes are receiving a lot of attention. While it is a fact that the medical device industry considers three main features, namely safety, usability, and efficacy of a product. However, sustainable product design and development play a major role in these characteristics. Similarly, the requirement to become a sustainable manufacturing organization is another burdensome challenge faced by most of the industry players. Environmentally conscious design, green design, or sustainable design have become a major topic [Duangpun et al. 2019]. Sustainable product design is now a key component of significant

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change in business operations. It is in line with the Sustainable Development Goals (SDGs), no SDG 9 and SDG 12 on industrial innovation and infrastructure, and responsible consumption and production.

Medical devices play the most essential role in diagnosing, preventing, monitoring, alleviating, and treating diseases. It helps improve the quality of life by providing innovative healthcare solutions, including for people with disabilities. However, the medical device industry has a hard time identifying the influencing factors that contribute to sustainable product development. The particular problem with the industry is that the majority of suppliers in the healthcare industry business leaders struggle to minimize the expenses associated with product design and development [Erdogan & Tosun 2021]. However, the consensus of experts may not recognize the problems and obstacles associated with this situation due to a lack of knowledge of the industry environment. Therefore, the objective of this study is to investigate the factors for the sustainable development of medical devices.

This study contributes to both academics and practitioners. From the academic perspective, this study adds to the understanding of sustainable medical device development and its consequences on the intention to use from the consumer's perspective. Like this study, this study added value by offering insight to medical device suppliers to enhance their current product development. Customer experience is in fact important to encourage loyalty and future use of medical device products. This would be one of the competitive advantages among medical device suppliers.

This paper is divided into five sections. In Section 2, a literature review is presented followed by section 3 where a discussion on the methodology used for data collection and analysis is revealed. The results of the study are shown and discussed in Section 4 while section 5 deliberated on the conclusion and possible areas for further research.

LITERATURE REVIEW

The new tendency in contemporary business

Currently, various sectors are promoting sustainable product development towards strengthening their brand in the market and positioning themself in a competitive market. However, in the medical device industry, the application of product design and development in relation to the sustainability approach is still in the infancy stage. Furthermore, cost pressures, lack of knowledge, and lack of resources to invest in the process of business improvement are among the barriers that hinder industry players to opt for sustainable product development [Bitkina et al. 2020]. Furthermore, Guzzo et al. [2020] highlighted that healthcare providers are finding an innovative solution for a fruitful opportunity to optimize sustainable medical device supply chains, particularly green purchasing-related activities. In comparison, the adoption of sustainable practices in the manufacturing industry enables businesses to maintain a robust position that leads to long-term business success. It also complies with a monitoring requirement and gives new opportunities to run the business [Bag et al. 2020].

Product development

Product development involves the actions of creating a new product and bringing it to the marketplace or improving current products by adding more features to meet consumer demand and needs. The development of a medical device that provides a good quality product in both capital-intensive and technology-intensive environments requires the best set of human skills from different multidisciplinary backgrounds. It includes engineers and users, such as medical doctors, who are typically not actively involved in sustainable product development [Bitkina et al. 2020]. Therefore, the most important point in successful medical device product development is a well-defined overall design [Abdel-Basset et al. 2019]. However, traditional product design focuses on product functionalities, volume, and lower costs in meeting customer requirements. On the other hand, sustainable product design plans, company business model, company size, medical device products manufactured, and a systematic approach help manage products across the lifecycle.

Sustainable and eco-product design

To produce a sustainable product, specific requirements must be met from various stakeholders' perspectives. From the consumer's point of view, price and quality will be the primary concern. Quality is the measurement of product excellence or the state of being free of weakness [Yi & Liu 2020]. From the producer's perspective, aspects that are taken into account are materials, manufacturing process, product usage, and end-of-life product care [Ngatilah et al. 2018]. Well-designed and high-quality medical products are essential in providing safe conditions and effective clinical treatment to patients. To respond to all these matters, the design of the medical device and its functionality must meet the intended users when designing medical devices. Thus, stakeholders with different positions and backgrounds should be involved from the design stage to the product application.

Factors affecting sustainable product design and development

To produce a sustainable product, the product itself must meet the user's requirements. However, there are other factors that users are looking at before a purchase decision. Table 1 shows some of the most prominent influencing factors related to this study based on previous research.

Table 1. List of the influencing factors

Main factor	*Sub-factors*	*Source*
Price	Affordable concerning quality, High concerning quality	[Weber 2020; Zhang et al. 2018]
Quality	Operating quality, Speed, Durability, User-friendliness, Energy saving	[Behera & Dash 2018; Zhang et al. 2018; Weber 2020]
Service	On-time service, Easy maintenance	[Majchrzak-Lepczyk & Bober 2016; Zhang et al. 2018]
Reliability	No toxic material released, Safety and security	[Chanques et al. 2020; Chen & Liu 2016]
Appearance	Size, Weight, Portable, Stationary	[Gannam et al. 2018; Kaspar & Vielhaber 2017]
End-of-life	Recyclability, Disposability	[Guzzo et al. 2020; De Aguiar et al. 2017]

The top of the list is the price of the product itself. It refers to the affordable price with respect to the quality of the product. The customer is always looking for a reasonable price that suits the quality of the product over other aspects. Customers may choose to buy a product that is durable for long-term use due to financial constraints [Weber 2020]. However, if they could find a good quality product at a less expensive price, that would be more attractive. On the other hand, high-quality products usually come at a high price. However, for healthcare products, quality is the priority because it is related to patient life [Zhang et al. 2018].

The second important factor is the operating quality. It refers to how well the product can operate towards improving a patient's life. This can be found when the product is tested and used at the point of consumption. It also includes speed, which is considered the main concern of product performance or the ability of the product capability [Zhang et al. 2018]. Similarly, product durability is also important, in terms of the resilience that the product possesses in the environment in which it is used. Customers are also looking for a product that is user-friendly [Weber 2020]. Quality is also concerned with the energy savings of a product that consumes less electricity [Behera & Dash 2018].

The next factor is the service offered by the product. It includes on-time service, which is the service delivery of the product when it is ordered or needed. This requires clear communication between the respected providers and users. Therefore, an agile response is needed to ensure smooth processes from point of origin to point of consumption [Zhang et al. 2018]. Comparable products with easy maintenance will be highly demanded. Furthermore, assembling the components of the product affects the start-up times and the quality of the product's performance. Therefore, it is important to ensure that the service offered during and after sale can sustain the competitive advantage [Majchrzak-Lepczyk & Bober 2016].

Like in the case above, reliability is another important factor of consideration. No toxic material released is a sub-factor of consideration. This is because it can damage environmental health when the product is disposed of either in a landfill or in an incineration site. Therefore, the material selected for the product must be checked in detail [Chen & Liu 2016]. Similarly, safety and security are also important in that no adverse event should happen when the product is in use. In particular, some products can be accessed by wireless connection, hence, the system control must be highly secure. It is also important to ensure that the safety and security of the product are maintained [Chanques et al. 2020].

Next, the other important factor is appearance. Appearance is associated with the size or dimensions of the whole product [Gannam et al. 2018]. Different product sizes may be needed for different purposes, depending on the condition of use. Subsequently, the appearance also relates to the portability of the product. It is the ability of the product to be brought in or moved from one place to another. Additionally, stationary is also important in the aspect of product appearance. It refers to a product that cannot be moved from one place to another. For example, CT scanners and other infusion devices are designed to remain in the same position due to the system's complexity, size, and weight [Kaspar & Vielhaber 2017].

Finally, the end-of-life factor that includes recyclability is another factor to consider. It is the ability of a material to be captured and separated from a waste stream for conversion or reuse. The environmentally-conscious consumer will consider a product that is able to recycle or reuse [De Aguiar et al. 2017]. The end-of-life of the product is important towards a resilient supply chain. Thus, the material used to manufacture the product should be able to be reprocessed and redefined for reuse or converted to new material after the product comes to end of life [Guzzo et al. 2020].

Analytical Hierarchy Process (AHP)

AHP is one of the most commonly applied tools in many fields. It is a decision-support method that can be used to deal with both quantitative and qualitative data. AHP consists of hierarchical structure objectives including the main criteria, sub-criteria, and alternative factors. It was introduced by Saaty in 1980. In this study, AHP uses expert judgments to identify medical devices that are worthy for product development. AHP is a supporting tool for decision-making that is used to solve complex problems [Improta et al. 2019]. Unal et al. [2021] proposed a new product development model in real estate by integrating data mining with AHP in market analysis. Henrique dos Santos et al. [2018] applied AHP in a bank to identify programs or services that the bank should offer to customers. Compared, Yang et al. [2020] used the AHP method to determine prioritization of customers' requirements by linking it to the NPD process. Furthermore, Gholizadeh and Fazlollahtabar [2021] developed a generic model for self-assessment in SMEs. In this field of study, numerous studies report on the successful use of the AHP method to identify and evaluating the key driving factors.

METHODOLOGY

AHP application

The AHP is a method of measurement through pairwise comparisons of factors, objects, or elements, which depend on the judgments of experts to establish priority scales [Hussain et al. 2015]. Comparisons are initially made by using an absolute scale of judgments that reveal how much more important one element may be than another. In addition, one element dominates another element concerning a given attribute. The AHP method is a multi-criteria decision-ranking process that enables the user to work with both tangible and intangible factors.

A) Hierarchy decomposition

AHP is a supporting tool to help break down this complexity. When it is applied in decision-making, it assists the authors to describe the general decision in operation by decomposing a complex problem into a multi-level hierarchic structure of objectives, criteria, sub-criteria, and alternatives. Hence, it enables the authors to easily find the optimal solution.

B) Pairwise comparison

Pairwise comparison required the authors to assume that the set of n objects which represent the alternatives among all of the criteria of the same level in a hierarchy are the set of weights, respectively. Consequently, the authors proceed to compare the weight of each object in the following form:

$$\begin{matrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \frac{w_1}{w_3} \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \frac{w_2}{w_3} \cdots & \frac{w_2}{w_n} \\ \frac{w_3}{w_1} & \frac{w_3}{w_2} & \frac{w_3}{w_3} \cdots & \frac{w_3}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \frac{w_n}{w_3} \cdots & \frac{w_n}{w_n} \end{matrix} \quad => \quad A = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \frac{w_1}{w_3} \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \frac{w_2}{w_3} \cdots & \frac{w_2}{w_n} \\ \frac{w_3}{w_1} & \frac{w_3}{w_2} & \frac{w_3}{w_3} \cdots & \frac{w_3}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \frac{w_n}{w_3} \cdots & \frac{w_n}{w_n} \end{bmatrix}$$

This is called the matrix of pairwise ratios

$$A = (a_{ij}), \quad a_{ij} = \frac{w_i}{w_j}, \quad i, \quad j = 1, 2, 3, \ldots, n.$$

in which
The coefficients of matrix A are defined according to the following rules:

a) If $a_{ij} = \frac{w_i}{w_j} = \alpha$, then $a_{ji} = \frac{1}{w_i / w_j} = \frac{1}{\alpha}$ in which $\alpha \neq 0$ and the possible value of $\alpha \in E =$ (1 to 9), E is the pairwise comparison scale shown in Table 2 below.

b) If w_i is as important as w_j, and then $a_{ij} = 1$, $a_{ji} = 1$. In particular, $a_{ii} = 1$ $\forall_i = 1, 2, 3, \ldots, n$. Therefore, the matrix of the pairwise comparisons for each pair becomes:

$$A = \begin{pmatrix} 1 & a_{12} & a_{13} \cdots & a_{1n} \\ \frac{1}{a_{21}} & 1 & a_{14} \cdots & a_{2n} \\ \frac{1}{a_{31}} & \frac{1}{a_{32}} & 1 \cdots & a_{3n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{n1}} & \frac{1}{a_{n2}} & \frac{1}{a_{n3}} \cdots & 1 \end{pmatrix}$$

which is called a reciprocal matrix.

Table 2. AHP pairwise comparison scale

Intensity	*Importance*	*Examination*
1	Equal	Two criteria have the same quality value.
3	Moderate	One is slightly more important than the other.
5	Strong	One is strongly more important than the other.
7	Very strong	One is dominantly more important than the other.
9	Extreme	One is extremely more important than the other.
2,4,6,8	Intermediate	When the comparison requires a compromise.

Note: Reciprocals of the above numbers when there is an inverse comparison [Source: Hussain et al. 2015]

The reciprocal matrix is the main matrix equation that essentially leads to the final answer. However, before reaching the goal of the answer, it is necessary to set the coefficients for each element of matrix A. To this end, a questionnaire is designed to allow experts to assign values concerning the scale shown in Table 2 above.

C) AHP solution

The authors now should proceed to consider a linear equation system. The aim is to look into how the solution of this equation appears by reason.

$A \cdot x = y$ in which $x = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}$ $y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}$

To form this equation explicitly, it can be made in the form: $\sum_{j=1}^{n} a_{ij} \cdot x_j = y_j$, $i = 1, 2, 3, \ldots, n$. On the other hand, the equation $a_{ij} = \frac{w_i}{w_j}$ can be rewritten in a different form by simply multiplying both terms with $\frac{w_j}{w_i}$. As a result, the new equation looks like $a_{ij} \cdot \frac{w_j}{w_i} = 1$, $(\forall i, j = 1, 2, 3, \ldots, n)$. Then the authors are required to sum up this equation again with respect to j, and the whole equation becomes: $\sum_{j=1}^{n} a_{ij} \cdot \frac{w_j}{w_i} = n$ or $\sum_{j=1}^{n} a_{ij} \cdot w_j = n \cdot w_i$, $i = 1, 2, 3, \ldots, n$. This expression can take the form of $A \cdot w = n \cdot w$ as a linear equation. It can also be rewritten in the form of a matrix as shown below:

$$\begin{pmatrix} 1 & a_{12} & a_{13} \cdots a_{1n} \\ \frac{1}{a_{21}} & 1 & a_{14} \cdots a_{2n} \\ \frac{1}{a_{31}} & \frac{1}{a_{32}} & 1 \cdots a_{3n} \\ \vdots & \vdots & \ddots \vdots \\ \frac{1}{a_{n1}} & \frac{1}{a_{n2}} & \frac{1}{a_{n3}} \cdots 1 \end{pmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \vdots \\ w_n \end{bmatrix} = n \cdot \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \vdots \\ w_n \end{bmatrix}$$

This matrix equation shows the concept that w is the vector of weights or priority vector and the main eigenvector of A, in which n represents the range of its value. Accordingly, this equation can be written in the form of $A \cdot w = \lambda_{\max} \cdot w$, in which $\lambda_1, \lambda_2, \lambda_3, \ldots, \lambda_n$ are n solutions of the eigenvalue. However, in the real practice of AHP, there is no value of w and λ. There is only the coefficient of the matrix A taken from the questionnaire. More complicatedly, there will be more than one expert making judgments in some special conditions. Although these things are inherent, Saaty [1980] recommended using the geometric mean when there are many experts. Therefore, the reciprocal matrix above develops as follows:

$$A = [a_{ij}]_{n \times n} = \begin{bmatrix} 1 & \sqrt[m]{\prod_{k=1}^{m} a_{12}} & \sqrt[m]{\prod_{k=1}^{m} a_{13}} \cdots \sqrt[m]{\prod_{k=1}^{m} a_{1n}} \\ \frac{1}{\sqrt[m]{\prod_{k=1}^{m} a_{21}}} & 1 & \sqrt[m]{\prod_{k=1}^{m} a_{23}} \cdots \sqrt[m]{\prod_{k=1}^{m} a_{2n}} \\ \frac{1}{\sqrt[m]{\prod_{k=1}^{m} a_{31}}} & \frac{1}{\sqrt[m]{\prod_{k}^{m} a_{32}}} & 1 \cdots \sqrt[m]{\prod_{k=1}^{m} a_{3n}} \\ \vdots & \vdots & \ddots \vdots \\ \frac{1}{\sqrt[m]{\prod_{k=1}^{m} a_{n1}}} & \frac{1}{\sqrt[m]{\prod_{k=1}^{m} a_{n2}}} & \frac{1}{\sqrt[m]{\prod_{k=1}^{m} a_{n3}}} \cdots 1 \end{bmatrix}$$

Importantly, Saaty [1980] mentioned that a simple way to obtain an approximated solution is as follows:

1. Sum the value in each column of the pairwise matrix:

$$S_{ij} = \sum_{j}^{n} C_{ij} \quad (j = 1, 2, 3, \ldots, n)$$

$$= (sc_{11}, sc_{12}, sc_{13}, \ldots, sc_{1n})$$

2. Divide each element in the matrix by each column total to generate a normalized pairwise matrix:

$$X_{ij} = \begin{bmatrix} \frac{1}{sc_{11}}\cdot 1 & \frac{1}{sc_{12}}\cdot\sqrt[m]{\prod_{k=1}^{m} a_{12}} & \frac{1}{sc_{13}}\cdot\sqrt[m]{\prod_{k=1}^{m} a_{13}} \cdots & \frac{1}{sc_{1n}}\cdot\sqrt[m]{\prod_{k=1}^{m} a_{1n}} \\ \frac{1}{sc_{11}}\cdot\frac{1}{\sqrt[m]{\prod_{k=1}^{m} a_{21}}} & \frac{1}{sc_{11}}\cdot 1 & \frac{1}{sc_{13}}\cdot\sqrt[m]{\prod_{k=1}^{m} a_{23}} \cdots & \frac{1}{sc_{1n}}\cdot\sqrt[m]{\prod_{k=1}^{m} a_{2n}} \\ \frac{1}{sc_{11}}\cdot\frac{1}{\sqrt[m]{\prod_{k=1}^{m} a_{31}}} & \frac{1}{sc_{12}}\cdot\frac{1}{\sqrt[m]{\prod_{k}^{m} a_{32}}} & \frac{1}{sc_{13}}\cdot 1 \cdots & \frac{1}{sc_{1n}}\cdot\sqrt[m]{\prod_{k=1}^{m} a_{3n}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{sc_{11}}\cdot\frac{1}{\sqrt[m]{\prod_{k=1}^{m} a_{n1}}} & \frac{1}{sc_{12}}\cdot\frac{1}{\sqrt[m]{\prod_{k=1}^{m} a_{n2}}} & \frac{1}{sc_{13}}\cdot\frac{1}{\sqrt[m]{\prod_{k=1}^{m} a_{n3}}} \cdots & \frac{1}{sc_{1n}}\cdot 1 \end{bmatrix}$$

3. Sum the value in each row of the pairwise matrix:

$$S_{ij}^{*} = \sum_{i=1}^{n} C_{ij} \qquad (i = 1,2,3,...,n)$$

$$= \left[s^{*}c_{11}, s^{*}c_{21}, s^{*}c_{31} ... s^{*}c_{n1} \right]^{T}$$

4. Divide each row total by the n-dimensional of the matrix to get the weighted matrix:

$$W_{ij} = \frac{S_{ij}^{*}}{n} \quad (\forall i, j = 1,2,3,...,n)$$

$$W_{ij}^{*} = [w_{11}, w_{21}, w_{31}, ..., w_{n1}]^{T}$$

The main consideration for practitioners when the AHP method is applied is the notion of consistency. The method which involves the eigenvalues in the solution of the linear equation helps practitioners to quantify the distance for its condition of consistency. As a small variation in a_{ij} implies a small variation in $\lambda_{\max}$, then the result of $(\lambda_{\max} - n)$ can be taken as a measure of the consistency expressed in matrix A. The authors define the notion of the consistency index as the ratio:

$$CI = \frac{(\lambda_{\max} - n)}{n - 1}$$

$$\lambda_{\max} = (sc_{11}, sc_{12}, sc_{13}, ..., sc_{1n}).[w_{11}, w_{21}, w_{31}, ..., w_{n1}]^{T}$$

n dimension of matrix A

CI is compared with the random index (RI) that is randomly generated by forcing reciprocal matrices. When n ranges from 1 to 15, it is estimated as the average in a sample where there is an increasing number from 100 to 500. This experiment was performed by Saaty [1980]. As a result, the consistency index table is formed as shown in Table 3 below.

D) Consistency evaluation

Table 3. Random consistency index

N	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty 1980

The ratio:

$CR = \frac{CI}{RI}$ defines the consistency ratio (CR).

As an empirical rule grounded by Saaty [1980], if CR is less than or equal to 0.10, it is assumed that the quality of the comparison derived from the experts' judgments is acceptable. When judgments do not align with reason, the decision maker should be given the opportunity to have another quick review of the comparison for each pair.

Input data for the model

The application of AHP produces a set of factors and sub-factors, generally called sub-criteria. Comparison is made in order to choose the best selection. Data is collected from the interviews based on the questionnaire with the 15 participating experts. After the evaluation criteria have been accepted by the interviewees as appropriate, a questionnaire is developed to gather primary data, which are the pairwise comparison judgments between each pair of main criteria and sub-criteria and the performance scores of each factor under each criterion. The data gathered from the questionnaire is analyzed by applying the statistical method and the AHP model to find the relative importance level, weighted performance score under each criterion, and the overall weighted main criteria and sub-criteria performance score.

RESULTS AND DISCUSSION

The data collected from the 15 experts was then analysed using Microsoft Excel. Comparison is made in order to choose the best selection. The geometric mean is applied to get the common data. Afterwards, the authors proceed with the AHP calculations to deal with the factor's consistency. The final result of the AHP is the multiplication between the score of the sub-criteria and the main criteria as listed in Table 4.

Table 4. Final result of the prioritization

Main factor	*Sub-factors*	*Main criteria*	*Sub-criteria*	*Result*
Price	Affordable concerning quality	0.039	0.166	0.006
	High with respect to quality	0.039	0.834	0.033
Quality	Operating quality	0.273	0.124	0.034
	Speed	0.273	0.133	0.036
	Durability	0.273	0.226	0.062
	User-friendliness	0.273	0.217	0.059
	Energy saving	0.273	0.299	0.082
Service	On-time service	0.133	0.547	0.073
	Easy maintenance	0.133	0.453	0.060
Reliability	No toxic material released	0.275	0.252	0.069
	Safety and security	0.275	0.748	0.206
Appearance	Size	0.079	0.173	0.014
	Weight	0.079	0.141	0.011
	Portable	0.079	0.429	0.034
	Stationary	0.079	0.258	0.020
End-of-life	Recyclability	0.202	0.741	0.150
	Disposability	0.202	0.259	0.052

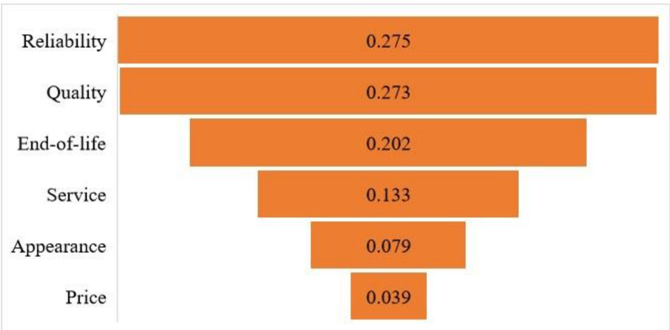

Fig. 1. Prioritization of main-criteria

Furthermore, the result shows that material selection is the highest priority among the other influencing factors. Follow by recyclability (0.150). This means that medical device users are concerned with the quality of the product not only for present use but also for the future of the product, which refers to after the end of its life. This is in line with the SDG agenda and is similar to a study done by Behera and Dash [2018]. In comparison, customers may not want the product to be disposed of (disposability=0.052). This means that they expect the manufacturer to ensure that the product can be recycled rather than disposed of. In addition, energy saving (0.082) is the third priority that product users find to be an important factor. Because sophisticated medical devices run on electricity, decent energy utilization may not only be able to save hospital expenses, nevertheless, it may also avoid triggered access when products are being operated at demanding times.

Moving forward, the value of 0.073 represents the on-time service. It refers to the service provided by the medical device company within both product delivery and after-sales service. Service delivery is critically important in hospitals because the product must be used to support patient lives and ensure adequate and effective processes in the healthcare business [Majchrzak-Lepczyk & Bober 2016]. Between the present use and after use of the product, safety and security (0.206) are more important than durability (0.062), user-friendliness (0.059), operating quality (0.034), and product speed (0.036). This contributes to the two factors of data quality and function quality. However, customers also demanded that all products should be able to function without having problems. If any unfortunate situation occurs, the product should be easy to repair or easy to maintain (0.060). Furthermore, if the product cannot be repaired, it is assumed that it will reach the end-of-life phase, which is required for disposal or recycling. This action also has an economic benefit for other businesses, such as product recycling businesses, where the refined material can be used to produce or remanufacture other high-quality products.

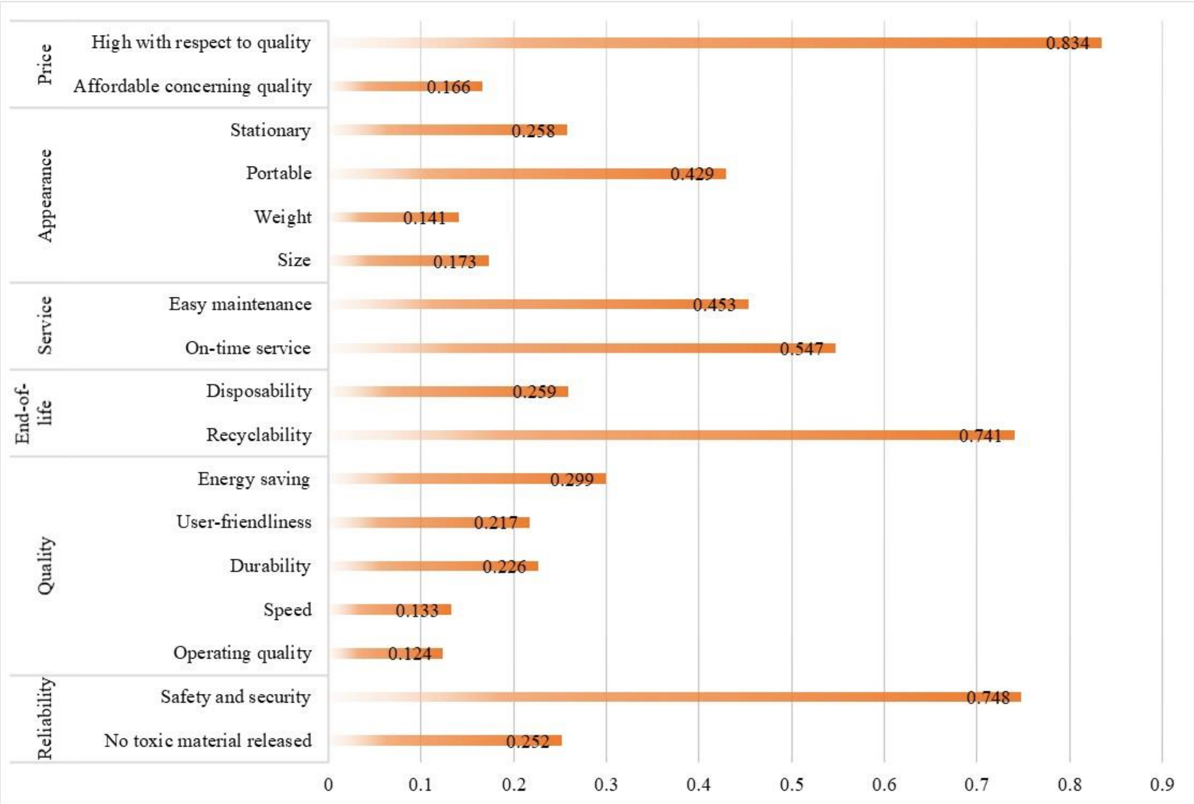

Fig. 2 Prioritization of sub-criteria

However, durability, operating quality and product speed are always in the user's mind. If the product is easy to use, the level of satisfaction continues at a high level, as exemplified in Figure 2. Among product appearance, being portable (0.034) has the highest value compared to stationary (0.02), size (0.014) and weight (0.011). A portable product is one that can be moved from one place to another. In the context of the healthcare sector, a patient may be moved from one place to another based on his condition. Therefore, it is necessary to be equipped with portable medical devices to avoid jeopardizing the patient's life. Stationery products can also be important given the complexity of some medical devices that cannot be moved, such as CT scanners and other diagnostic equipment. Note that a high price with high quality is more important than a low price with low quality. This is related to the devices being used by humans. Therefore, it is important to ensure that no risk is allowed when using the medical device [Weber 2020]. Even though the values of the above factors and sub-factors are arranged in descending order, they all play a role in ensuring the good quality of the product. These influencing factors will enable perceptions that can influence healthcare hospital procurement staff to rethink before deciding to buy medical products.

In the healthcare sector, patients need a sense of confidence and hope that the treatment service provided can improve or save their lives. To provide effective service, the hospital needs a set of skills ranging from skilled doctors and nurses to other related agencies, drugs, and technology. Green initiatives can also help to win public acceptance for hospital services. Furthermore, it also has the potential not only to save the planet, but also to enhance a business's bottom line. However, it takes much effort on the way to become an eco-friendly hospital. It involves many aspects such as green building design, energy efficiency, mode of transportation, food, water, waste management, and technology usage. Going green also involves optional things which can offer benefits to medical staff, patients, and the environment. Especially, being a green or sustainable hospital helps to increase the hospital's reputation and image.

CONCLUSION AND DIRECTION FOR FUTURE RESEARCH

Business can be created not just by operating in the way that an enterprise wants to, but it also has to pay attention to and the observe both the inside and outside environment. Therefore, collecting all the right information from stakeholder requirements and including them in the process is the engine of success. The product users and developers are two sides of the same coin that cannot be separated. The result of this study shows the growing awareness of sustainability in the healthcare industry towards a resilient supply chain. This means that designers are tending to take responsibility for using medical products that can reduce any side effects on the environment and conserve natural resource utilization. It is suggested that future research should be conducted using the Data Envelopment Analytic Hierarchy Process (DEAHP) approach. It is one of the most suitable solutions for possible influencing factors. This study helps to shed light for future researchers or those who are new in the field of medical products to turn their attention to conducting further research by taking into account the concept of sustainability toward the SDG agenda.

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ORIGINAL PAPER

APPLICATIONS OF PERFORMANCE INDICATORS FOR OPTIMIZATION OF HUMANITARIAN CHAINS

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ABSTRACT. Background: Humanitarian operations are a key contribution to alleviating human suffering and reducing property damage. The success of these measures is conditioned by the implementation of efficient and sufficiently flexible logistics chains. The specificity of the conditions for the distribution of material aid requires the preparation of a suitable distribution system, the necessary capacities, and the creation of conditions to achieve the flexibility of individual solutions. The key issue for the implementation of the humanitarian aid distribution itself is the identification of suitable performance indicators, considering the specifics in the individual phases of humanitarian aid implementation.
Methods: The approach is based on the research and content analysis, followed by creating a conceptual model and workflow diagram using interviews with experts, and identifying key performance indicators for optimization within the case study.
Results: The humanitarian supply process was identified through a workflow diagram. A model was built to illustrate a case study of the use of rail transport to the provide humanitarian aid to Ukraine crisis in 2022. Performance indicators are compiled for the model. Recommendations are formulated for the creation of suitable indicators of the performance of humanitarian logistics chains.
Conclusion: A gap and research problem in performance improvement and its measurement is identified within humanitarian logistics. This study examines the opportunity to improve the performance of humanitarian distribution to Ukraine in 2021.

Keywords: Humanitarian logistics, optimization of humanitarian chains, key performance indicators

INTRODUCTION

In recent years, there has been an increasing number of incidents requiring a response from humanitarian supply chains (HSCs). Academic interest has also increased in the last 15 years and humanitarian logistics is becoming an independent research discipline. This is coupled with an increase in interest from the commercial sector and a political inclination to engage in humanitarian operations. Humanitarian organisations (HO) are receiving more financial sources, and their capabilities are increasing. As capacities expand, interest increases in improving the efficiency of humanitarian aid delivery.

The specificity of the conditions for the distribution of material aid requires the preparation of a suitable distribution system, the capacities, and the creation of conditions to achieve the flexibility of solutions. The key issue for the implementation of the humanitarian aid distribution itself is the identification of suitable performance indicators, considering the specifics of the humanitarian sector.

This paper deals with the development of a conceptual model of humanitarian aid distribution and explores options for applying key performance indicators (KPIs). Subsequent optimization is based on a case study based on data from a HOs.

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CONDITIONS FOR DISTRIBUTION IN THE HUMANITARIAN SECTOR

In practice, several constraints affect the effectiveness of the distribution of humanitarian aid. This issue is described comprehensively in the literature [Kovács & Spens, 2011]. However, the research area is relatively young compared to the commercial sector. Based on keywords, 200 articles and conference papers dealing with the performance of humanitarian supply chains can be searched in the leading databases Web of Science (WOS) and Scopus [Repík and Foltin, 2022a]. This is countered by Thomas and Kopczak's [2005] prediction that disaster death rates will increase over the next 50 years.

The conditions that affect the performance of HSC are rooted in the main differences between the humanitarian and commercial sectors. HSCs typically operate under uncertainty and time pressure. Several logistical complications are often encountered in humanitarian deliveries (e.g., destroyed or disrupted infrastructure, the need to obtain storage space and personnel, or means of transport and handling). An infrastructure problem usually has two possible scenarios:

- the constraint improves over time (e.g., high winds);
- or the constraint expands with time (e.g., war or floods).

Given the chaotic environment, an analogy for HSCs can be found in military supply chains [Repík and Foltin, 2022b]. Researchers have identified several challenges facing HSCs in trying to measure and improve performance. As the main problems, Sawhill and Williamson [2001] identified difficulty and cost in linking HO's annual efforts to the reflection of those efforts on the organisation's mission. Van der Laan et al. [2009] discovered data accuracy problems and that performance indicators are not geared toward future improvement. Similarly, Abidi et al. [2014] found that it is challenging to link the performance of HSC to their objectives. Schiffling and Piecyk [2014] described the influence of different stakeholders who each define objectives differently, which causes problems in defining milestones.

In the case of the HO for our case study, several additional conditions that affect performance were defined and that may not apply to other HOs. One of the main shortcomings is human resources (HR), which is due to the organisation's volunteer structure. HR affects many aspects from data collection in the field to the ability to sustain long-term workload [Repík and Foltin, 2022a]. Especially the data collection problem is a significant limitation in subsequent optimization attempts [Tulach and Foltin, 2019]. Another specificity is the lack of funding, which is largely dependent on public interest and media attention [Schiffling and Piecyk, 2014; Repík and Foltin, 2022a]. The problem is also the variability of events. In the last 3 years alone we have seen floods, tornadoes, pandemics, and a war accompanied by a massive refugee wave on the territory of the Czech Republic [Repík and Foltin, 2022a].

Based on the above, insufficient coordination between individual actors in humanitarian aid and entities providing distribution services in affected regions was identified as the main research gap. From the point of view of the urgency of the required humanitarian aid, the uncertain and uncertain conditions of the distribution of this aid, there is a requirement for synchronized optimization of individual transport and distribution services, including the subsequent processes of humanitarian logistics.

OBJECTIVES AND METHODS

The purpose of the research is to identify the possible approaches to optimize the available humanitarian aid distribution capacities and their effective use in phase delivery.

RQ: What are the key workflow aspects of HSC and their optimization possibilities through KPI and conceptual modelling?

The primary aim of the paper was identified as the necessity to develop a conceptual model of humanitarian transport to Ukraine using freight trains and to investigate KPIs by which the performance can be measured in further research. The first step is a detailed description from a process-oriented and object-oriented perspective.

Our approach is based on the research and content analysis, followed by creating a conceptual model and identifying KPIs for subsequent optimization within the case study. Data were collected and the model was built in collaboration with the Czech Red Cross (CRC). The model was drawn using the diagrams.net platform and model was converted into Simio software.

IDENTIFICATION OF PERFORMANCE INDICATORS IN THE AID DELIVERY PHASE

Researchers have developed several approaches over the last 20 years. Among the most well-known is the use of methods that are commonly used in the commercial sector, e.g., the Balanced Scorecard (BSC) by Kaplan and Norton [1992], the Supply Chain Operations Reference (SCOR) model by Supply Chain Council [2010], or modifications thereof [Abidi et al., 2014]. Researchers also use a variety of modern tools, e.g. Mukhopadhyay and Roy [2016] discussed the use of Radio-Frequency Identification (RFID) to increase the efficiency of HSCs. However, emerging technologies have not yet been seen much in the sector. This is related to the limited budgets and skills of HOs. However, based on data from the WOS and Scopus databases, the use of modelling and simulations is no longer unknown (see Figure 1).

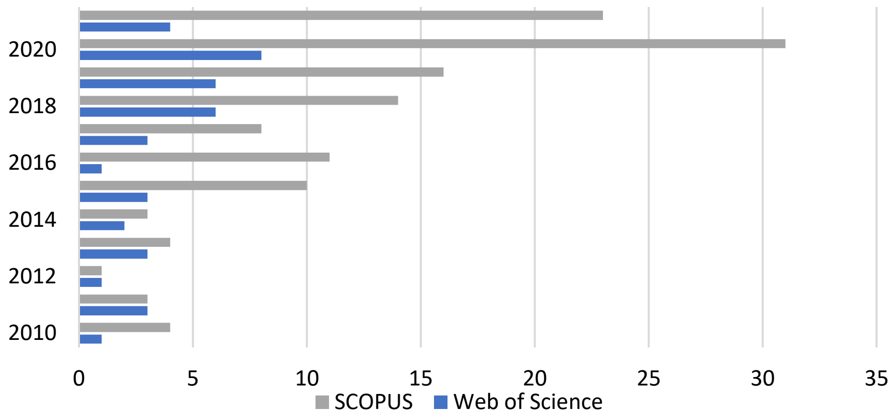

Fig. 1. Number of publications on humanitarian supply chains combined with modelling and simulations between 2010 and 2021
Source: [own]

Setting performance indicators is problematic due to differences between operations, long-term and short-term interventions, and the pre-disaster and post-disaster phases [Repík and Foltin, 2022a]. Therefore, there is a need to investigate indicators that are general enough to be generalisable. However, there is the trap of over-generalisation.

At this point, logistics in the aid delivery phase was separated from the improvement of the HSC as a whole. There are several reasons why it is relevant. Van Wassenhove [2006] states that nearly 60-80 % of the costs incurred in humanitarian operations are due to logistics activities. Balcik [2017] notes that effective logistics management is a key objective in the management of HSC. For logistics performance monitoring, we suggest the use of indicators:

- response time;
- lead time;
- percentage of successful deliveries;
- use of transport capacity in reverse flow;
- logistic cost.

The use of transport capacity in reverse flow can be challenging to meet. However, this indicator is related to the European Commission's (EC) assistance efforts in Ukraine [European Commission, 2022]. It is possible to use reverse flow material, e.g. in the form of packaging and waste, or use of the commercial sector requirements for exports from Ukraine.

The last option brings additional benefits, e.g., support of the Ukraine's economic recovery.

CASE STUDY

Intense fighting broke out in Ukraine on 24 February 2022. As a result, millions of people have been in need, and a refugee crisis has emerged. Our study focuses on supplies to meet the huge and urgent needs in Ukraine. Overall, 92,5 tons of humanitarian aid worth more than EUR 2 300 000 were transported by the CRC during the reviewed period (see Table 1). All of the material was based on active demand. However, there was the problem of low demand for train transport in each order. The items were transported during 23 missions.

Table 1. List of transport materials

Specification		Weight (kg)	
Medical material	trauma sets		5029
	surgical material		6640
	medicines and disinfectants		3723
	medical supplies		15110
	rescue tents		1180
	medical backpacks		200
	external fixators		1320
	transport aids		1058
	gurneys		4050
	other		6043
Food & water			30854
Drugstore goods			8977
Emergency equipment			4930
Electronics			2126
Other			1216
Overall			
Boxes		560	pcs
Pallets		264	pcs
Tons of material		92.456	t
Worth of material (CZK)		58 334 517.92	CZK
Worth of material (EUR)		2 330 944.55	EUR
Number of cars used		32	pcs
Number of kilometres travelled		40532	km

Source: (Czech Red Cross data)

Data based on road transport can be used for comparison in the simulation software to see how train transport performs compared to road transport. The maximum allowed train length in the Czech Republic is 720 m and the maximum weight can be set at 25 t per wagon of 27 wagons [Pohl and Michálek, 2018]. The length varies with infrastructure capacity and legislation in different countries. Based on research by Allianz pro-Schiene [2006], up to 89% of freight trains in Germany in 2006 were less than 700 meters long. Therefore, we count on a train length of 600 meters when demand is high.

CONCEPTUAL MODEL

In cooperation with the CRC and other partners, a visualised HSC for train transport is highlighted in Figure 3. In the next step, we transferred the model to Simio (see Figure 2). This is relevant for further research, where we will explore scenarios through simulations. The main reasons we based our model with train transport mode can be found in economic, environmental, and geopolitical aspects. As concerns individual means of transports, e.g. to switch from road to rail transport is in accordance with the European Commission, for example the European Commission [2021]. The savings of train transport compared to road transport are about EUR 30 000 per consolidated train. The price of fuel is rising, and the EU is trying to reduce its dependence on Russia. Train transport is less environmentally impactful. However, there are disadvantages, e.g. the need for large volumes of freight, or the different track gauges.

We designed a workflow diagram (see Figure 4). In the context of humanitarian aid, there are several possible scenarios for the flow of information and materials, among the most common are:

1. demand side requests goods and transport;
2. demand side requests only transport;
3. HO offers goods and transport;
4. private actors offer goods (and/or transport) through a HO, which offers to the demand side.

We place importance on active demand. In practice, it is often the case that humanitarian situations are targeted for political and commercial marketing purposes. This principle corresponds to Schiffling's and Piecyk's [2014] customer-oriented approach. It is also needed to check the inquiry for items that are against humanitarian principles (e.g. military material), or special authorisation requirements (e.g. the Regulation on the International Carriage of Dangerous Goods by Rail (RID)). Failure to meet demand is usually based on the fact that these entities are against the principles of a HO.

In the transportation phase, we need to evaluate the different alternatives based on cost, risk, and speed for the maximization of 7Rs.

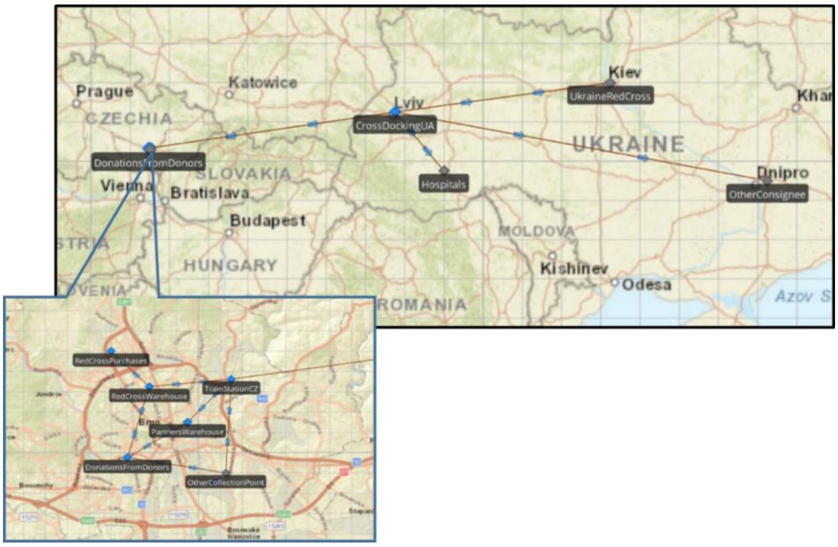

Fig. 2. Model of the supply chain in Simio
Source: (own)

DISCUSSION OF RESULTS

The research goal was the identification of possible approaches, which could contribute to increasing of the overall capabilities of the humanitarian aid, through the application of KPI and conceptual modelling. On the basis of the Ukrainian humanitarian case study, the conceptual model was developed. This model could be considered as a base for further optimization steps of the HSC. Measuring and improving HSC performance has long been a research gap. This problem was already identified by Blecken [2010]. On the basis of our investigation, it can be confirmed as a constant occurrence in our HO. Behl and Dutta [2019] identified a number of studies that examine the performance of HSC. However, there is still a problem with empirical validation. Kunz and Reiner [2012] state that HOs cannot fully control the performance of HSC. However, the performance of systems can be improved by improving the performance of its parts.

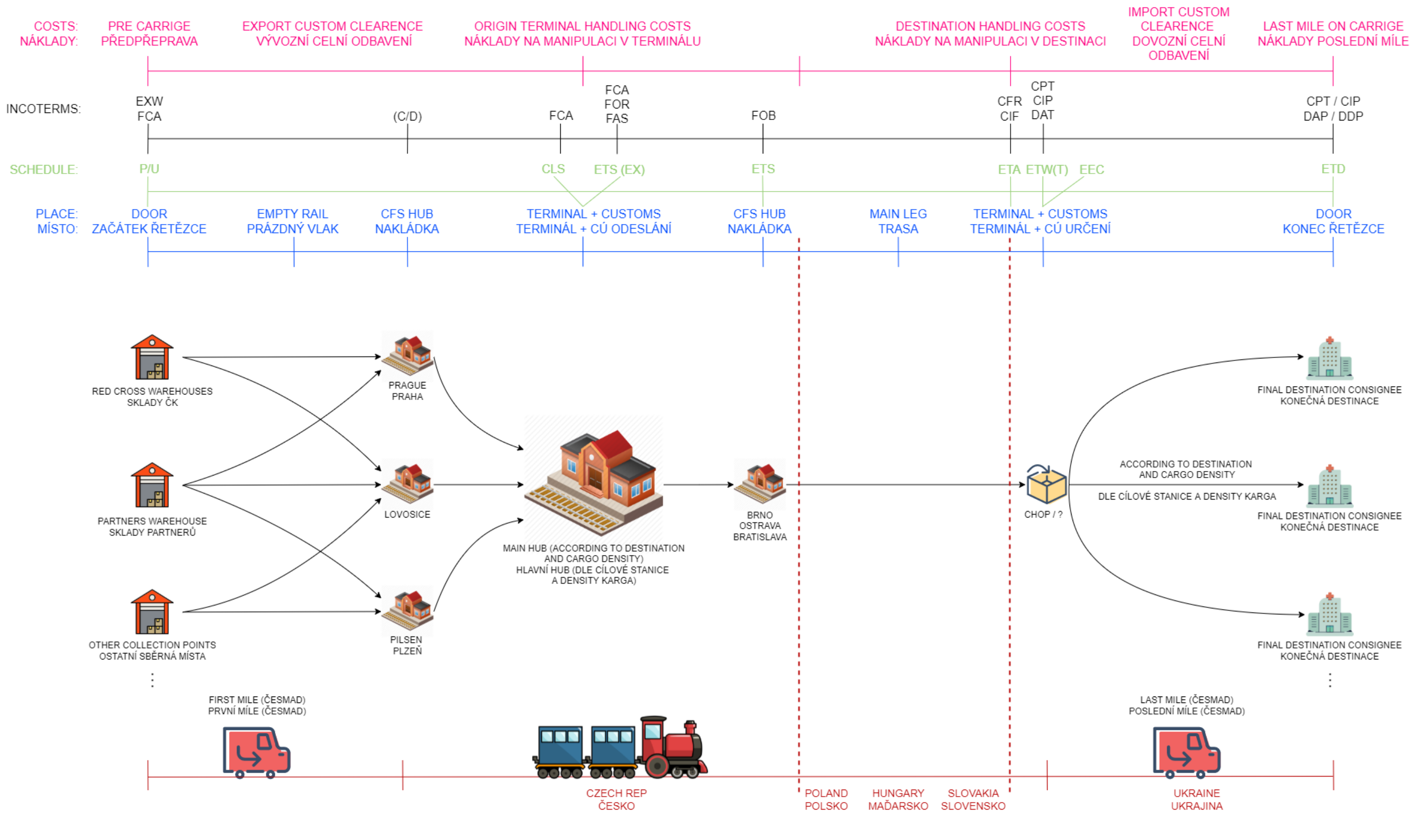

Fig. 3. Model of the supply chain

Source: (own)

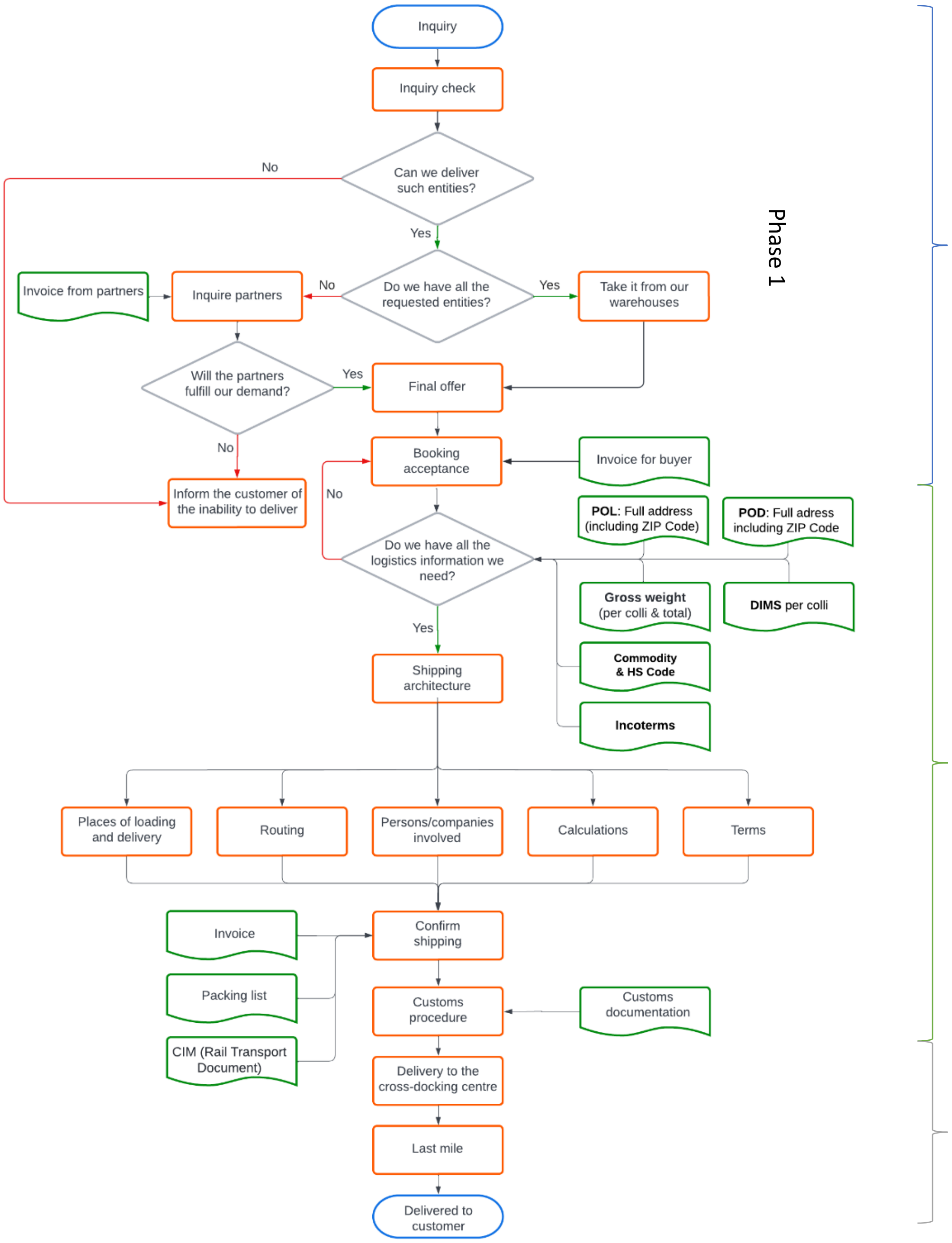

Fig. 4. Workflow diagram for the delivery of humanitarian aid

Source: (own)

The research question is answered through the outcome of the conceptual modelling and created workflow diagram. As an important step, the synchronization of workflows with other partners in affected areas and the synchronization on the main transportation network infrastructure were identified. Dubey et al. [2020] confirm that information sharing and collaboration in humanitarian operations increase the agility of the HSC. Within the conceptual model, three main phases of preparation and implementation of humanitarian aid were identified. Based on the generalization of the prepared research, the overall distribution process could be divided into a three-phase functional algorithm for the distribution of humanitarian aid. We build the model to be considered generally useable for various types of humanitarian operations. This should be further validated in practice and research.

As a research limitation, the availability of suitable data sources could be considered. This corresponds to the overall uncertainty which is characteristic for all humanitarian operations

For further research, it is recommended to develop the conceptual model within the modelling/simulation environment for the dynamic discrete event, e.g. Simio software, which allows us to use the agent approach at the same time. Based on a review article, Anjomshoae et al. [2022] summarize that simulations are a useful tool for HSC performance management. Our data show an increasing trend in the number of articles dealing with simulations in HSC. The crucial element for these next steps will be data farming and its availability and validity. Van der Laan et al. [2009] identified data as a big problem for the HSC back in 2009. This problem is still relevant. For example, Sigala et al. [2020] are looking for a solution in ERP systems for HSC, but this is still a distant solution in our HO.

CONCLUSION

The provision of humanitarian assistance is an increasing concern with the increasing number and variability of adverse events. Today, society is becoming aware of the need to address social aspects of human activities. On the basis of the research results, humanitarian aid must be treated with a certain degree of rationality within the whole supply chain.

The conceptual model is based on a real case study and develops a proposal for the distribution of humanitarian aid. In this specific case, rail transport was found to be the most economically advantageous mode of transport for ensuring the transport and distribution of humanitarian aid. Rail transport is more cost-effective over long distances than road transport. This is exactly the situation that may arise when Ukraine's post-conflict reconstruction phase begins. The situation will be characterised by the long distance and the large amount of cargo to be transported.

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ORIGINAL PAPER

GENETIC BASED ALGORITHMS TO SOLVING MULTI-QUAYS BERTH ALLOCATION PROBLEM WITH SETUP TIME CONSTRAINTS

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ABSTRACT. Background: This study focuses on efficient berth planning in multi-purpose terminal composed of multiple quays. A multi-quay berth offers infrastructure, equipment, and services for different types of cargo and vessels to meet the needs of users from various freight markets. Moreover, each berth from any quay can be dedicated for one or two different types of cargo and vessels. To improve port efficiency in terms of reducing the waiting time of ships, this study addresses the Multi-Quay Berth Allocation Problem (MQ-BAP), where discrete berthing layout is considered along with setup time constraints and practical constraints such as time windows and safety distances between ships. Sequence dependent setup times may arise due to the berth can convert from dedicated function to another function according to the variance of cargo demand. This problem was inspired by a real case of a multi-purpose port in Thailand.

Methods: To solve the problem, we propose a mixed-integer programming model to find the optimal solutions for small instances. Furthermore, we adapted a metaheuristic solution approach based on Genetic algorithm (GA) to solving the MQ-BAP model in large-scale problem cases.

Results: Numerical experiments are carried out on randomly generated instances for multi-purpose terminals to assess the effectiveness of the proposed model and the efficiency of the proposed algorithm. The results show that our proposed GA provides a near-optimal solution by average 4.77% from the optimal and show a higher efficiency over Particle swarm optimization (PSO) and current practice situation, which are first come first serve (FCFS) rule by 1.38% and 5.61%, respectively.

Conclusions: We conclude that our proposed GA is an efficient algorithm for near-optimal MQ-BAP with setup time constraint at acceptable of computation time. The computational results reveal that the reliability of the metaheuristics to deal with large instances is very efficient in solving the problem considered.

Keywords: Multi-Quay, Berth Allocation Problem, Genetic algorithm, Sequence-Dependent Setup Times

INTRODUCTION

Maritime transport contributes to more than 80% of the world's seaborne trade and is considered significant transportation for global trade and the economy. In 2020, sea freight accounted for 10.7 billion tons. The value is slightly lower than the total transportation of sea freight in 2019, resulting from the COVID-19 epidemic around the world. In the past 10 years, the ocean freight volume has continuously increased. In addition, in 2022, the average growth rate is expected to be 2.4% per year [UNCTAD, 2021].

Due to the increased volume of ocean freight volume, the demand for port services has increased accordingly. Therefore, each port must develop strategies to compete or attract customers to use their ports. The key strategy is to enable it to provide integrated services. Especially the berth expansion and adjust according to demand trend for loading and unloading changes over time. As a result of the strategies mentioned above, the current port has become more extensive. There is a more complicated operation, including more flexibility to use highly competent port management methods to maximize port efficiency.

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The Berth Allocation Problem (BAP) is a critical problem of seaside port operations and is affected by the change in the competitive port strategy. BAP are related to the allocation of berths for each ship that will use the service. Included allocation of the berth position and the berthing time for the arriving vessel. Regarding spatial dimension, there are three types of berth layouts: discrete layout, continuous layout, and hybrid layout. The discrete layout is the most basic layout where the quay area is clearly divided into several berths, and each berth can be serviced by only one vessel at any time. For the continuous layout, the quay area is not divided into several berths and the arriving vessel can berth in any quay area without overlapping. The hybrid layout is similar to discrete layout but ships can occupy one or more berths if necessary [Bierwirth and Meisel, 2010]. In addition, the BAP problem can also be divided into 2 types of the ship's arrival time dimension: static arrival and dynamic arrival. Static arrival requires that each ship arrive at the port and be ready for service before the planning horizon. In the dynamic arrival, arrival times are scheduled and assigned to each ship. The ship may arrive before or after the planned time [Imai et al., 2001].

BAP is a problem that has been studied by several researchers using different solutions. The static variant of the discrete BAP was first formulated by Imai et al. [1997], while the dynamic variant was addressed by Imai et al. [2001]. Mostly, the purpose of berth allocation is to focus on the service level and reliability of the port. Each research has different objectives, for example, to minimize the waiting time for docking services, to reduce the workload of terminal resources, and to minimize the number of service rejections. Bierwirth and Meisel, [2010, 2015] and Carlo et al. [2015] are the most recent reviews of the literature regarding seaside operations, including the BAP. In recent years, researchers have proposed new solution methods to address BAP which respect more realistic conditions and characteristics. For example, Mauri et al. [2016] developed a variant of the neighborhood search method called adaptive large neighborhood search (ALNS) to deal with the dynamic and continuous berth allocation problem (DCBAP). The objectives of this study are to minimize the total service cost and the total time at port. Another study [Chen and Huang, 2017] also develops a GA-based approach to deal with the DCBAP to minimize penalty costs for late departures. The study presented in Xu et al. [2018] proposed a simulated annealing (SA) algorithm to deal with BAP with traffic limitations in the consideration of the navigation channel. In 2019, Jos et al. [2019] developed a new mixed-integer linear programming (MILP) model to deal with the BAP to minimize operation costs and Hsu et al. [2019] developed a hybrid genetic algorithm (HGA) to solve the BAP and Quay Crane Assignment Problem Simultaneously. Prencipe and Marinelli. [2021] proposed a novel arithmetical formula that was presented as MILP model to deal with the Discrete and Dynamic Berth Allocation Problem (DDBAP). In addition, a new approach solution was adapted to meta-heuristic based on Bee Colony Optimization (BCO) to solve a large scale BAPs. Bacalhau et al. [2021] developed a hybrid heuristic-based genetic algorithm (GA) with dynamic programming (DP) to solve the dynamic and discrete berth allocation problem (DDBAP) to avoid the problem of high computation time in exact approaches. Several approaches are reported in the literature dealing with the BAP. However, metaheuristics approaches are more popular over exact methods due to their efficiency in terms of computational complexity. Among the heuristic approaches, Genetic Algorithms and Evolutionary Algorithms take the by far largest share with 40%; see Bierwirth and Meisel [2015] and Prencipe and M. Marinelli [2021].

Academic work has primarily focused on the problem of BAP in a single quay. Currently, ports are expanding in terms of area and service. Some ports will consist of multiple quays that can be configured to serve different types of vessels. So, considering quay as a single is inconsistent with the current situation. Considering the nature of multiple quays in the BAP problem, it means the problem of assigning vessels to the quay and assigning berthing positions and times for each separate berth. Very few studies have researched Multi-quay BAP (MQ-BAP), For example, Frojan et al. [2015] deals with an updated form of BAP, where multiple quays and continuous berth layouts are considered. They proposed a first formulated as an integer linear model and then solved using GA. Another study by Krimi et al. [2020] studied a multi-quays berth allocation and crane assignment problem under availability restrictions on bulk terminals. They proposed a mixed-integer programming model and investigated a set of heuristics based on the general variable neighborhood search (GVNS) approach. The proposed GVNS heuristic turns out to be very efficient in solving the problem considered. Moreover, a study presented in Cheimanoff et al. [2021] also addresses multiple continuous quays and dynamic BAP. The study also considers tidal constraints for optimal berth assignment, and the main objective of this study is to reduce the total service time of the vessels. They presented a mixed-integer linear model and adapted Iterated Local Search (ILS) approach to solve industrial-sized instances.

This research aims to study the problem of Multi-quay BAP to find an effective method for berth allocation. This problem was inspired by a real case of a multi-purpose port in Thailand that considered special conditions in addition to practical conditions, as seen in Figure 1. This includes changing the type of cargo that the berth can provide for more than one type of cargo, known as a multipurpose berth, to increase flexibility in port operation management in case of increased cargo handling demand or decreases in each product type. Furthermore, the setup time conditions are also considered when adjusting the types of cargo capable of each berth. Setup times may arise due to the berth can convert from dedicated function to another function according to the variance of cargo demand, known as sequence-dependent setup time. However, the study of the MQ-BAP solution with multi-purpose berth and sequence-dependent setup time constraints has not been considered previously in the literature.

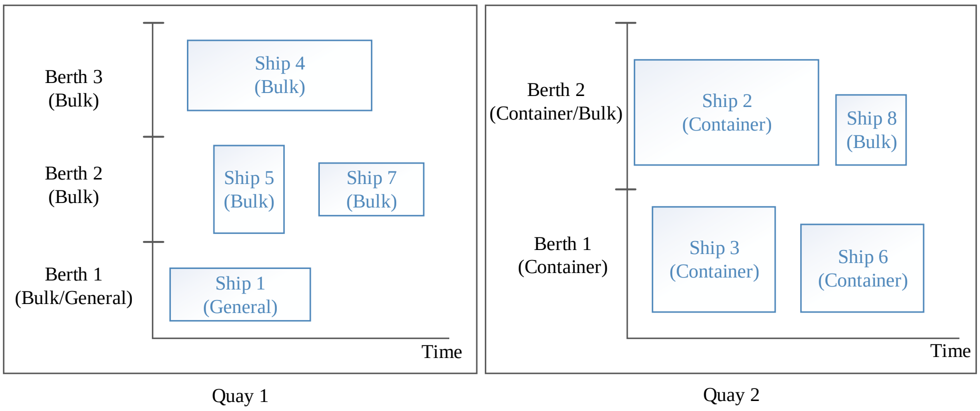

Fig. 1. An illustration of two discrete berthing quays with 8 arriving ships and 3 types of cargo

.

This paper proposes a mixed-integer programming model to find the optimal solutions for small instances and adapted a metaheuristic solution approach based on Genetic algorithm (GA) to solving the MQ-BAP model in large-scale problem cases. Furthermore, numerical experiments are carried on randomly generated instances for multipurpose terminals to assess the effectiveness of the proposed model and the efficiency of the proposed algorithm. The remainder of this article is organized as follows. The problem description and formulation are presented in the next section. Then, we present the detail of the proposed metaheuristic based on the GA algorithm. While, the result and conclusion are described.

PROBLEM DESCRIPTION AND FORMULATION

Problem Definition

This study addresses the Multi-Quay Berth Allocation Problem (MQ-BAP), where the discrete berthing layout is considered. The quay is divided into a number of berth $i \in I$ and berth can service one vessel at a time. In each berth, there is an eligibility constraint *Cij*, which means the compatibility between berths and ships (i.e., cargo type, length of berth, depth of berth). Moreover, setup times for ST_{hj} may arise due to the changing of berth type according to the sequence of assigning ships. There is a set of arriving ships J = {1,2,3,…J} along with the attribute of cargo type and each ship $j \in J$ has multiple known characteristics, including Length of Ship (*LS*), Draft of Ship (*DS*) Expected Time of Arrival (*AT*) and Handling Time (*HT*). The objective of this study is to determine the berthing position and berthing time for all arriving ships in J in order to minimize the maximum waiting time of all ships. The waiting time is defined as the time that a ship in waiting for the previous ship to leave the same berth.

Assumptions

- All berths are assumed to be free in the initial state.
- Each ship corresponds to at least one compatible berth due to the discrete layout of the quays.
- A berth is considered as a specific point on the quay (referred to by a number).
- Each berth can be dedicated to one or two different types of cargo and vessels.
- The compatibility between ships and berths is related to geometric and cargo-type constraints.
- One ship can occupy only one berth and is not allowed to interrupt the operations when a vessel starts operations at a particular berth.
- The berths of any quay become available immediately after a ship completes its operations.
- Ships arrive at the port in the harbour area according to scheduled arrival times and not in delay.
- The arrival times and handling times for all arriving ships are known.

Mathematical Formulation

The notation used in the MIP model for Multi-Quay Berth Allocation Problem is presented in Table 1 and the model is presented in Table 2.

Table 1. Notation used in the MIP model for Multi-Quay Berth Allocation Problem

Sets and indices
I : Set of berths, indexed by i=1, 2, 3,…, I
J : Set of ships, indexed by j,h = 1, 2, 3,…, J
K : Set of service orders, indexed by k,p = 1, 2, 3,…, K
P_k : Subset of K such that $P_k = \{p \mid p < k \in K\}$
W_i : Subset of ships with $AT_j \geq BA_i$
Parameters
CB_{ij} : $\begin{cases} 1 & \text{if berth } i \text{ is capable of berthing ship } j \\ 0 & \text{Otherwise} \end{cases}$
ST_{hj} : Setup time to berthing ship j after ship h on the same berth
AT_j : Arrival time of ship j
LB_i : Length of berth i
LS_j : Length of ship j
DB_i : Depth of berth i
DS_j : Draft of ship j
HT_{ij} : Handling time of ship j at berth i
BA_i : Initial available time of berth i
M : Very large positive number
Decision variables
R_{ijk} : $\begin{cases} 1 & \text{if ship j is berthing as the } k\text{th ship at berth } i \\ 0 & \text{Otherwise} \end{cases}$
ID_{ijk} : Idle time of berth i between the departure of the k-1th ship and the arrival of the kth ship when ship j is berthing as the kth ship
ATB_{ik} : Arrival time of the kth ship at berth i
SH_{ik} : Start time of handling the kth ship at berth i
FH_{ik} : Completion time of the kth ship at berth i
$MaxW$: Maximize waiting time of all ships

Table 2. MIP model for Multi-Quay Berth Allocation Problem

Objective function		
$Min\ Z = MaxW$		(1)
Constraints		
$MaxW \le SH_{ik} - ATB_{ik}$	$\forall I \in I, k \in K$	(2)
$\sum_{i \in I} \sum_{k \in K} R_{ijk} = 1$	$\forall j \in J$	(3)
$\sum_{j \in J} R_{ijk} \le 1$	$\forall i \in I, k \in K$	(4)
$LS_j \le LB_i + M(1 - R_{ijk})$	$\forall i \in I, j \in J, k \in K$	(5)
$DS_j \le DB_i + M(1 - R_{ijk})$	$\forall i \in I, j \in J, k \in K$	(6)
$R_{ijk} \le CB_{ij}$	$\forall i \in I, j \in J, k \in K$	(7)
$\sum_{j \in J} R_{ijk+1} \le \sum_{j \in J} R_{ijk}$	$\forall i \in I, k \in 1 \ldots K\text{-}1$	(8)
$ATB_{ik} = \sum_{j \in J} R_{ijk} * AT_j$	$\forall i \in I, k \in K$	(9)
$SH_{ik} \ge \sum_{j \in J} R_{ijk} * BA_i$	$\forall i \in I, k \in K$	(10)
$SH_{ik} \ge \sum_{j \in J} R_{ijk} * AT_i$	$\forall i \in I, k \in K$	(11)
$SH_{ik+1} \le M * \sum_{j \in J} R_{ijk+1}$	$\forall i \in I, k \in 1 \ldots K\text{-}1$	(12)
$\sum_{l \in J} \sum_{m \in P_k} (HT_{il} R_{ilm} + ID_{ilm}) + ID_{ijk} - (AT_j - BA_i) R_{ijk} \ge 0$	$\forall i \in I, j \in W_i, k \in K$	(13)
$FH_{ik} = SH_{ik} + \sum_{j \in J} R_{ijk} HT_{ij}$	$\forall i \in I, k \in K$	(14)
$FH_{ik-1} + ST_{hj} - SH_{ik} \le M * (2 - R_{ijk} - R_{ihk-1})$	$\forall i \in I, h, j \in J, k \in 2 \ldots K$	(15)
$R_{ijk} \in \{0,1\}$	$\forall i \in I, j \in J, k \in K$	(16)
$ID_{ijk} \ge 0, \in int$	$\forall i \in I, j \in J, k \in K$	(17)
$ATB_{ik}, SH_{ik}, FH_{ik} \ge 0, \in int$	$\forall i \in I, k \in K$	(18)

In this model, the objective function (1) and constraints (2) denote the optimization process to minimize the Maximum waiting time of all ships. Constraints (3) and (4) ensure the uniqueness of the assignment. Constraints (5), (6), and (7) ensure the compatibility between the length, the draft of the ships, and the cargo type of ship with respect to those of the berths. Constraints (8) ensure the service order *k* and *k*+1 for the same berth. Constraints (9), (10), (11) and (12) evaluate the start time of handling the *k-th* ship at berth *i*. Constraints (13) ensure that ships must be serviced after their arrival. Constraints (14) and (15) define the completion time of handling the *k*th ship at berth *i* that consists of handling time of the the ship and setup time of berth in any case. Constraints (16) define the binary nature of the decision variable. Finally, constraints (17) and (18) define the decision variable as greater than or equal 0.

GENETIC BASED ALGORITHMS FOR MULTI-QUAYS BERTH ALLOCATION PROBLEM

The MIP model presented in the previous section is not tractable for the MQ-BAP because it is a typical combinatorial optimization problem. Thus, we focus instead on developing effective metaheuristic approaches, and the Genetic Algorithm proposed by Holland [1992] is modified. The general pseudocode of the proposed GA is presented in Figure 2.

Chromosome representation

The chromosome can be seen as the assignment of each ship for berth on any quay, considering the berth sequence. Table 3. shows a sample of data for a problem with three berths and ten ships. The chromosome used to represent the solution in this study consists of N (number of ships) genes, as shown in Figure 3. A pair of numbers [berth, ship] in each gene represents an assignment of a berth and the sequence of the ships on each berth.

```
Procedure: the proposed GA
Inputs: crossover rate: P_C, mutation rate: P_M, population size: popSize, and maximum generation: maxGen.
Output: the near optimal solution
Begin
    Let generation index T = 0.
    Randomly generate an initial population.
    While (T ≤ maxGen)
            Let population index P = 1.
            While (P ≤ popSize)
                    Randomly select two chromosomes from current population.
                    If (random number ≤ P_C)
                        Do ordered crossover operations.
                    End If
                    If (random number ≤ P_M)
                        Do swap mutation operations.
                    End If
                    Evaluation and calculate the fitness value of each schedule.
                    P = P + 1:
            End While
            Construct the next generation by a roulette-wheel and elitism from the children.
            T = T + 1:
    End While
End
```

Fig. 2. The pseudo code of the genetic based algorithms to solving multi-quays berth allocation problem.

Table 3. Example of a multi-purpose port problem data

Ship no.	1	2	3	4	5	6	7	8	9	10
Ship Type	1	2	3	1	1	2	3	2	1	2
Berth capable	1/2	2/3	3	1/2	1/2	2/3	3	2/3	1/2	2/3
Handling time (hrs.)	5	15	20	10	30	10	25	10	15	25

Notes. Ship type 1: Container, 2: General, 3: Bulk. Berth capable 1: Container, 2: Container/General, 3: General/Bulk.

Encoding

[2,2]	[3,3]	[1,1]	[1,5]	[1,4]	[2,8]	[2,10]	[3,6]	[3,7]	[1,9]

Decoding

Berth1	Ship1	Ship5	Ship4	Ship9
Berth2	Ship2	Ship8	Ship10	
Berth3	Ship3	Ship6	Ship7	

Fig. 3. An illustrative example of chromosome representation.

Population and selection

For the present study, we propose to construct the population that has been created based on the constraint (7). After producing solutions, constraints (10), (11), (13), (14) and (15), which show evaluate the start time of handling and the completion time of handling of ships at berth, are considered. At each generation, the roulette wheel selection method and elitism are used for selection method. With elitism, the best performing chromosome of the population will automatically carry over to the next generation, ensuring that the most successful chromosome persists.

Crossover and Mutation

Crossover exchanges a certain portion of the chromosome between two chromosomes. Figure 4. shows an example of ordered crossover, in which the parents are generated based on the data in Table 1. In the example, two genes are randomly selected (the fourth and seventh) for crossover.

For each GA iteration, the swap mutation is applied for this study. Mutation changes the sequence of genes, related to sequencing of ship. An example of the swap mutation is shown in Figure 5.

P1	[2,2]	[3,3]	[1,1]	[1,5]	[1,4]	[2,8]	[2,10]	[3,6]	[3,7]	[1,9]
P2	[1,4]	[1,5]	[2,1]	[2,6]	[3,2]	[1,9]	[2,8]	[3,3]	[3,7]	[1,10]

O1	[3,3]	[1,1]	[1,5]	[2,6]	[3,2]	[1,9]	[2,8]	[1,4]	[2,10]	[3,7]
O2	[2,1]	[2,6]	[3,2]	[1,5]	[1,4]	[2,8]	[2,10]	[1,9]	[3,3]	[3,7]

Fig. 4. Example of ordered crossover operations

Before Mutation

[2,2]	[3,3]	[1,1]	[1,5]	[1,4]	[2,8]	[2,10]	[3,6]	[3,7]	[1,9]

Berth1	Ship1	Ship5	Ship4	Ship9
Berth2	Ship2	Ship8	Ship10	
Berth3	Ship3	Ship6	Ship7	

After Mutation

[2,2]	[3,3]	[2,10]	[1,5]	[1,4]	[2,8]	[1,1]	[3,6]	[3,7]	[1,9]

Berth1	Ship5	Ship4	Ship1	Ship9
Berth2	Ship2	Ship10	Ship8	
Berth3	Ship3	Ship6	Ship7	

Fig. 5. Example of swap mutation

COMPUTATIONAL RESULTS

In this section, we conducted computational experiments using randomly generated test problems to evaluate the performance of proposed method in this article. All experiments using CPLEX and GA are executed on a PC Intel® Core^{TM} i5 2.30 GHz with 8 GB of RAM. The GA algorithm was developed in Python 3.7.0, while ILOG CPLEX 12.10 is used to obtain the optimal solution through MIP as presented in Section 3.

The computational results of the proposed GA on two MQ-BAP groups are reported. A small- sized problem group, involving problem instances with the number of ships (S) as 10, 15, 20 and 25 and number of quays (Q) as 1 and 2 with 3 and 5 berths (B), is for comparing solution obtained by GA with the optimal solution. A large-size problem group, involving problem instances with the number of ships as 50, 70, 90 and 110 and number of quays as 2, 3, 4 and 5 with 5, 7, 10, and 15 berths, is for comparing the performance of GA with current practice situation which are first come first serve (FCFS) rule. Moreover, we also implement PSO, a wildly popular metaheuristic approach proposed by Kennedy and Eberhart [1995], for performance comparison purposes. All cases comprise lengths of ships, draft of ships, lengths of berths, depth of berths, Number of cargo types, Ship handling times, Setup time of berth, and Inter-arrival time of ships as shown in table 4. Moreover, according to the problem constraint, at least one berth must be compatible with each ship in terms of length and draft.

Table 4. Test problem data

Lengths of ships	100, 150, 200, and 250 m.
Lengths of berths	100, 150, 200, and 250 m.
Draft of ships and	8, 10 and 15 m.
Depth of berths	8, 10 and 15 m.
Number of cargo type	3 Types
Ship handling times	5 to 24 hrs.
Setup time of berth	1, 2 and 3 hrs.
Inter-arrival time of ships	0 to 3 hrs.

Concerning the GA algorithm, the parameters of the algorithm are fixed and determined as 50 and 100 individuals for both population size and maximum iterations for small-size instance, and large-size instance respectively, 90% of crossover rate, 5% of elitism rate, and 2% of mutation rate. For the control parameters of PSO, the particle numbers were set to 100, the acceleration coefficients $c1$

and $c2$ are set to 2 and set the inertia weight (w) to 0.4. The computation times (t) are related to the average CPU time over 10 runs. The PSO stops when the computation time reaches the same time spent by the proposed GA for the problem instance. Regarding CPLEX, we set the time limit for finding the global optimum equal to 21600 s.

The results of the comparison in the small-size problem are reported in Table 5. We found that the GA algorithm is achieved by the exact solution in many cases and shows that the results in terms of the objective function gap, compared with CPLEX, give a low value on average 4.77%. The objective function gap between FCFS and CPLEX gives a value by average 19.10%. Moreover, the results of the comparison in large-size problem instances are reported in Table 6. We can observe that the average percentage of improvement in terms of the minimizing of maximum ship's waiting time is 5.61% when compared to the FCFS rule. While, the average percentage of improvement between GA and PSO gives a value of average 1.38%. A statistical analysis is also performed by applying a paired-t test at a significant level of $\alpha = 0.05$ to confirm whether there are significant differences between algorithms. Table 7 shows that the p-values for the two-tailed form of the t-test are 0.004 and < 0.001 for both GA-PSO and GA-FCFS respectively. They are less than the significance level of 0.05. Therefore, the differences between means are statistically significant, and the results also confirm that the proposed GA algorithm guarantees a near-optimal solution in low computation time and gives a better performance than both PSO and FCFS.

Table 5. Result comparison for small-sized problems.

Instance	Problem size	CPLEX		GA			FCFS	Gap (%)	
	S*×*Q*×*B	*f*	*t*	*f* Best	*f* Avg.	*t*	*f*	GA- CPLEX	FCFS - CPLEX
S1	10×1×3	26	0.30	26	26.00	0.92	33	0.00	26.92
S2	10×1×3	12	1.86	12	12.10	1.00	21	0.83	75.00
S3	10×1×3	42	0.48	42	42.00	1.01	42	0.00	0.00
S4	10×2×5	2	2.72	2	2.10	0.93	2	5.00	0.00
S5	10×2×5	12	1.41	12	12.10	0.89	12	0.83	0.00
S6	10×2×5	8	2.39	8	8.00	0.84	8	0.00	0.00
S7	10×1×3	17	14.95	17	17.00	0.98	24	0.00	41.18
S8	10×1×3	9	5.28	9	9.00	0.98	9	0.00	0.00
S9	10×1×3	16	14.13	17	17.00	0.98	18	6.25	12.50
S10	10×2×5	10	176.44	10	10.00	1.01	14	0.00	40.00
S11	10×2×5	10	8.49	10	10.40	1.00	10	4.00	0.00
S12	10×2×5	12	113.17	12	12.00	1.00	12	0.00	0.00
S13	20×1×3	37*	21,622.38	37	37.70	1.12	45	1.89	21.62
S14	20×1×3	26	5,830.97	27	27.00	1.01	33	3.85	26.92
S15	20×1×3	35*	21,620.98	35	37.10	1.09	40	6.00	14.29
S16	20×2×5	15	3,612.17	17	18.20	1.11	24	21.33	60.00
S17	20×2×5	13	4,627.81	15	17.10	1.09	19	31.54	46.15
S18	20×2×5	9*	21,620.98	12	13.30	1.10	13	47.78	44.44
S19	25×1×3	62**	4,811.00	63	63.60	1.23	65	2.58	4.84
S20	25×1×3	61*	21,620.20	59	60.00	1.20	65	-1.64	6.56
S21	25×1×3	51	335.20	51	51.00	1.22	51	0.00	0.00
S22	25×2×5	20**	3,662.05	13	15.30	1.21	23	-23.50	15.00
S23	25×2×5	13**	7,970.45	12	14.80	1.22	16	13.85	23.08
S24	25×2×5	25**	3,856.19	22	23.50	1.22	25	-6.00	0.00

Notes. *f* denotes the maximize ship's waiting time in hours. *t* denotes the average computation time in seconds. * Best found before time limitation at 6 hours. **Best found before out of memory.

Table 6. Result comparison for large-sized problems.

Instance	Problem size $S \times Q \times B$	GA			PSO		FCFS	Gap (%)	
		f Best	*f* Avg.	*t*	*f* Best	*f* Avg.	*f*	GA-FCFS	GA-PSO
L1	50×2×5	97	99.10	10.05	101	102.30	114	-13.07	-3.13
L2	50×2×5	115	117.80	9.47	116	118.10	124	-5.00	-0.25
L3	50×3×7	87	93.60	9.64	91	94.70	107	-12.52	-1.16
L4	50×3×7	188	188.00	9.54	193	193.00	193	-2.59	-2.59
L5	50×4×10	66	72.50	11.20	39	73.30	78	-7.05	-1.09
L6	50×4×10	65	67.70	9.80	66	69.20	72	-5.97	-2.17
L7	70×2×5	162	165.30	12.26	162	165.30	173	-4.45	0.00
L8	70×2×5	197	197.00	12.30	207	207.00	207	-4.83	-4.83
L9	70×3×7	192	192.70	13.13	192	192.40	198	-2.68	0.16
L10	70×3×7	149	154.30	11.98	150	155.00	172	-10.29	-0.45
L11	70×4×10	103	106.00	14.05	104	107.40	115	-7.83	-1.30
L12	70×4×10	92	98.80	13.57	97	104.60	110	-10.18	-5.54
L13	90×3×7	140	141.00	15.26	140	142.60	150	-6.00	-1.12
L14	90×3×7	193	193.40	15.41	193	193.40	201	-3.78	0.00
L15	90×4×10	139	141.90	16.23	142	146.20	151	-6.03	-2.94
L16	90×4×10	143	150.80	14.97	144	151.20	157	-3.95	-0.26
L17	90×5×15	192	192.80	17.81	193	193.00	198	-2.63	-0.10
L18	90×5×15	123	125.50	16.65	121	125.40	133	-5.64	0.08
L19	110×3×7	225	257.10	18.24	257	258.20	269	-4.42	-0.43
L20	110×3×7	288	288.70	17.99	288	288.20	293	-1.47	0.17
L21	110×4×10	261	262.70	20.45	261	262.80	263	-0.11	-0.04
L22	110×4×10	154	162.00	20.42	163	171.70	178	-8.99	-5.65
L23	110×5×15	180	181.20	18.89	180	180.50	183	-0.98	0.39
L24	110×5×15	176	177.20	19.63	177	178.50	185	-4.22	-0.73

Notes. *f* denotes the maximize ship's waiting time in hours. *t* denotes the average computation time in seconds.

Table 7. Results of Statistical Test

Pair algorithm	Mean Difference	p-Value
GA-PSO	-1.95417	.004
GA-FCFS	-8.20417	<0.001

CONCLUSIONS

This paper has investigated MQ-BAP with multi-purpose berth and sequence-dependent setup time constraints. We develop metaheuristics based on the Genetic Algorithm approach to address the problem, which focuses on the minimizing of the maximum ship waiting time. Furthermore, three benchmark schemes, an exact approach (MIP), a current practice (FCFS) solution, and PSO have also been implemented for comparison purposes. The computational results of the proposed GA on two MQ-BAP groups are reported. A small problem group is for comparing solution obtained by GA with the optimal solution. A large problem group is for comparing the performance of GA with the PSO and current practice situation. The results show that our proposed algorithm has higher efficiency over PSO and FCFS by 1.38% and 5.61% respectively. Compared to MIP, our proposed GA provides a near-optimal solution by average 4.77% from the optimal at acceptable computation time. Hence, we conclude that our proposed GA is an efficient algorithm for near-optimal multiple quays berth allocation in very low computation time and shows a better performance than both PSO and FCFS considerably.

There are some works we will investigate in the future. We plan to extend the modeling to incorporate continuous berthing layouts and investigate the application of GA in solving the berth allocation problem combined with the related quay crane assignment problems. Finally, we plan to improve the performance of the proposed GA in solving the MQ-BAP by integrating with other metaheuristics such as PSO or adding a self-adaptation concept.

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