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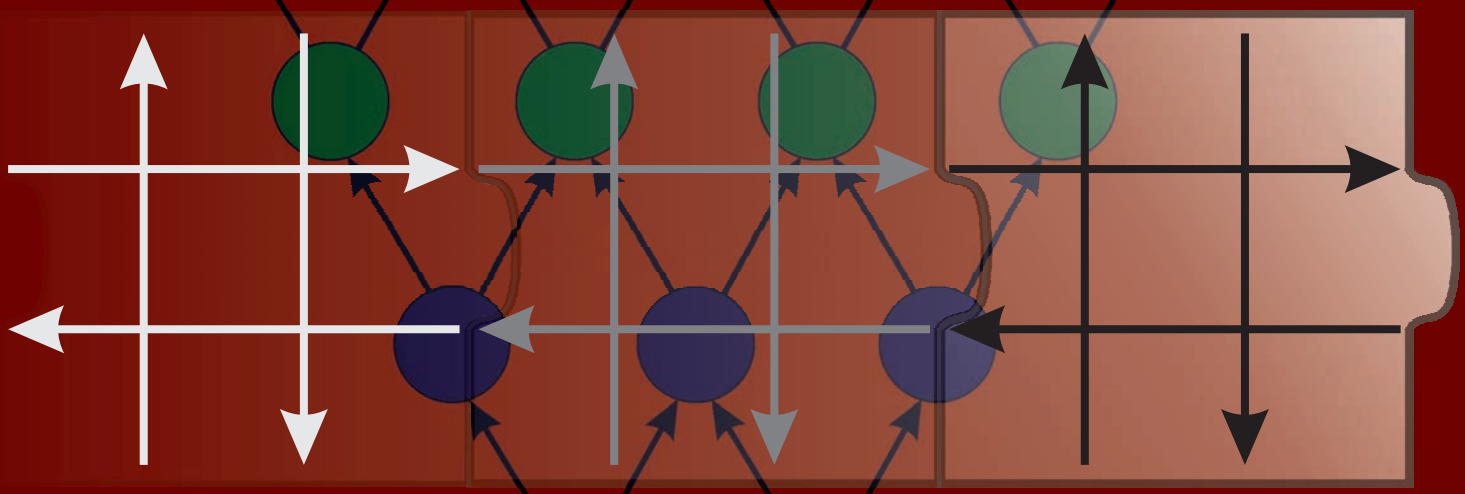

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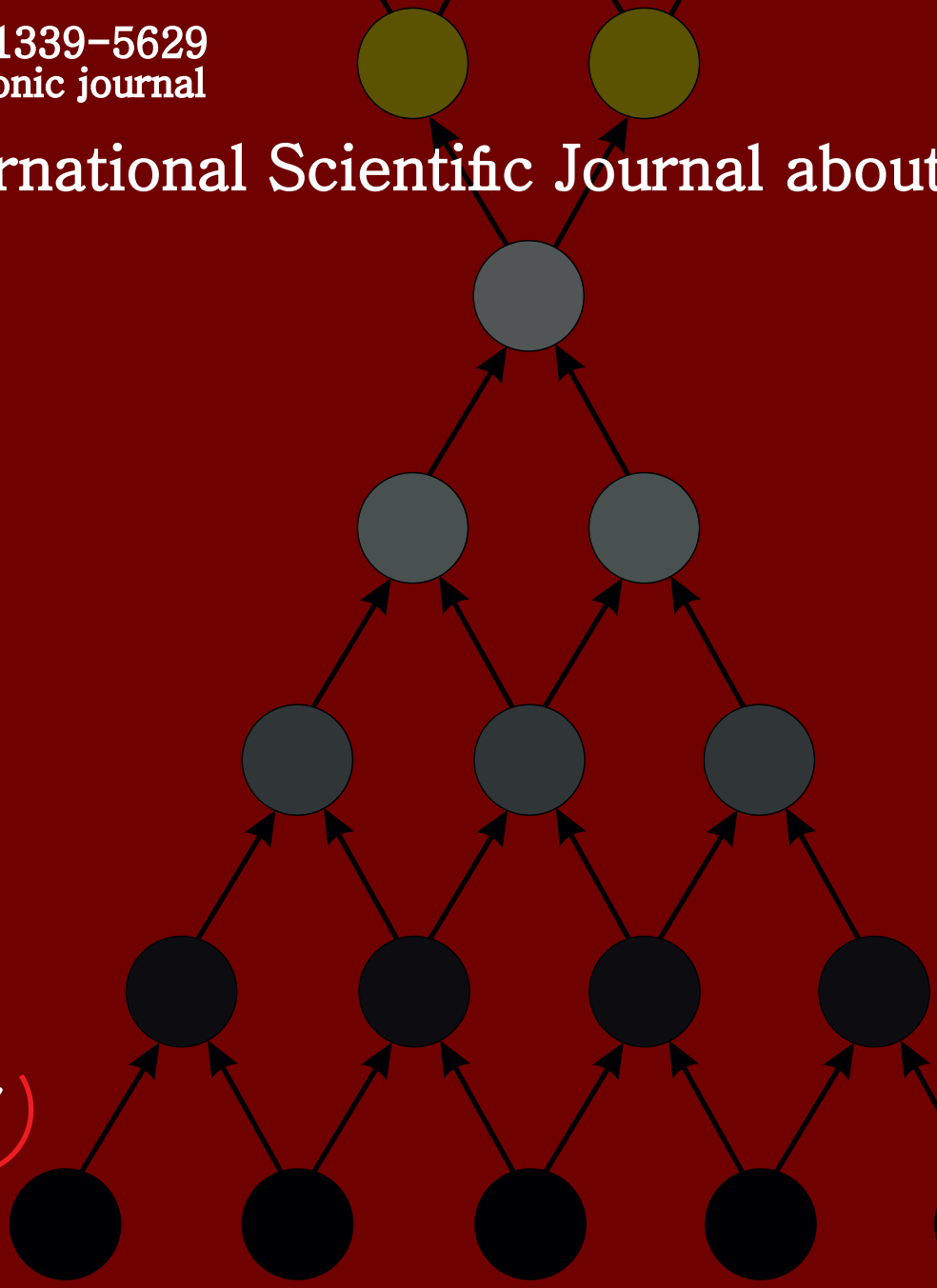

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Intellectual capital meets Industry 4.0: transforming logistics through bibliometric insights
Natalia Slyvkanyc, Jozef Glova, Alena Andrejovska, Robert Barski

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Intellectual capital meets Industry 4.0: transforming logistics through bibliometric insights

Natalia Slyvkanyc
Technical University of Košice, Faculty of Economics, Nemcovej 32, 042 00, Košice, Slovak Republic, EU, natalia.slyvkanyc@tuke.sk
Jozef Glova
Technical University of Košice, Faculty of Economics, Nemcovej 32, 042 00, Košice, Slovak Republic, EU, jozef.glova@tuke.sk (corresponding author)
Alena Andrejovska
Technical University of Košice, Faculty of Economics, Nemcovej 32, 042 00, Košice, Slovak Republic, EU, alena.andrejovska@tuke.sk
Robert Barski
The Jacob of Paradies University, ul. Teatralna 25, 66 400, Gorzow Wielkoposki, Poland, EU, rbarski@ajp.edu.pl

Keywords: intellectual capital, intangible assets, Industry 4.0, logistics.
Abstract: This study conducts a comprehensive bibliometric analysis to explore the evolving relationship between intellectual capital and Industry 4.0 within the logistics sector. The research identifies trends, key contributors, and thematic developments in this interdisciplinary field using data from two leading scientific databases, Web of Science and Scopus. The primary objective is to understand the critical areas of intellectual capital—human, structural, and relational—and their application in Logistics 4.0, driven by technological innovations such as cyber-physical systems and digital transformation. The methodology employs established bibliometric techniques, including co-occurrence and thematic mapping, to evaluate research questions addressing publication trends, country contributions, source relevance, and author influence. Data from 2001–2024 for Web of Science and Scopus datasets reveal key insights: consistent publication growth, leading contributions by countries like China and the USA, and the emergence of themes such as sustainability, innovation, and digital transformation. Comparative analysis highlights differences in keyword trends and collaborative networks between databases, with Scopus displaying a notable time lag in topic evolution. Findings emphasise the pivotal role of intellectual capital in driving logistics innovation, underscoring its integration with Industry 4.0 technologies. Limitations include potential database biases and a data lag for 2024. This study is a foundational reference for scholars and practitioners who leverage intellectual capital for competitive advantage in the digitised logistics era.

1 Introduction

The changes accompanying economic transformations have forced the company to adapt to the evolving competitive landscape. In the twenty-first century, a product no longer plays as significant a role in building a competitive advantage, as its features can be easily replicated in other products. Today, the product and service strength is determined by the knowledge used in their creation [1]. Intellectual capital is a significant aspect of the 21st century. In today's rapidly changing business environment, organisations continuously seek new ways to improve their competitive edge and sustain long-term growth. As a result, acknowledging and efficiently utilising intellectual capital has become a crucial factor influencing organisational success [2].

Intellectual capital is integral to Logistics 4.0, a concept that applies Industry 4.0 principles to the logistics sector. The logistics industry has undergone significant changes in recent years due to rapid technological advancements. In production engineering, integrating cyber-physical systems (CPS) has played a vital role in improving the flow of information between execution and decision-making systems. These systems are increasingly important in logistics as well. Technological innovations supporting physical logistics processes have led to systems with advanced computational and communication capabilities, facilitating seamless information exchange between all resources and components of a product. Like the Industry 4.0 revolution in production, Logistics 4.0 represents a shift from hardware-focused logistics to a software-centric, intelligent, service-oriented landscape. The key areas where intellectual capital is closely linked with Industry 4.0 are human capital, relational capital, structural capital, and innovation and knowledge management. The first three fields are the primary components of intellectual capital [1,3,4].

This study is structured as follows: The first part is dedicated to the theoretical background, where we explain the terms “Intellectual capital” and “Industry 4.0” and how they relate to logistics. The second part describes the data collection process and the methodology used in our

bibliographic research. We also describe the research questions of this study. The third part is devoted to empirical results, where we describe descriptives, country/sources/author analyses, and co-occurrence analysis to answer the research questions set in the beginning. The last part is the conclusion of the paper. The main aim of this study is to analyse the intersection of intellectual capital and Industry 4.0 in logistics to help academics and practitioners understand how knowledge assets—such as human, structural, and relational capital—drive innovation and competitive advantage in modern logistics. By identifying key trends, influential contributors, and thematic developments, this research equips academics and practitioners with insights to align their strategies with the evolving demands of digital transformation, fostering more effective applications of Industry 4.0 principles in logistics.

This study investigates publication trends across Web of Science and Scopus, identifies leading countries in research output, determines the most relevant publication sources, highlights influential authors in the field, and explores key trends and themes through keyword analysis. The methodology part of the study formulates research questions.

2 Literature review

Technological innovation, information technology, and economic growth are closely related and can be described as a general concept of a cycle or wave. Each wave represents a distinct phase in a series of technological innovations that create new economic sectors and opportunities for investment and growth. Since the beginning of the Industrial Revolution at the end of the 18th century, researchers have identified six waves [5,6] (Figure 1). The first wave (1785–1845) introduced hydropower, textiles, and iron innovations, focusing on essential goods production and leveraging improved maritime and inland water transport to reduce costs and expand colonial trade. The second wave (1845–1900) saw coal and steam engines driving rail and steamship expansion, opening new markets and boosting textile production through mass-produced cotton. Electrification defined the third wave (1900–1950), enabling urban transport systems, machinery, and the automobile industry, which enhanced passenger and freight mobility. The fourth wave (1950–1990) brought innovations in plastics, electronics, and aerospace, with jet engines facilitating global travel. The fifth wave (1990–2020) transformed logistics and communication through information systems, personal computing, and e-commerce advancements. The sixth wave (2020–present), or Industry 4.0, integrates robotics, automation, and digitisation, emphasising sustainability and IT-driven efficiency in operations.

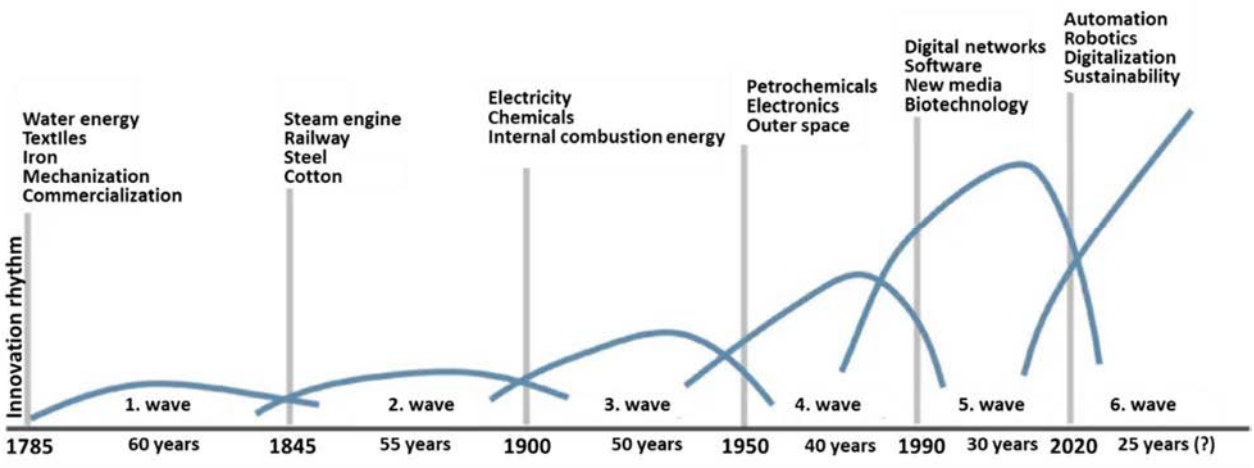

Figure 1 Waves of the industrial revolution

The Industry 4.0 phenomenon emerged in Germany in 2011 as a proposed economic policy development based on the High-Tech Strategy [5,7]. It involves the application of the Internet of Things (IoT) and Internet of Services (IoS) to industrial processes. Using digital technologies that bridge the physical and virtual worlds, manufacturing companies are rapidly transitioning from mass production to custom production [8,9].

Digitally transformed logistics, also known as "Smart logistics," "Logistics 4.0," or "supply chain management 4.0", involves the use of the internet to formalise and standardise logistics business processes. Using ICT technology defines smart logistics as increasing transparency through higher levels of automation and efficiency. This transformation has been driven by the invention of the internet and the 4th industrial revolution (Industry 4.0), leading to the use of Cyber-Physical systems (CPS) for monitoring and controlling the physical flow, a concept referred to as "Logistics 4.0" [3,4]. Intellectual capital is crucial for the success of Logistics 4.0, as it encompasses the required skills, systems, relationships, and innovation capacity to utilise advanced

digital technologies effectively. Human flow, structural, and relational capital interaction empower logistics companies to revamp their operations and excel in the digital logistics era [10]. Intellectual capital is crucial in driving the innovation required for developing and implementing Logistics 4.0 technologies. This involves creating new solutions for automation, AI-based decision-making, and IoT-enabled logistics management. The innovative capacity of a company's intellectual capital is a crucial competitive advantage in Logistics 4.0 [11]. Effective knowledge management within Logistics 4.0 ensures capturing, sharing, and utilising valuable insights from data analytics, customer interactions, and operational experiences. This continuous loop of knowledge flow enhances decision-making and operational efficiency [12]. Recent research emphasises integrating soft skills, advanced technologies, and innovative approaches in modern logistics and supply chain management. Cantoni et al. highlight the significance of soft skills, such as communication and adaptability, in fostering collaboration and addressing complex logistics challenges [13]. Fareed et al. explore how digital technologies like AI, IoT, and blockchain enhance efficiency and sustainability in multimodal logistics operations [14]. Pekarčíková et al. (2024) focus on improving logistics efficiency in storage and picking processes, providing practical insights into specific operational challenges [15]. Pozzo et al. and Rejeb et al. reveal key trends in Logistics 4.0 and IoT applications, highlighting their transformative impact on automation, data-driven strategies, and real-time decision-making in supply chains [16,17]. Straka et al. demonstrate the utility of simulation modelling in optimising production processes, showcasing its relevance for logistics efficiency [18]. Lastly, Núñez-Merino et al. identify research gaps in Industry 4.0 and supply chain integration, providing a roadmap for future advancements [18].

3 Methodology

This study involves analysing literature to gain insights into research trends and gaps in the evolution of intellectual capital concerning Industry 4.0 in logistics. The analysis of published literature data informs the study and highlights vital themes [19]. The research applies mathematical and statistical methods to books and other forms of communication-based on Pritchard's approach [20].

Our research used the standard science mapping workflow created by Börner et al. [21] and improved by Aria and Cuccurullo, Cobo et al., and Zupic and Čater [22-24]. This workflow involves five stages: study design, data collection, data analysis, data visualisation, and interpretation. For our study design, we developed the following research questions:

RQ1: What are the specific trends in publication patterns concerning intellectual capital and Industry 4.0 in logistics in the Web of Science and Scopus databases?
RQ2: Which countries have contributed significantly to research on intellectual capital and Industry 4.0 in logistics, based on publication metrics?
RQ3: What are the most relevant publication sources that advance intellectual capital and Industry 4.0 knowledge within the logistics domain?
RQ4: Who are the most influential authors contributing to intellectual capital and Industry 4.0 in logistics?
RQ5: What are the key themes and emerging trends in intellectual capital and Industry 4.0 in logistics, as reflected in publication keywords?

On August 17th, 2024, we gathered data from the Web of Science and Scopus databases to answer the research questions. Table 1 describes the inclusion criteria for data filtering.

Table 1 Inclusion criteria for data collecting

	Web of Science	Scopus
Keywords	**intellectual capital, intangible assets, industry 4.0, logistics**	
Document Type	**Article**	
Language	**English**	
Subject Area / Category	**Business Finance; Management; Business; Economics; Multidisciplinary Sciences. Exclude all other**	**Business, Management and Accounting; Economics, Econometrics and Finance; Multidisciplinary Limited to the mentioned area**
Total number of selected documents	5,866 documents	739 documents

To better understand the evolution of our research topic, we collected data from all available years without limiting any specific time. We analysed data from 2001 to 2024 for the Web of Science and Scopus. As 2024 is still ongoing, our analyses may be updated by the end of the year. However, we anticipate changes only in the number of published documents, not in the research area itself. We included the year 2024 to capture the most current trends.

We used the latest version of RStudio (2024.04.2+764) to analyse the collected data on a Windows 11 platform. We used the "bibliometrix" package for bibliometric analysis. Data from both databases were imported as ".bib" files, and we utilised the "bibliophily" package in the R command to remove duplicate articles and conduct the analyses [22,25,26].

4 Results

Table 2 provides essential information about the selected samples.

Table 2 Summary of selected samples

	Web of Science	Scopus
Timespan	**2001 - 2024**	**2001 - 2024**
Sources (Journals, Books, etc.)	**618**	**359**
Documents	**5,866**	**739**
Annual Growth Rate %	**19.69**	**18.11**
Document Average Age	**6.39**	**4.9**
Average citations per doc	**18.32**	**27.07**
Author's Keywords (DE)	**15,327**	**2,372**
Authors	**12,893**	**1,915**
Timespan	**2001 – 2024**	**2001 - 2024**

Between 2001 and August 17, 2024, 12,893 authors produced 5,866 documents across 618 sources listed in the Web of Science database. Additionally, for 359 sources listed in Scopus, 1,915 authors produced 739 papers from 2001 to August 17, 2024. Figure 2 illustrates the publication trend for both scientific databases. Both databases show a consistent increasing trend in publications related to intellectual capital in logistics.

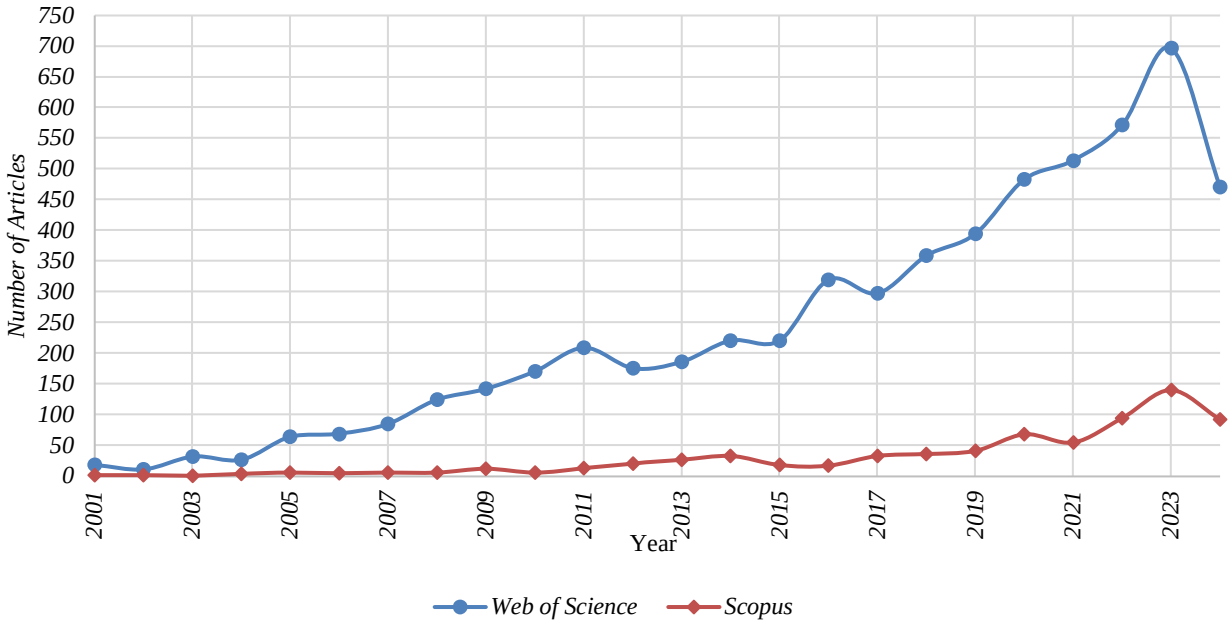

Figure 2 The publication trend. Source: own proceeding

Understanding the creators of these publications is not less important. We provide structural analyses of producing countries, sources, and authors in this case. Based on our findings, the top five most productive countries in the Web of Science are China (2,603 publications), the USA (2,238 publications), India (1,162 publications), the United Kingdom (1,044 publications), and Australia (858 publications). The results for all available countries are illustrated in Figure 3.

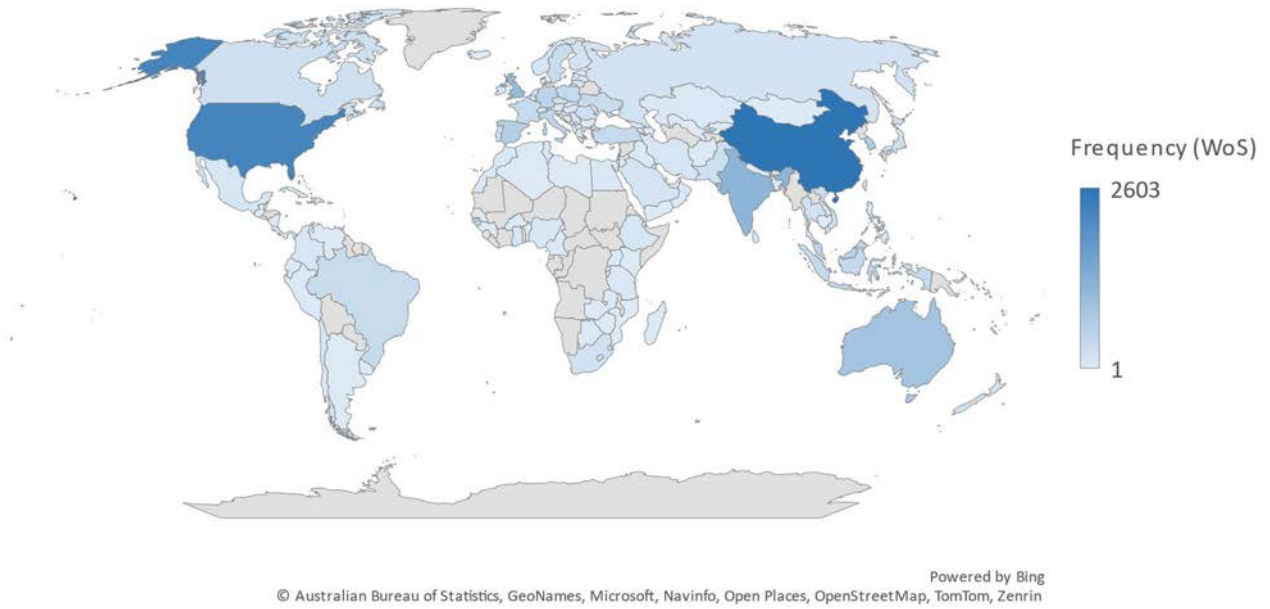

Figure 3 Country scientific production: Web of Science

On the other hand, the top 5 more productive countries are China (198 publications), the USA (131 publications), Italy (130 publications), the United Kingdom (98 publications) and Malaysia (92 publications). The results for all available countries are illustrated in Figure 4.

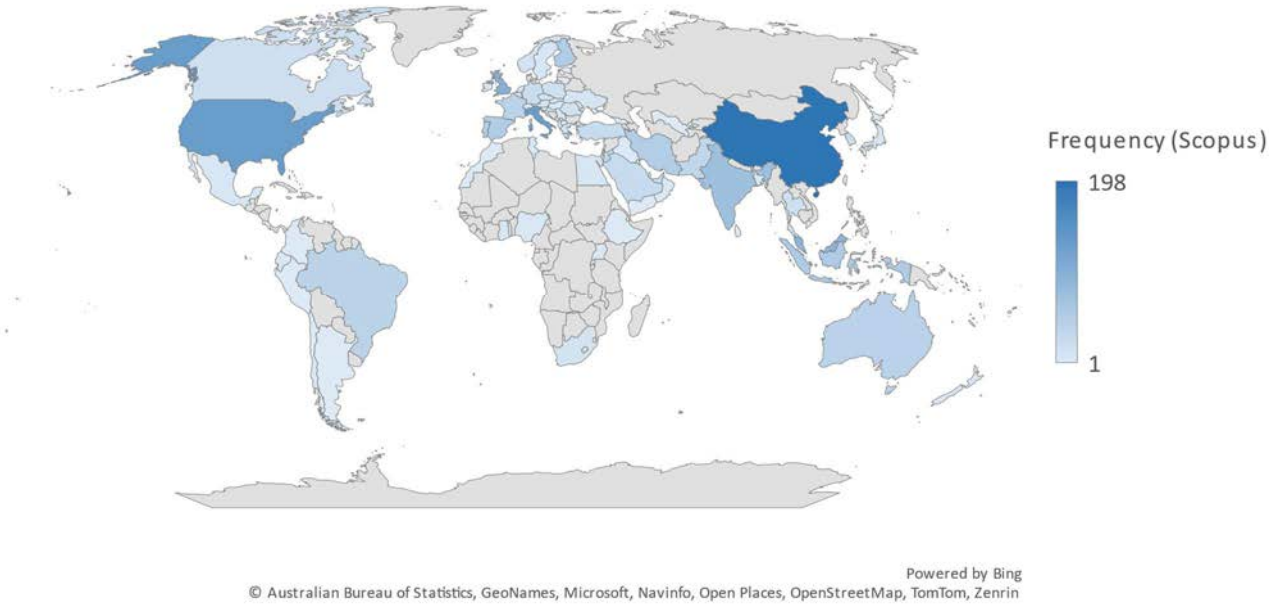

Figure 4 Country scientific production: Scopus

As international collaboration drives the quantity and quality of research, understanding the structure of these collaborative networks is crucial. In the case of the Web of Science, the most frequent research collaborations are between China and the USA (109), China and Australia (57), China and the United Kingdom (51), the USA and Korea (50), and the USA and the United Kingdom (46). The entire collaboration map is illustrated in Figure 5.

Figure 5 Collaboration world map: Web of Science

The collaboration map in the Scopus sample is the weakest, with lower levels of collaboration. The most frequent research collaborations are between China and Pakistan (10), the United Kingdom and France (10), Italy and the United Kingdom (9), Malaysia and Pakistan (8), and the USA and France (8). The complete collaboration map is illustrated in Figure 6.

Figure 6 Collaboration world map: Scopus

The following essential aspect of every research is the publication sources for these articles. According to our results, the most relevant source in the Web of Science is the "Asia Pacific Journal of Marketing and Logistics," with 1,097 published articles. The second most relevant source is "Supply Chain Management—An International Journal," with 216 publications. The third spot in the top three is taken by "Industrial Marketing Management," with 101 publications. The top 10 relevant sources are illustrated in Figure 7.

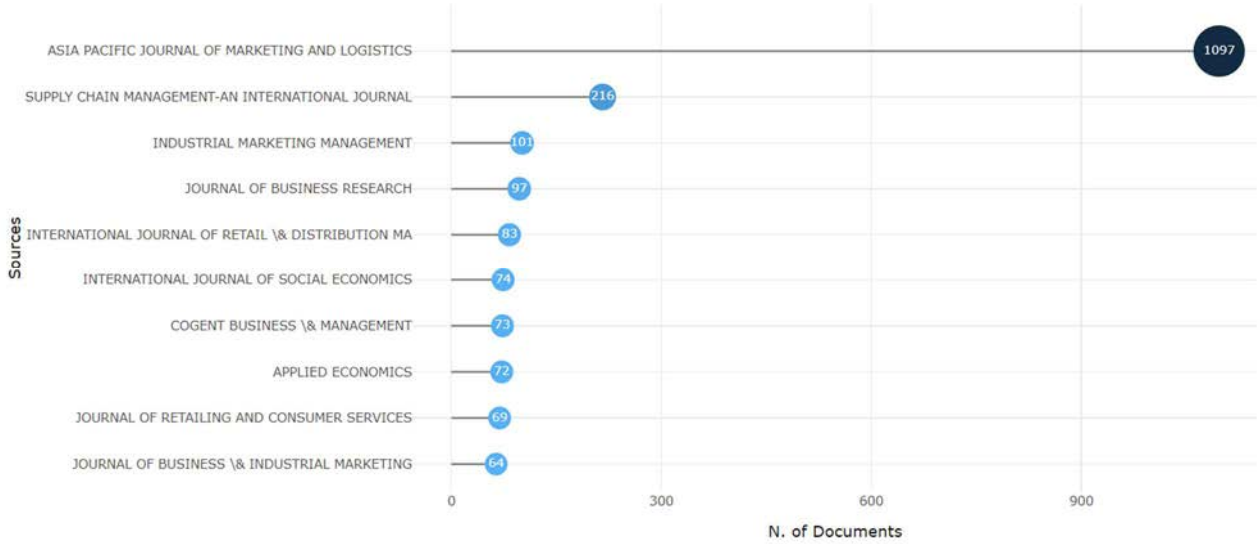

Figure 7 The most relevant source is the Web of Science

In the case of Scopus, the most relevant source is the "Journal of Intellectual Capital" with 62 publications. Following a significant gap in counts, the second most relevant source is the "Journal of Knowledge Management" with 26 articles, and the top 3 is closed by the "Journal of Business Research" with 12 publications. The top 10 relevant sources are illustrated in Figure 8.

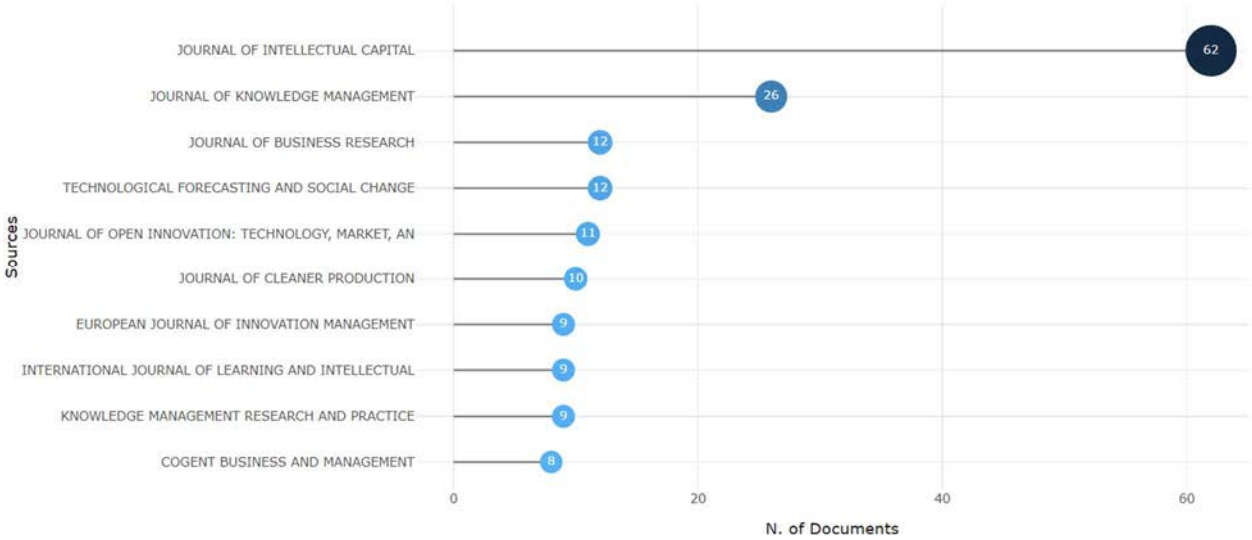

Figure 8 The most relevant sources: Scopus

Based on our findings, the top 10 authors in the case of Web of Science are: Liu Y., Wang X., Li X., Zhang Y., Wang Y., Liu M.T., Wang J., Zhang J., and Li Z. The number of published articles by each of them is illustrated in Figure 9.

In the Scopus sample, the top 10 authors are Lönnqvist A., Laihonen H., Xu J., Bontis N., Grimaldi M., Ramayah T., Sillanpää V., Soewarno N., Al-Hawamleh A., Chatterjee S. The number of published articles by each of them is illustrated in Figure 10.

Furthermore, we examined the country of the corresponding author. We analysed the collaborative patterns among countries to ascertain whether they had publications solely within their own country or if they participated in international co-authorship. We utilised maps to illustrate the collaboration between corresponding authors and countries to gain better insights into these connections. Results for Web of Science and Scopus are illustrated in Figure 11 and Figure 12, where MCP stands for Multiple Country Publications, and SCP stands for Single Country Publications.

The following part of this article provides a co-occurrence analysis, which helps identify the main topics and trends in research. We analysed 15,327 keywords from the Web of Science sample and 2,372 keywords from the

Scopus sample. Table 3 lists the top 20 most frequent keywords for both samples.

Table 3 The 20 most frequently used keywords

Web of Science		***Scopus***	
Keyword	**Frequency**	**Keyword**	**Frequency**
Logistics	**259**	Intellectual capital	**145**
Logistic regression	**241**	Knowledge management	**57**
Supply chain management	**197**	Human capital	**55**
Innovation	**170**	Innovation	**44**
China	**140**	Relational capital	**29**
Consumer behaviour	**136**	SMEs	**27**
Supply chain	**110**	Social capital	**25**
Management	**99**	Intangible assets	**24**
Sustainability	**99**	Firm performance	**23**
Performance	**96**	Performance	**23**
India	**93**	Sustainability	**22**
Entrepreneurship	**91**	Structural capital	**20**
E-commerce	**87**	Competitive advantage	**19**
SMEs	**86**	Organisational performance	**18**
Covid-19	**82**	Financial performance	**17**
Regression	**77**	Value creation	**17**
Customer satisfaction	**73**	Resource-based view	**15**
Reverse logistics	**73**	Business performance	**14**
Trust	**71**	Digital transformation	**14**
Gender	**66**	Corporate social responsibility	**13**

All available keywords are analysed using the co-occurrence method. The keywords were split into three clusters in the Web of Science sample. The first cluster (red) consists of 19 keywords summarising topics related to logistics supply chains and their management. The second cluster (blue) contains 14 keywords describing customer behaviour and e-commerce. The last cluster (green) includes 16 keywords describing corporate governance and competitiveness. The results are illustrated in Figure 9.

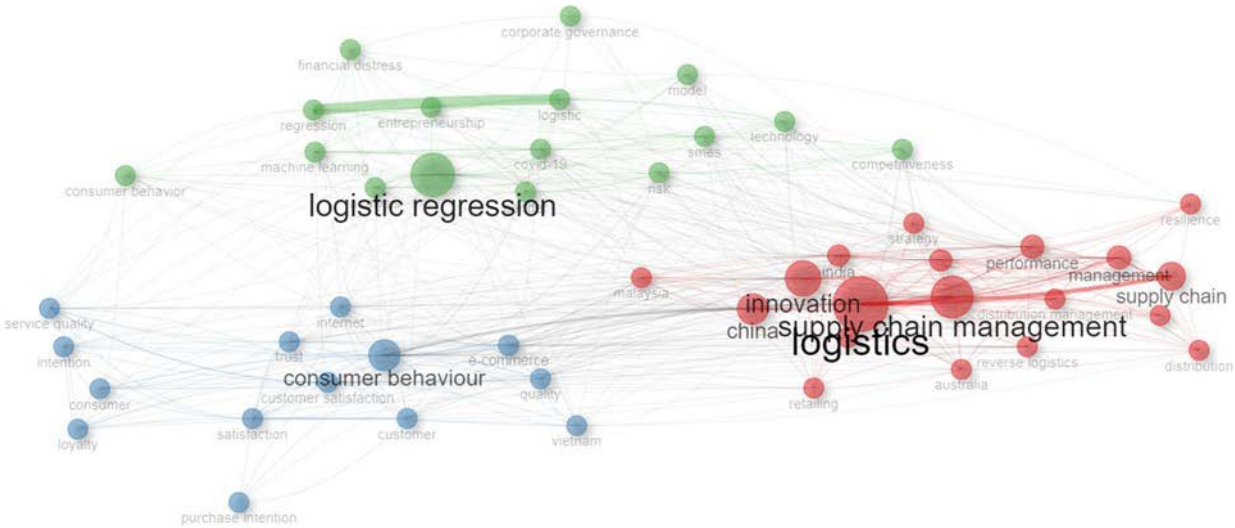

Figure 9 Co-occurrence analysis: Web of Science

Based on the keywords analysis, we created the thematic map for the Web of Science data (see Figure 10) and Scopus data (see Figure 12). All topics were divided into four quadrants based on their relevance and level of development. In other words, we categorised key issues into four groups: niche themes, motor themes, emerging

themes, and basic themes. In the case of Web of Science, logistic regression is the niche theme. Between motor themes belonging to research about consumer behaviour, China and India. Entrepreneurship, SMEs and COVID-19 issues are detected as emerging or declining themes. Basic themes include logistics, supply chain management, and innovation.

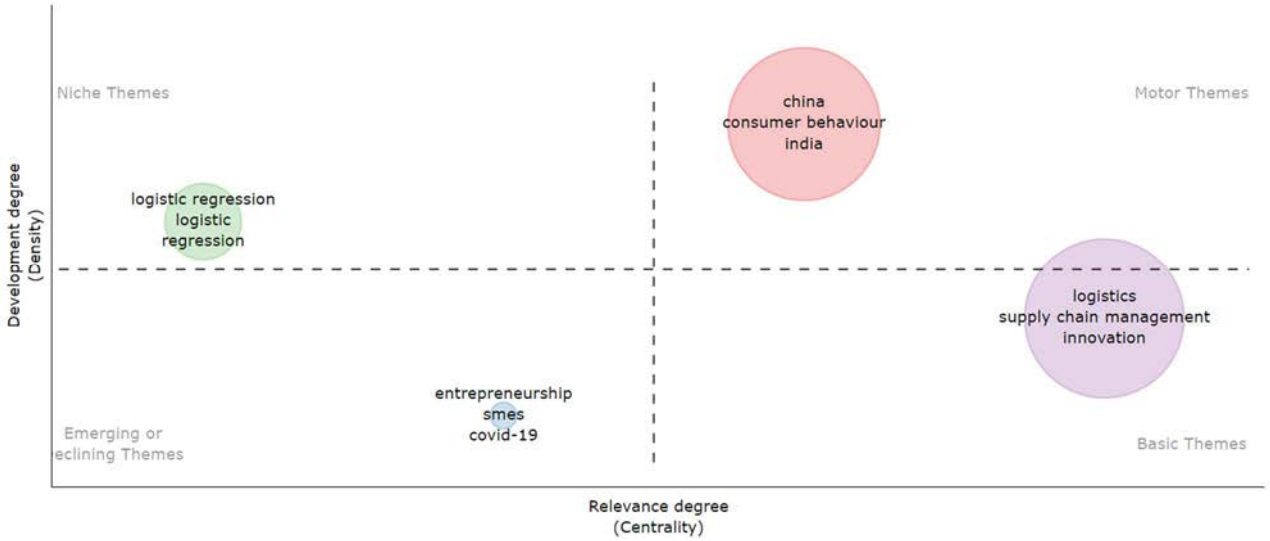

Figure 10 Thematic map: Web of Science

In analysing Scopus, we have identified five clusters. The first cluster (red) consists of nine keywords describing intangible assets and their management. The second cluster (blue) contains eight keywords related to intellectual capital, industry 4.0, and research and development. The third cluster (green) comprises eleven keywords summarising innovations and their competitive advantages. The fourth cluster (purple) includes ten keywords that summarise the topic of value creation and management of intellectual capital and supply chains. Finally, the fifth cluster (orange) contains eleven keywords describing intellectual capital and innovation capability components. The results are illustrated in Figure 11.

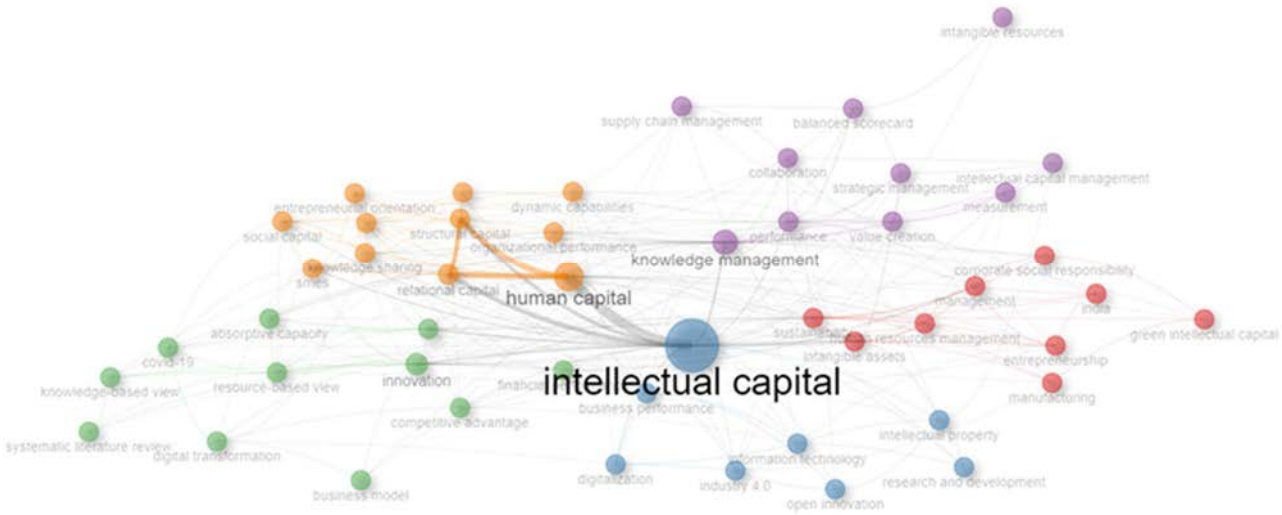

Figure 11 Co-occurrence analysis: Scopus

Scopus's thematic map is broader, as visible in Figure 12. Niche themes include value creation and strategic management research, digitalisation, open innovation, and Industry 4.0. Basic themes include intellectual capital and its components, knowledge management, innovation, intangible assets, sustainability, and corporate social responsibility.

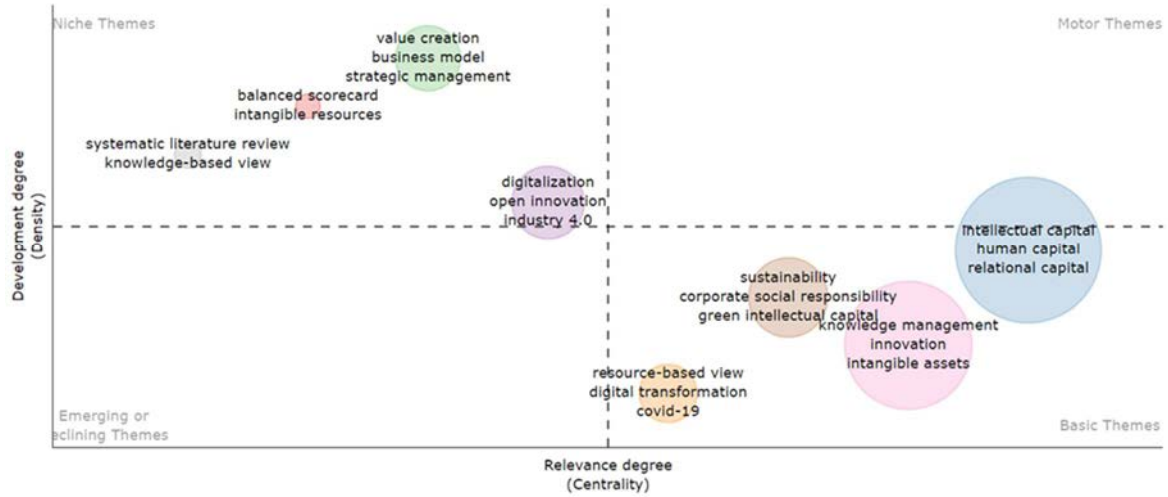

Figure 12 Thematic map: Scopus

5 Discussion

This study provides a comprehensive bibliometric analysis of published research on intellectual capital and Industry 4.0 in logistics based on data from the Web of Science and Scopus databases. The analysis spans all available years, covering 2001 – 2024 for the Web of Science and Scopus. It addresses key research questions to elucidate trends, contributors, and thematic developments within this field.

The first research question (RQ1) examines trends in publication patterns. The findings reveal a consistent increase in publications in both databases, underscoring growing academic interest in integrating intellectual capital and Industry 4.0 in logistics. This upward trajectory reflects the field's relevance in addressing the challenges and opportunities of digital transformation in logistics. The second research question (RQ2) identifies the leading countries in publication metrics. The Web of Science results highlight China, the USA, India, the UK, and Australia as the top contributors. At the same time, Scopus identifies China, the USA, Italy, the UK, and Malaysia as the most productive. Collaboration patterns differ between databases; Web of Science showcases strong international partnerships, such as those between China and the USA. Scopus highlights more regionally focused collaborations, including China, Pakistan, and the UK and France. These findings underscore the importance of global and regional collaboration networks in advancing research. The third research question (RQ3) explores the most relevant sources. In the Web of Science, the "Asia Pacific Journal of Marketing and Logistics," "Supply Chain Management—An International Journal," and "Industrial Marketing Management" emerge as the leading publication platforms. In Scopus, the "Journal of Intellectual Capital," "Journal of Knowledge Management," and "Journal of Business Research" are the most significant sources. These journals play a pivotal role in disseminating research and advancing the theoretical and practical understanding of intellectual capital in logistics. The fourth research question (RQ4) focuses on the most influential authors. In the Web of Science, key contributors include Liu Y., Wang X., Li X., Zhang Y., and Wang Y., among others. In Scopus, prominent authors such as Lönnqvist A., Laihonen H., Xu J., Bontis N., and Grimaldi M. are identified. These authors significantly shape the intellectual landscape of the field. Additionally, an analysis of corresponding author countries highlights the geographical distribution of research leadership and collaboration networks. The fifth research question (RQ5) delves into key trends and themes based on publication keywords. In the Web of Science, keywords cluster into three themes: niche topics such as logistic regression, basic themes like logistics, supply chain management, and innovation, and motor themes such as consumer behaviour and research activity in China and India. Scopus reveals five clusters, with niche themes including value creation and digitalisation, basic themes such as intellectual capital components and corporate social responsibility, and emerging themes like Industry 4.0 and open innovation. These clusters provide a nuanced understanding of the field's thematic evolution, pointing to foundational topics and emerging research frontiers. This study answers critical questions regarding the trends, contributions, and thematic focus of research on intellectual capital and Industry 4.0 in logistics. It provides a valuable resource for academics and practitioners seeking to understand and advance the integration of these concepts in the logistics domain.

6 Conclusion

This study's findings are informative and provide a profound understanding of the evolving relationship between intellectual capital and Industry 4.0 within the logistics domain. Through a comprehensive bibliometric analysis, significant trends and themes have been uncovered, shedding light on the current state of research, its geographical distribution, key contributors, and thematic focus areas.

The analysis revealed a consistent upward trend in publications related to intellectual capital and Industry 4.0 in logistics, highlighting growing academic and practical

interest in the field. However, notable differences between the Web of Science and Scopus databases were observed. For instance, Web of Science demonstrated a longer historical trajectory, while Scopus showed a higher annual growth rate, suggesting a more recent intensification of research activity. This discrepancy underscores the importance of leveraging multiple databases to capture a holistic view of the research landscape.

Geographically, China and the USA emerged as dominant contributors across both databases, reflecting their leadership in technological innovation and logistics research. However, the collaboration patterns differed significantly between the databases. While Web of Science demonstrated robust international collaborations, Scopus highlighted less extensive but regionally focused partnerships. These differences suggest collaboration networks are critical in shaping research productivity and quality. Identifying key sources, such as the Asia Pacific Journal of Marketing and Logistics and the Journal of Intellectual Capital, underscores the field's interdisciplinary nature. These sources are pivotal platforms for disseminating cutting-edge research and advancing the theoretical and practical understanding of intellectual capital in Industry 4.0, bridging domains such as marketing, knowledge management, and industrial logistics. The thematic analysis highlighted the integration of intellectual capital components—human, structural, and relational—with Industry 4.0 technologies. Basic themes such as logistics, supply chain management, and innovation remain foundational, while niche themes like value creation and digital transformation point to emerging research frontiers. The motor themes, including consumer behaviour and sustainability, reflect the field's alignment with broader societal and environmental concerns, emphasising the need for sustainable and adaptive logistics practices. One notable finding is the thematic divergence between the databases. Web of Science prioritises logistics and supply chain management, while Scopus emphasises intangible assets and strategic management. This divergence suggests that the databases cater to slightly different academic audiences and priorities, which may influence the framing and dissemination of research in the field. Despite these insights, it's crucial to acknowledge the study's limitations. Including data up to 2024 may not fully capture ongoing developments, and language biases inherent in the databases may have excluded relevant non-English research. Additionally, the analysis relies heavily on bibliometric techniques, which, while powerful, may only partially account for the qualitative nuances of intellectual capital research. Awareness of these limitations is essential to understand the study's scope and implications comprehensively.

Overall, this study contributes to the growing body of literature by providing a structured and detailed understanding of how intellectual capital underpins logistics transformation in the era of Industry 4.0. The findings are valuable for academics and practitioners, offering a roadmap for future research and practical applications. We hope that future studies could build on this foundation by incorporating qualitative analyses, exploring case studies, and examining the role of intellectual capital in specific logistics technologies, such as blockchain, IoT, and AI-driven supply chain management. These efforts would further enrich the understanding of how intellectual capital drives innovation and competitive advantage in the digital age.

This study has some limitations. First, there is a data lag issue. We chose not to exclude 2024 to ensure we have the most current information available. It's important to note that while the basic information might remain mostly the same, the number of publications could still vary. Second, there is a coverage bias due to the databases needing to cover all languages uniformly. These limitations emphasise the need for cautious interpretation of our findings, particularly regarding the currency of data and the language bias inherent in our database selection.

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References

[1] KIANTO, A., SÁENZ, J., ARAMBURU, N.: Knowledge-based human resource management practices, intellectual capital and innovation, *Journal of Business Research*, Vol. 81, pp. 11-20, 2017. https://doi.org/10.1016/j.jbusres.2017.07.018

[2] ALVINO, F., DI VAIO, A., HASSAN, R., PALLADINO, R.: Intellectual capital and sustainable development: A systematic literature review, *Journal of Intellectual Capital*, Vol. 22, No. 1, pp. 76-94, 2020. https://doi.org/10.1108/JIC-11-2019-0259

[3] ELKADER, M.A.A., MORALES, M.L.V., SINGH, P.: *Logistics 4.0, innovation & intellectual property evaluation: the moderating effects of its adoption*, 30th Annual Conference of the International Association for Management of Technology, pp. 474-485, 2021. https://doi.org/10.52202/060557-0035

[4] TIMM, I.J., LORIG, F.: *Logistics 4.0—A challenge for simulation*, Winter Simulation Conference (WSC), Huntington Beach, CA, USA, pp. 3118-3119, 2015. https://doi.org/10.1109/WSC.2015.7408428

[5] RADIVOJEVIC, G., MILOSAVJEVIC, L.: *The concept of logistics 4.0*, Logic, 4th Logistics International Conference, Belgrade, Serbia, pp. 283-292, 2019.

[6] RODRIGUE, J.-P.: *The Geography of Transport Systems*, 6th ed., London, Routledge, 2024. https://doi.org/10.4324/9781003343196

[7] MOSCONI, F.: *The New European Industrial Policy: Global Competitiveness and the Manufacturing*

Renaissance, London, Routledge, 2015. https://doi.org/10.4324/9781315761756

[8] BUIL, I., MARTÍNEZ, E., MATUTE, J.: Transformational leadership and employee performance: The role of identification, engagement and proactive personality, *International Journal of Hospitality Management*, Vol. 77, pp. 64-75, 2019. https://doi.org/10.1016/j.ijhm.2018.06.014

[9] CABRITA, M.R, CRUZ-MACHADO, V., DUARTE, S.: *Enhancing the Benefits of Industry 4.0 from Intellectual Capital: A Theoretical Approach*, Springer, The 12th International Conference on Management Science and Engineering Management, pp. 1581-1591, 2019. https://doi.org/10.1007/978-3-319-93351-1_124

[10] GHOBAKHLOO, M.: Industry 4.0, digitization, and opportunities for sustainability, *Journal of Cleaner Production*, Vol. 252, No. April, 119869, 2020. https://doi.org/10.1016/j.jclepro.2019.119869

[11] WANG, X., SADIQ, R., KHAN, T.M., WANG, R.: Industry 4.0 and intellectual capital in the age of FinTech, *Technological Forecasting and Social Change*, Vol. 166, No. May, 120598, 2021. https://doi.org/10.1016/j.techfore.2021.120598

[12] GASHENKO, I.V., KHAKHONOVA, N.N., OROBINSKAYA, I.V., ZIMA, Y.S.: Competition between human and artificial intellectual capital in production and distribution in Industry 4.0, *Journal of Intellectual Capital*, Vol. 21, No. 4, pp. 531-547, 2020. https://doi.org/10.1108/JIC-11-2019-0275

[13] CANTONI, F., RICCIARDI, A., BISOGNI, P.G., ZSIFKOVITS, H.: The unravelled role of soft skills in the logistics and supply chain management field, *Journal of Innovation & Knowledge*, Vol. 9, No. 1, 100615, pp. 1-18, 2024. https://doi.org/10.1016/j.jik.2024.100615

[14] FAREED, A.G., DE FELICE, F., FORCINA, A., PETRILLO, A.: Role and applications of advanced digital technologies in achieving sustainability in multimodal logistics operations: A systematic literature review, *Sustainable Futures*, Vol. 6, No. December, 100278, pp. 1-16, 2024. https://doi.org/10.1016/j.sftr.2024.100278

[15] PEKARČÍKOVÁ, M., TREBUNA, P., KOPEC, J.: Increasing the efficiency of logistics for the area of storage and picking of special materials, *Acta logistica*, Vol. 11, No. 3, pp. 485-493, 2024. https://doi.org/10.22306/al.v11i3.536

[16] POZZO, D.N., CORREA, K.R., MADRID, A.I.C., CAMPO, C.J.C., DONADO, M.E.G., BIEGELMEYER, U.H.: Logistics 4.0: A review of current trends using bibliometric analysis, *Procedia Computer Science*, Vol. 204, pp. 163-170, 2022. https://doi.org/10.1016/j.procs.2022.07.075

[17] REJEB, A., SIMSKE, S., REJEB, K., TREIBLMAIER, H., ZAILANI, S.: Internet of Things research in supply chain management and logistics: A bibliometric analysis, Internet of Things, Vol. 12, 100318, pp. 1-16, 2020. https://doi.org/10.1016/j.iot.2020.100318

[18] STRAKA, M., SOFRANKO, M., VEGSOOVA, O. G., KOVALCIK, J.: Simulation of Homogeneous Production Processes, *International Journal of Simulation Modelling*, Vol. 21, No. 2, pp. 214-225, 2022. https://doi.org/10.2507/IJSIMM21-2-597

[19] NÚÑEZ-MERINO, M., MAQUEIRA-MARÍN, J. M., MOYANO-FUENTES, J., CASTAÑO-MORAGA, C.A.: Industry 4.0 and supply chain: A systematic science mapping analysis, *Technological Forecasting and Social Change*, Vol. 182, No. August, 121788, pp. 1-13, 2022. https://doi.org/10.1016/j.techfore.2022.121788

[20] LEUNG, X.Y., SUN, J., BAI, B.: Bibliometrics of social media research: A co-citation and co-word analysis, *International Journal of Hospitality Management*, Vol. 66, pp. 35-45, 2017. https://doi.org/10.1016/j.ijhm.2017.06.012

[21] GUTIÉRREZ, B.R., REINA QUINTERO, A.M.R., PARODY, L., GÓMEZ LÓPEZ, M.T.: When business processes meet complex events in logistics: A systematic mapping study, Computers in Industry, Vol. 140, No. January, 103788, pp. 1-16, 2022. https://doi.org/10.1016/j.compind.2022.103788

[22] BÖRNER, K., CHEN, C., BOYACK, K.W.: Visualizing knowledge domains, *Annual Review of Information Science and Technology*, Vol. 37, No. 1, pp. 179-255, 2003. https://doi.org/10.1002/aris.1440370106

[23] ARIA, M., CUCCURULLO, C.: bibliometrix: An R-tool for comprehensive science mapping analysis, *Journal of Informetrics*, Vol. 11, No. 4, pp. 959-975, 2017. https://doi.org/10.1016/j.joi.2017.08.007

[24] COBO, M.J., LÓPEZ-HERRERA, A.G., HERRERA-VIEDMA, E., HERRERA, F.: Science mapping software tools: Review, analysis, and cooperative study among tools, *Journal of the American Society for Information Science and Technology*, Vol. 62, No. 7, pp. 1382-1402, 2011. https://doi.org/10.1002/asi.21525

[25] ZUPIC, I., ČATER, T.: Bibliometric Methods in Management and Organization, *Organizational Research Methods*, Vol. 18, No. 3, pp. 429-472, 2015. https://doi.org/10.1177/1094428114562629

[26] DONTHU, N., KUMAR, S., MUKHERJEE, D., PANDEY, N., LIM, W.M.: How to conduct a bibliometric analysis: An overview and guidelines, *Journal of Business Research*, Vol. 133, pp. 285-296, 2011. https://doi.org/10.1016/j.jbusres.2021.04.070

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Towards efficient logistics through suitable negotiation strategies: the role of uncertainty
Frantisek Zapletal, Jan Volny, Radim Lenort

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Towards efficient logistics through suitable negotiation strategies: the role of uncertainty

Frantisek Zapletal
VSB-Technical university of Ostrava, Faculty of Economics, 17. listopadu 15, 70800, Ostrava, Czech Republic, EU, frantisek.zapletal@vsb.cz (corresponding author)
Jan Volny
VSB-Technical university of Ostrava, Faculty of Economics, 17. listopadu 15, 70800, Ostrava, Czech Republic, EU, jan.volny@vsb.cz
Radim Lenort
Škoda Auto University, Na Karmeli 1457, Mladá Boleslav, Czech Republic, EU, radim.lenort@savs.cz

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Abstract: Uncertainty is a factor that affects many decision-making situations in practice. Supplier management and its flows in companies is no exception. This paper focusses on the choice of the most appropriate strategy towards suppliers in a company. This topic is unfairly neglected in the literature compared to other decisions related to suppliers, such as supplier selection or evaluation. For the sake of robustness, two different hybrid methods of multicriteria decision making, allowing managers to capture the uncertainty, are applied and compared. Namely, the AHP method together with Stochastic Multicriteria Acceptability Analysis (SMAA), and the fuzzy extension of the PROMETHEE method. The goal of this paper is twofold. First, the best strategy is explored with respect to time and uncertainty before the nomination of a supplier is done and after that. Second, it is pointed out how much oversimplifying and distorting the aggregation of opinions using the averaging operator can be. The results showed that examining individual evaluations helps better understand the impact of the uncertainty on the most suitable strategies towards suppliers, in comparison with the final ranking based on averaging individual opinions. The performed survey revealed that choosing the best strategy before nominating a supplier is more difficult than doing so after the nomination.

1 Introduction

Decision-making plays a vital role in numerous organizations and for individuals, who employ various approaches to evaluate its effects on the company, themselves, and the surroundings. The nature of decisions can depend significantly depending on the level of certainty or uncertainty faced by the decision-maker. Additionally, the framework within which decisions are made may evolve over time, resulting in circumstances that differ from those at present. By delving into a real-world scenario within the flows in logistics within the automotive sector, we explore how alterations in cost management can be impacted both before and after the selection of a supplier.

Numerous studies in the literature have examined supplier management and its flows, with a predominant focus on identifying optimal suppliers for inclusion in the portfolio [1], developing negotiation models to determine order quantities [2], or a combination of both [3]. In this study, we operate under the assumption that supplier selection has been completed and cannot be altered further. As precise price bids and quantities are not yet known, the model presented merely suggests a broad strategy to be implemented both before and after a supplier is designated.

Suggested strategies are tools, that could be implemented during negotiations process. The study [4] shows that the process preparation and information are essential during negotiation. In this paper, the most suitable strategy towards suppliers during negotiation process is investigated (before and after nomination of a supplier), and the impact of imprecise inputs on this strategy is carefully explored.

This paper builds on the contribution presented at the conference and published in its proceedings, see [5]. Unlike this work, this study is extended by the PROMETHEE analysis which enables one to understand the impact of the uncertainty in a more systemic and complex way. The basic structure of the introduced model has already been published in [5]. This paper uses extensive survey data collected from a car manufacturing company, previously utilized in [5]. Unlike that study, the main objective here is not to rank alternatives but rather to thoroughly investigate the influence of uncertainty on the issue at hand at the two considered moments – before the nomination of a supplier is done, and after this nomination. The uncertainty can impact the results in two ways: first, individual opinions may carry inherent uncertainty (all criteria in the model are nominal and subjective), and second, variability in opinions can also potentially impact the final recommendation.

In [5], the fuzzy-AHP method was used to find the best behaviour towards suppliers of a car manufacturer. This paper uses a different method. Namely, the Stochastic Multi-criteria Acceptability Analysis [6] and fuzzy-

PROMETHEE [7] are used. The motivation for this choice is that the optimal strategy obtained by Fuzzy-AHP in [5] was surprisingly unambiguous. SMAA (Stochastic Multicriteria Acceptability Analysis) together with the AHP (Analytical Hierarchy Process) method and a different way of capturing the uncertainty in fuzzy sets within Fuzzy-PROMETHEE will help us to explore whether this unambiguity was caused by the fact that the solution is really absolutely clear, or if it was brought by a simplifying aggregation operator which was used to aggregate individual opinions together.

The rest of the paper is organized as follows. Section 2 introduces the necessary methodological background of the used methods: AHP, SMAA and Fuzzy-PROMETHEE methods. Section 3 recalls the model taken over from [5]. The core part is Section 4, where the results of SMAA-AHP and fuzzy-PROMETHEE methods are provided, discussed and compared with the results of the Fuzzy-AHP method presented by [5].

2 Methodological background

If one has a decision problem where k criteria are used to assess n alternatives (where both sets are finite, discrete and 'reasonably' small), we talk about a multi-criteria decision-making problem (MCDM). Since many MCDM methods exist, one must be very careful when selecting the one for some particular real-life problem. The methods differ in many parameters: a way, how the final value of the alternatives is calculated, how a decision-maker evaluates parts of the model, suitability for some of all data types, ability to work in dynamic or uncertain environment, etc. For this study, we have decided for two different settings: (a) the combination of the AHP [8] and SMAA [6] and (b) fuzzy-PROMETHEE method. The reason for the first choice is straightforward. The AHP method is by far the most popular MCDM method all over the world (according to the number of records obtained when searching the name of the method in the Web of Science database), the input data from the decision-makers have been adapted to this method, and its fuzzy extension has already been used by [5], thus making the comparability of the results will be easier. However, group decision making with AHP usually works with the aggregation of opinions using some averaging function. On the other hand, SMAA allows us to consider all individual opinions without the necessity of using some simplifying aggregation operators such as the geometrical mean in [5]. In line with [6], SMAA is a highly suitable method when the robustness of the results is explored. As for the fuzzy-PROMETHEE, this method is built on a different logic than AHP and allows one to define the set of strengths and weaknesses of each alternative.

In order to keep the length of this paper acceptable, both methods will be outlined rather than completely described. An interested reader can look at many descriptions in the literature.

2.1 Analytical Hierarchy Process (AHP)

The AHP is based on pairwise comparisons using the Saaty's matrices, see [8]. The Saaty's matrix pair-wisely compares either the importance between two criteria, or the performance between two alternatives in terms of a given criterion. The matrix for weights' determination will be of size $k \times k$ and each of k matrices comparing the alternatives will be of size $n \times n$. Each Saaty's matrix must be reciprocal and its elements must belong to the Saaty's scale (the values from 2 to 9 to express the preferences in favour of an entity in a row over an entity in the column, and their reciprocals to express the opposite preference; 1 is used for equal preferences). Before the priorities are derived, each Saaty's matrix should be checked for the consistency, e.g., using the consistency ratio, see [8]. The weights w_i from the Saaty's matrix are calculated using Eq. 1, the utilities u_{ij}, revealing the performance of the j-th alternative in terms of the criterion i, would be analogical.

$$w_i = \frac{\prod_{j=1}^{k} s_{ij}}{\sum_{m=1}^{k} \prod_{j=1}^{k} s_{mj}} \tag{1}$$

The ranking is determined according to the value of total utilities of alternatives is calculated using Eq. 2.

$$U_i = \sum_{j=1}^{k} w_j \cdot u_{ij}, i = 1, \ldots, n \tag{2}$$

2.2 Stochastic Multicriteria Acceptability Analysis

The SMAA method operates on the principle that it searches for the percentage of weights for which a given option is the best – this metric is referred to as the acceptability index and which weight vector is the centroid of the hyperplane of all weights where the given variant is the best. In cases where we have stochastic evaluations of options, we also obtain a confidence factor that tells us how likely it is that the weight vector, which is the centroid of the weight hyperplane that was best for a given variant, will actually turn out to be the best for that variant.

According to [6], the acceptability index a_i is calculated using the ratio of the volume of the weight vector W_i to the total volume of the weight vector W. Here, W represents the set of all possible weight vectors that meet the criteria of the user or the problem, and W_i is a subset of W that corresponds to the best variant. The function vol represents 'volume', or the measure of how much of the weight vector space the given subset W_i occupies compared to the total space W, see Eq. 3.

$$a_i = \frac{vol(W_i)}{vol(W)} \tag{3}$$

In the case of stochastic evaluations, we calculate a_i using the ratio with the expected value of the weight vector volume (Eq. 4).

$$a_i = \frac{E(vol(W_i(\gamma)))}{vol(W)} \quad (4)$$

The central weight vector for alternative i is defined as the expected centre of gravity and can be calculated as follows in deterministic case (Eq. 5) and stochastic case (Eq. 6).

$$w_i^c = \int_{W_i} w \, \mathrm{d}w / \int_{W_i} \mathrm{d}w \quad (5)$$

$$w_i^c = \int_{\gamma} f(\gamma) \left(\int_{W_i(\gamma)} w \, dw \int_{W_i(\gamma)} dw \right) d\gamma \quad (6)$$

The confidence factor is obtained as the area of the probability distribution function for which it holds that for a random variable, the utility of variant i is greater than the utility of other variants, see (Eq. 7).

$$p_i^c = \int_{\gamma: u_i(\gamma, w_i^c) \geq u_k(\gamma_k, w_i^c)} f(\gamma) d\gamma, \quad (7)$$

where w_i^c is the central weight vector ~~in~~ for which the variant i is optimal.

For more detailed description of the SMAA method and its application in various fields, see [9]. For purposes of this work, the results of the integrals are calculated using Monte Carlo simulation for the sake of convenience.

2.3 *Fuzzy PROMETHEE*

The PROMETHEE ranking method, introduced by [10], has gained widespread popularity during the last decades, see the review paper by [11], or its particular application in logistics, see [12]. At its core, PROMETHEE ranking employs a preference function, which assigns a preference degree $P_i(a, b)$ to each pair of alternatives a, b with regard to each criterion i from the set of considered criteria. This preference degree is determined based on the difference in performance values between the alternatives compared with respect to the given criterion. Decision-makers have the flexibility to select from various types of preference functions, each with different configurations for individual criteria. The authors of [10] work with six predefined shapes of preference functions. Among the published applications, as reviewed by [11], the linear function type, with indifference and preference thresholds q and p, stands out as the most commonly utilized (see Figure 1). After comparing all pairs of alternatives across all criteria, the positive and negative flows of the alternative a are calculated using Eqs. 8 and 9.

$$\tilde{\phi}^+(a) = \frac{\oplus_{a \neq b}^{n} \oplus_{i=1}^{k} (w_i \odot \tilde{P}_i(a,b))}{n-1}, \text{for } \forall a. \quad (8)$$

$$\tilde{\phi}^-(a) = \frac{\oplus_{a \neq b}^{n} \oplus_{i=1}^{k} (w_i \odot \tilde{P}_i(b,a))}{n-1}, \text{for } \forall a, \quad (9)$$

where w_i represents the weight assigned to the i-th criterion, indicating its relative significance among the criteria, k indicates the number of criteria, n the number of alternatives.

In line [7], the preference degrees are expressed with the triangular fuzzy number $\tilde{P} = (p_l, p_c, p_r)$ (denoted by tilde), see Figure 2. This fuzzy number captures the uncertainty by admitting that the corresponding variable can reach any value from some interval with the assigned value of the membership degree μ ($\mu \in (0; 1]$). This membership degree anwers the question to what extent some value belongs to the given set. The binary operators $\oplus$ and $\odot$ extends the classical binary operations of addition and multiplication for fuzzy sets, see Eqs. 10, and 11.

$$\tilde{P} \oplus \tilde{Q} = (p_l, p_c, p_r) \oplus (q_l, q_c, q_r) = (p_l + q_l, p_c + q_c, p_l + q_l) \quad (10)$$

$$\tilde{P} \odot k = (p_l, p_c, p_r) \odot k = (kp_l, kp_c, kp_l), k \in \mathbb{R}^+ \quad (11)$$

The fuzzy positive flow indicates to what extent the alternative surpasses, on average, the other alternatives. The other way around, the negative flow indicates the degree at which the alternative falls short, on average, compared to all other alternatives. To ensure a complete ranking of the alternatives, the positive and negative flows must be combined into net flows using (Eq. 12).

$$\tilde{\phi}(a) = \tilde{\phi}^+(a) \ominus \tilde{\phi}^-(a), \text{for } \forall a \quad (12)$$

where $\ominus$ stands for the fuzzy extension of classical subtraction given by Eq. 13.

$$\tilde{P} \ominus \tilde{Q} = (p_l, p_c, p_r) \ominus (q_l, q_c, q_r) = (p_l - q_r, p_c - q_c, p_r - q_l) \quad (13)$$

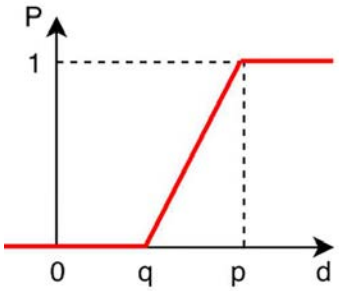

Figure 1 Linear preference function and preference degree

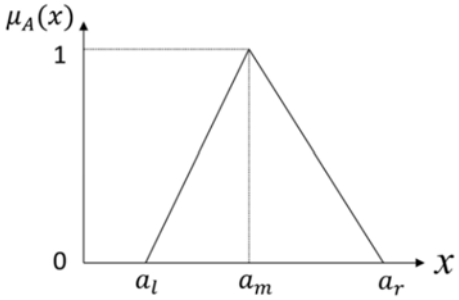

Figure 2 Triangular fuzzy number

3 Decision model

This section recalls the decision model introduced by [5]. The criteria and alternatives (strategies) have been expertly defined expertly based on the interviews conducted in the same car manufacturing company where the case study was performed. The selection of criteria is supported by [13] and [14], where the authors consider speed of process, complexity of process, and cost of processess in man-hours important factor for the evaluation. Despite the fact that the model has been proposed based on expert opinions from the automotive company, it does not use any criterion or strategy, which could not be reasonably expected in case of any industrial company.

3.1 Criteria

The following criteria for evaluations are considered:

- Speed of implementation,
- Complexity,
- Capacity effort,
- Setting of premises,
- Internal know-how,
- Output.

The speed of implementation is a very important factor in the selection of the tools. It is very important how fast each topic can be implemented in practice; how complex are the topics in the preparation and how much capacity must be used in terms of manpower and time. Furthermore, it is also very important whether premises can be set for the respective topic. For example, if premises are kept too coarse and generous in a change catalogue, the costs cannot be precisely defined. A precise and detailed definition of the premises also enables a detailed statement of costs for a specific measure. It is also important to ask whether the know-how is available internally. The employees and their experience are essential. Employees from development and purchasing can bring the topics into the lessons learnt tools. These topics have to be evaluated by the supplier. Finally, output is the last, also very important criterion. It can happen that everything can be implemented very fast, with low capacity and high know-how, but if the output is small or it brings little savings, the focus is usually placed on another topic. All six criteria are considered categorial (qualitative).

3.2 Alternatives

The alternatives in the presented model are three particular strategies which can be adopted by a company. These strategies can rarely be applied separately, but their combination with different 'power' is expected to be used:

- Change catalogue or pre-negotiation of possible changes in the future,
- Improvement of the technical requirements and specifications,
- A decrease in overhead and profit surcharge or a question of the 'Surcharge calculation' used by many OEMs, is future orientated.

The use of a change catalogue after nomination can be useful for example, to negotiate changes better and more effectively. A high-quality change catalogue is developed in close cooperation between the purchasing and development teams.

When specifying the details and quality of the specifications, the company can avoid many changes through the development of the product in the future, so that the change catalogue can be made redundant or at least greatly reduced in complexity.

The third main strategy, when trying to reduce the costs of product development and its delivery, is a decrease in overhead and profit surcharges. Many OEMs use a surcharge calculation as a calculation basis. The calculation uses the bottom-up approach to calculate the cost components and then adds the overhead and profit surcharges as a percentage of the material and production costs. This is determined primarily during the nomination and is agreed with the supplier.

4 Case study

This section begins with the introduction of the input data. Then, the results obtained by [5] of the implementation of the fuzzy-AHP and fuzzy-PROMETHEE approach to the presented model. The core part of this section focusses on the results of the application of the hybrid AHP-SMAA and fuzzy-PROMETHEE method. The results of all three methods are carefully compared, and recommendations are provided.

4.1 Input data

In this paper, we present the implementation of the model on the data brought by the survey in a single car manufacturer. That is, 113 managers (out of approximately 500) from the fields of purchase and logistics have been asked (in the fall, 2022) to evaluate the importance of criteria and performance of the alternatives using the Saaty's scale with the possibility to express their hesitance using the interval within the scale. All evaluations have had

to be done twice – first for the period before nomination (before the contract is signed) and second after nomination.

As for the AHP-SMAA method, the evaluations were considered random variables with discrete empirical distribution. The probability of each grade on the Saaty's scale corresponds to the relative proportion between all decision-makers. For instance, if all 113 decision-makers chose in total 200 different values for some compared pairs of alternatives (note that each decision maker could select more values from the scale because of the uncertainty), and if the value 2 (a very weak preference in favour of the first evaluated alternative) occurs 20 times, its relative proportion is 0.1. In this way, each individual opinion is considered without loss of data.

As for fuzzy PROMETHEE, the input values were handled in a completely different way. Unlike the AHP-SMAA, not all opinions were preserved for the evaluation process. Namely, only the grades with at least 10% of the evaluations were kept, the rest was ignored as outliers (otherwise, the ranges were too wide, and almost all possible rankings could occur then). The fuzzy inputs for fuzzy-PROMETHEE were derived in the following way: the minimum and maximum of the 80% range were used to calculate the lower and upper bound of the triangular fuzzy number, the vertex of the triangle (with $\mu = 1$) is equal to the mode of the empirical distribution (i.e., the most frequently chosen value). Due to the same scale used for all criteria, an identical preference function was used for all criteria. Namely, the linear function with $q = 1$ and $p = 9$ was set (it means that the maximum preference on the Saaty's scale leads to the maximum value of the preference degree, the lowest possible value of preference (0.125) corresponds with the value 2 on the Saaty's scale and then, the preference degree increases by 0.125 with each grade.

4.2 Results

The authors of [5] applied the fuzzy AHP method to the same dataset and get an unambiguous ranking of the alternatives, see Figure 3 and Figure 4. In other words, the uncertainty does not impact the final ranking at all. This gives rise to the idea that the solution is absolutely robust and that no hesitance about the prioritization of the strategies seems to be justified.

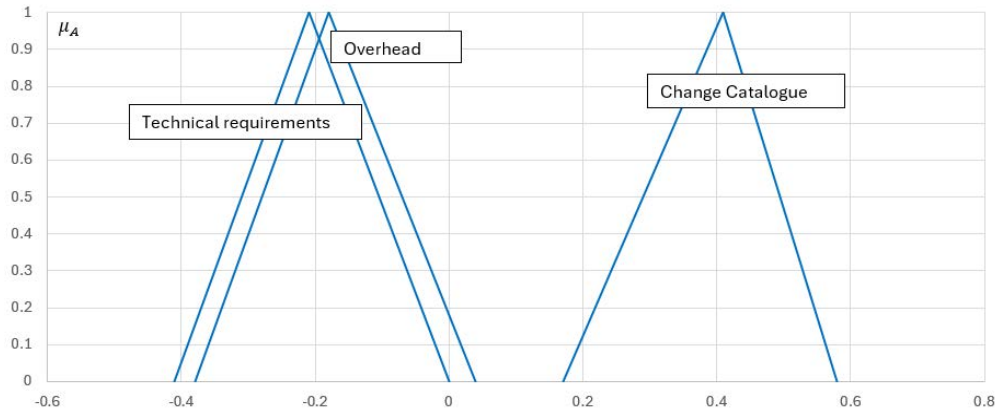

Figure 3 Final results of alternatives by fuzzy-AHP method before the nomination [Trumić and Zapletal (2023)]

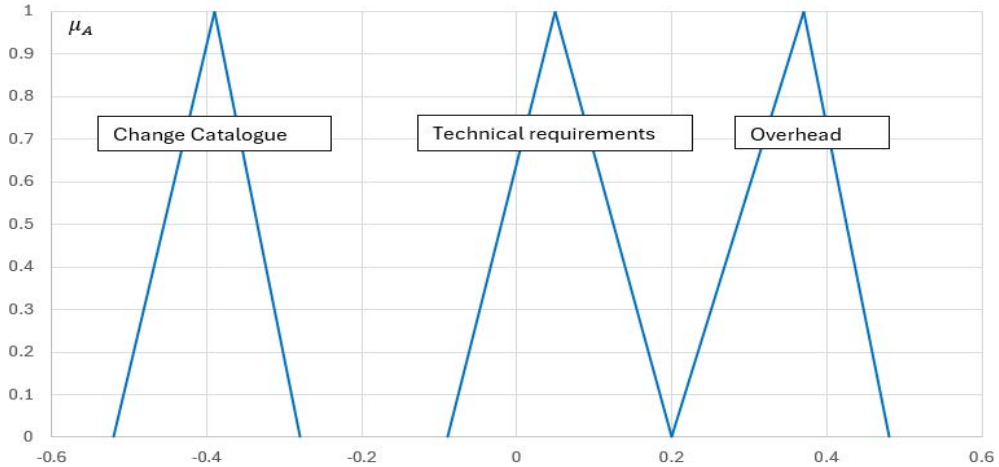

Figure 4 Final results of alternatives by fuzzy-AHP method after the nomination [Trumić and Zapletal (2023)]

In the lead-up to the supplier decision before nomination, it is crucial to prioritize the development of a cost catalogue, while defining highly detailed technical specifications is of lesser importance. This is reasonable because negotiating the list of changes with the best conditions is only possible before the contract is signed. Good prices for future changes after signing a contract cannot be expected. The reason why these future changes should be negotiated before the contract is signed is the better power position of purchasing and the leverage to be able to place the order with another supplier.

For the period after nomination, the ranking obtained by [5] is also unambiguous, but differs substantially. The most important tool is the overhead, followed by the technical requirements and the catalogue of changes. After the nomination, the lever towards the suppliers is gone and purchasing loses its position of power. For this reason, the prioritization of the change catalogue slipped to third place after a nomination, which is also understandable, because negotiating the change costs after the nomination makes little sense.

However, these results were based on the aggregation of the individual uncertain opinions using the (fuzzy-) geometric mean, and as for any other use of an aggregation operator, a part of information is potentially lost.

4.2.1 Results of AHP-SMAA method

Now, let us have a look at the results of the AHP-SMAA analysis. Unlike the fuzzy AHP, no evaluations by the decision-makers were lost by their aggregation. This means that the method reflects all assessments, even extremely outlying ones. Such an approach checks very well to what extent the final ranking is stable and unambiguous.

The results of the application of the AHP-SMAA method are shown in Figure 5. Namely the acceptability indices for all three positions of the strategies before and after the nomination are provided there. For the situation after nomination, the results are not so surprising. Althought each strategy can potentially be ranked at all positions, 3% of the cases are omittable for both, the first position of 'Change catalogue' and the last position of 'Overhead'. These results were expected in light of knowledge of the previous fuzzy AHP results. The results before nomination are much more interesting. It can be seen that the most frequent individual ranking need not necessarily correspond with the aggregated ranking. Technical requirements are ranked in almost 50% as the second one, however, according to aggregated results, this alternative is clearly the last one. 'Overhead' was ranked using the aggregated opinion as clearly second, but the AHP-SMAA analysis revealed that this position is the least frequent at all. The results indicated how much simplifying the aggregation can be, despite the included uncertainty. The results pointed out how unwise would be to focus only on the 'winning' strategy and ignore the remaining two strategies.

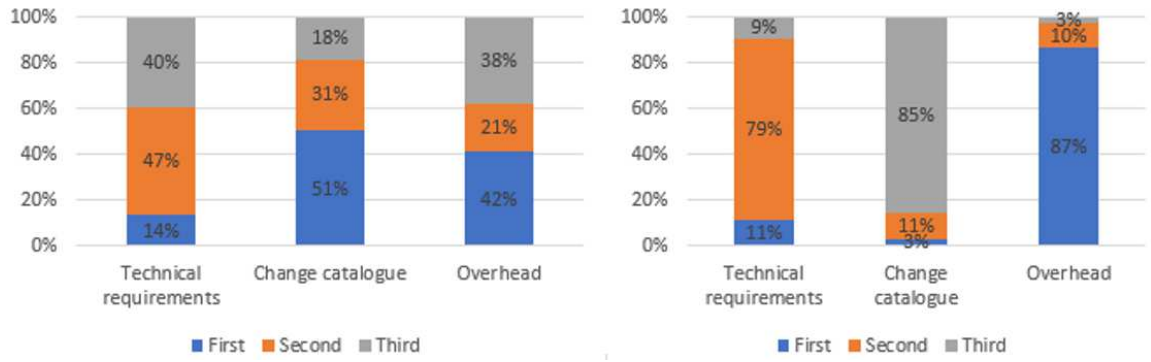

Figure 5 Final results of alternatives before (left) and after (right) the nomination

Table 1 Central weight vector for the results before nomination

Top ranked/criterion	Speed	Complexity	Capacity	Premises	Know-how	Output
Change catalogue	0.32	0.20	0.09	0.05	0.07	0.27
Technical requirements	0.29	0.22	0.12	0.06	0.08	0.23
Overhead	0.30	0.19	0.13	0.06	0.07	0.26

Since the ranking of the strategies before the nomination is by far more ambiguous, the central weight vector for this situation was calculated, see the results in Table 1. The weights in this table represent the mean value of the weights when one of the strategies is ranked the first. This analysis reveals to what extent the first position depends on the weights of the criteria. It can be seen that the average weights of some criteria are the same or very similar, regardless of the winning strategy (premises, know-how). On the other hand, the mean weights differ significantly (the statistical significance has been checked using the Mann-Whitney test in IBM SPSS statistics at 5% level of significance) in case of speed (the highest priority if change catalogue wins), complexity (the highest priority

if technical requirements win), and output (the highest priority is assigned to this criterion if change catalogue or overhead are ranked the first).

4.2.2 Results of Fuzzy-PROMETHEE method

Now, let us focus on the results of the fuzzy PROMETHEE method, see Figure 6 and Figure 7. The results before the nomination closely align with the AHP-SMAA findings, indicating a less clear ranking compared to fuzzy-AHP. The strategy that should be prioritized the most is, as well as the one that showed the original results of fuzzy-AHP, 'Change catalogue'. The remaining two strategies are more or less equally suitable. After the nomination, the alternative ranking matches that of fuzzy AHP. However, there is a reduction in the gap between the leading 'Overhead' and the second-place 'Technical requirements'. The removal of the outliers for the fuzzy-PROMETHEE did not substantially impact the final ranking. Moreover, for managers, the resulting fuzzy flows are easy to interpret when compared with the acceptability indices in SMAA.

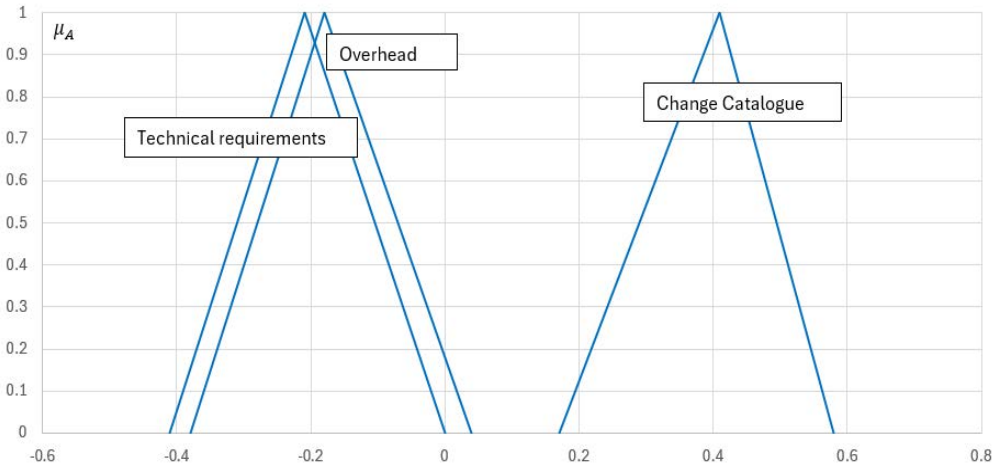

Figure 6 Final result of alternatives by fuzzy-PROMETHEE method before the nomination [Trumić and Zapletal (2023)]

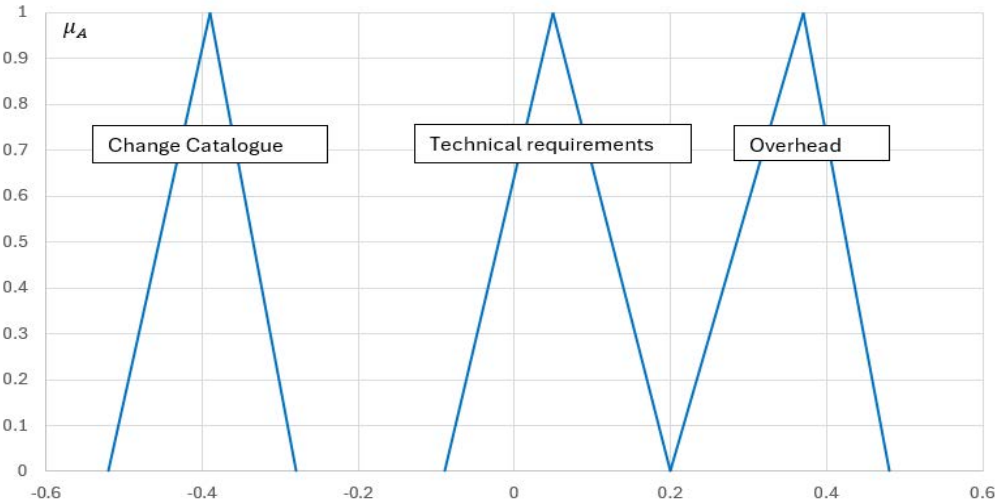

Figure 7 Final result of alternatives by fuzzy-PROMETHEE method after the nomination [Trumić and Zapletal (2023)]

One significant advantage of PROMETHEE is its capability to break down the net flow values, see Eq. (12). Essentially, the net flow can be decomposed into individual contributions of criteria. This means that the net flow can be seen as the sum of contributions from each criterion separately. If a criterion's individual contribution to the net flow is negative, it indicates that the alternative is weaker in that criterion compared to others, on average, thereby reducing the total net flow (such a criterion can be seen as a disadvantage of the alternative). On the contrary, if the individual contribution is positive, it signifies the strength in that criterion, boosting the total net flow. These individual criterion contributions are illustrated in Figure 8 and Figure 9.

When looking at Figure 8, we can see unicriterion net flows before supplier nomination. The alternative of

creating a change catalogue has no got any significant weaknesses and has three important strengths. It is relatively fast to create a change catalogue and it provides a good performance in premises and outputs. The alternative of improving technical requirements has advantage, that it is not a complex task, but on the other hand, it is not easily specified at this stage, and it would not make a large difference in outcomes. The remaining alternative (Overhead) has two main weaknesses: it takes a lot of time to negotiate overheads and it is difficult to know overheads before the production starts.

When looking at the structure of the net flows at the period after the nomination (Figure 9) four criteria are the most driving (the size of their columns is the greatest). 'Change catalogue' is the most preferred strategy because of its outstanding performance in outputs, premisses and speed (the contribution of all these three criteria to the net flow is more or less the same). The strategy of 'Overhead' is mainly undermined by poor performance in complexity (it is too high) and related slow speed.

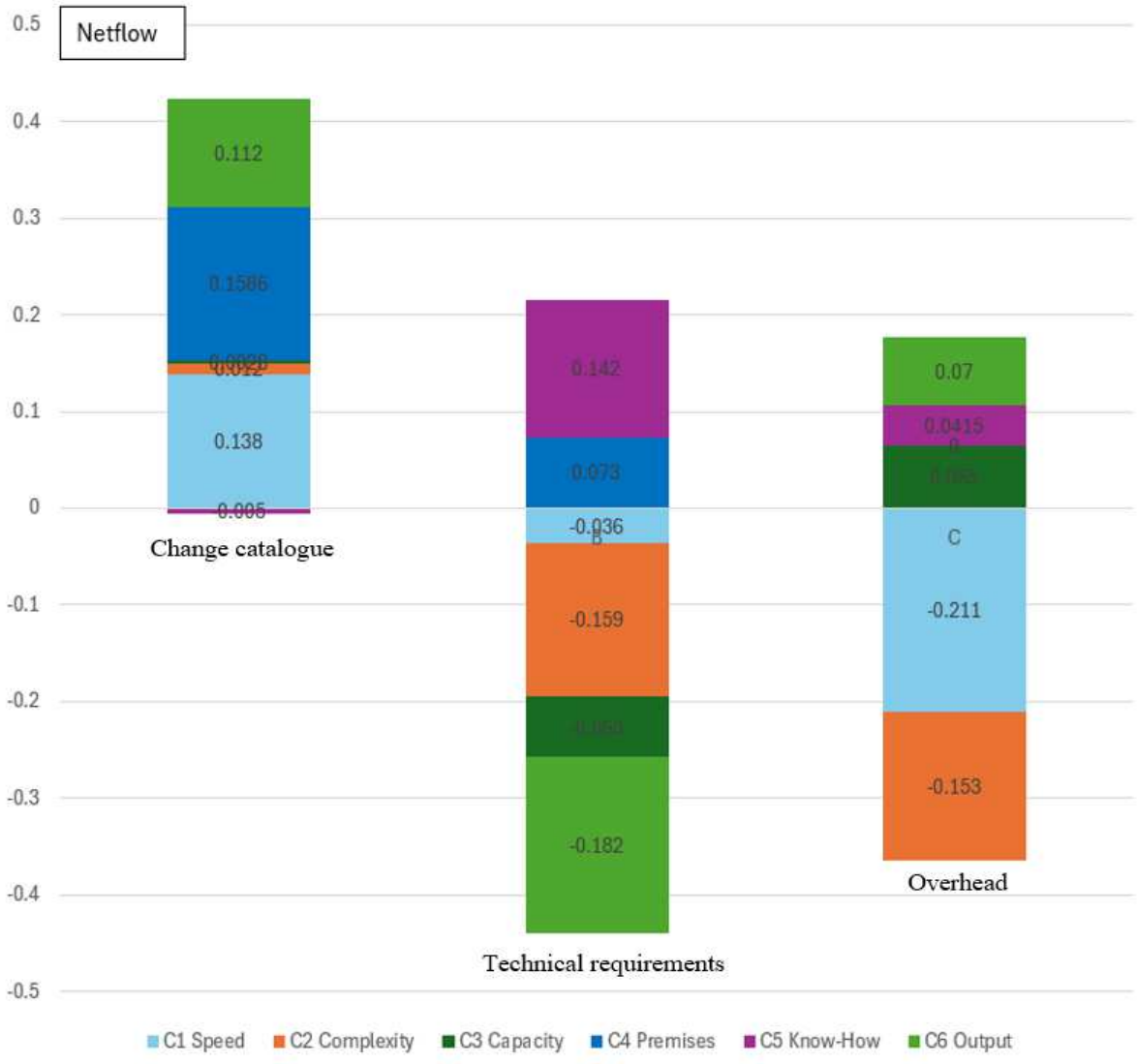

Figure 8 Results from fuzzy-PROMETHEE before the nomination

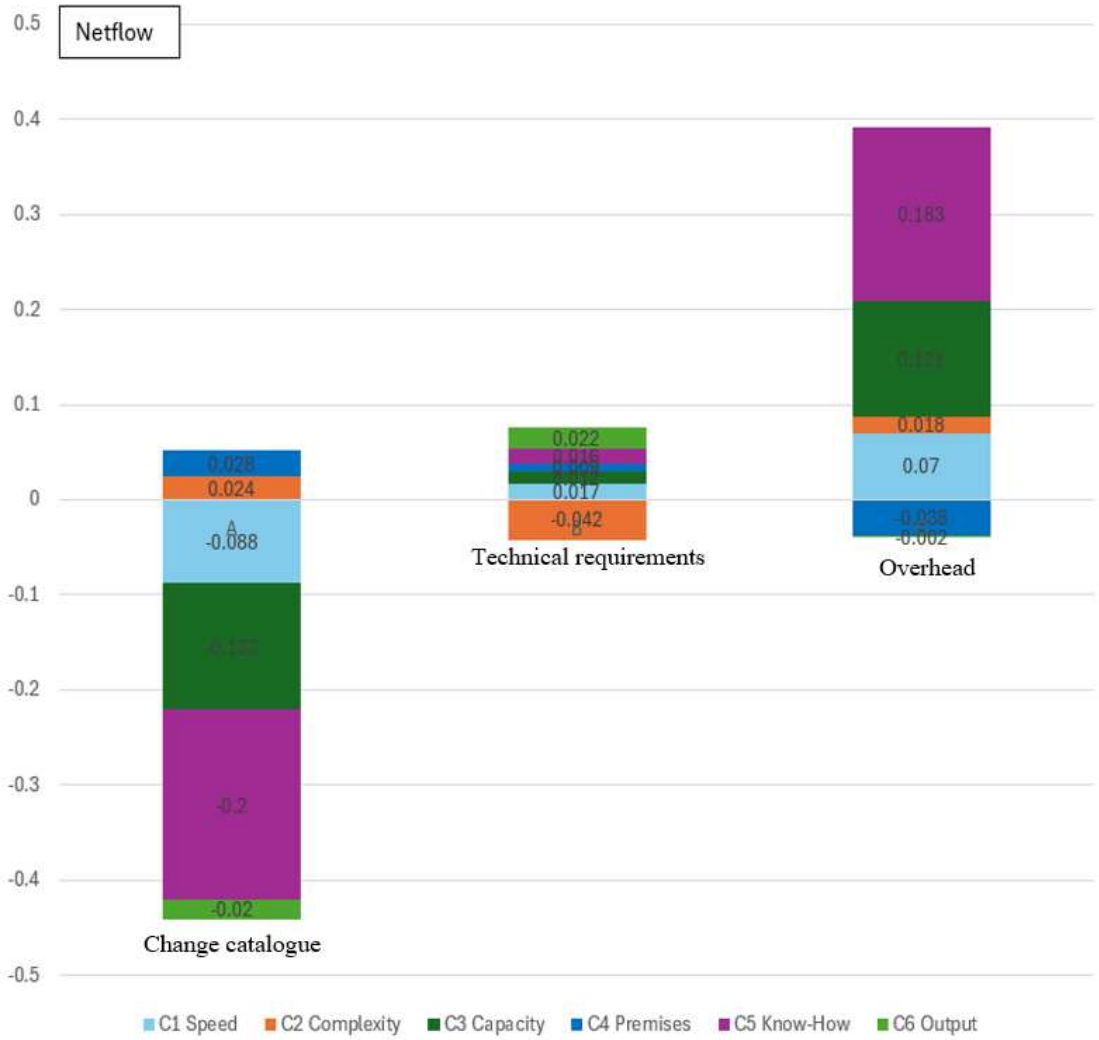

Figure 9 Results from fuzzy-PROMETHEE after the nomination

5 Conclusions

In this paper, an optimal strategy of a company towards its suppliers was explored for the periods before and after the nomination of a supplier is done. The model introduced by [5] has been solved using a completely different approach to investigate the impact of uncertainty on the results. Rather than aggregating individual opinions to derive a single outcome, every individual opinion was taken into account, including the hesitations of the participants. The findings showed that meanwhile aggregated rankings may appear clear and straightforward, analyzing individual evaluations could potentially reveal a completely different perspective. The research demonstrated that, based on survey data, selecting the best strategy before supplier nomination is more challenging compared to the post-nomination scenario. A drawback of detailed results is their complexity in interpretation compared to aggregated results. If the proportions for alternatives are closely similar, a supplementary analysis becomes necessary. For example, segmentation of individuals to understand the variability of the ranking or exploration of the weight values of the average criteria weights for each ranking could be beneficial. The main limitation of this study is that the conclusions are made based on the survey conducted in a single company, despite the fact that the company is a key player on the market, and that a significant number of expert opinions were collected. Above that, the model does not consider the dependencies between evaluation criteria at all, which can potentially be simplifying too. Future research will focus on verifing the results using further datasets. Then, an impact of other factors, that are not considered in this study, can be explored, like different type of products (or their parts), or the aforementioned dependencies between the criteria.

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References

[1] BAI, C., ZHU, Q., SARKIS, J.: Supplier portfolio selection and order allocation under carbon neutrality: Introducing a 'Cool' ing model, *Computers & Industrial Engineering*, Vol. 170, No. August, 108335, 2022.

[2] CAKRAVASTIA, A., TAKAHASHI, K.: Integrated model for supplier selection and negotiation in a make-to-order environment, *International Journal of Production Research*, Vol. 42, No. 21, pp. 4457-4474, 2004.

[3] MARTÍNEZ-DE-ALBÉNIZ, V., SIMCHI-LEVI, D.: Supplier–buyer negotiation games: Equilibrium conditions and supply chain efficiency, *Production and Operations Management*, Vol. 22, No. 2, pp. 397-409, 2013.

[4] LENARČIČ, B., BRCAR, F.: Analysis of influences on buyer-supplier negotiation, *Innovative Issues and Approaches in Social Sciences*, Vol. 7, No. 2, pp. 81-98, 2014.

[5] TRUMIĆ, R., ZAPLETAL, F.: *On uncertainty in optimal behavior towards suppliers in automotive industry*, Proceedings: Strategic Management and its Support by Information Systems 2023, VŠB – TU Ostrava, Ostrava, pp. 289-300, 2023.

[6] SONG, S., WEI, T., YANG, F., XIA, Q.: Stochastic multi-attribute acceptability analysis-based heuristic algorithms for multi-attribute project portfolio selection and scheduling problem, *Journal of the Operational Research Society*, Vol. 72, No. 6, pp. 1373-1389, 2021.

[7] GELDERMANN, J., SPENGLER, T., RENTZ, O.: Fuzzy outranking for environmental assessment, Case study: iron and steel making industry, *Fuzzy Sets and Systems*, Vol. 115, No. 1, pp. 45-65, 2000.

[8] RUIZ BARGUENO, D., SALOMON, V.A.P., MARINS, F.A.S., PALOMINOS, P., MARRONE, L.: State of the art review on the analytic hierarchy process and urban mobility, *Mathematics*, Vol. 9, No. 24, 3179, pp. 1-13, 2021.

[9] PELISSARI, R., OLIVEIRA, M.C., AMOR, S.B., KANDAKOGLU, A., HELLENO, A.L.: SMAA methods and their applications: A literature review and future research directions, *Annals of Operations Research*, Vol. 293, pp. 433-493, 2020.

[10] LIU, X., LIU, Y.: Sensitivity analysis of the parameters for preference functions and rank reversal analysis in the PROMETHEE II method, *Omega*, Vol. 128, No. October, 103116, 2024.

[11] BEHZADIAN, M., KAZEMZADEH, R., ALBADVI, A., AGHDASSI, M.: PROMETHEE: A comprehensive literature review on methodologies and applications, *European Journal of Operational Research*, Vol. 200, No. 1, pp. 198-215, 2010.

[12] OUBAHMAN, L., DULEBA, S.: Fuzzy PROMETHEE model for public transport mode choice analysis, *Evolving Systems*, Vol. 15, No. 2, pp. 285-302, 2024.

[13] CHINWOOD, CH., LEE, S.: A study on process evaluation and selection model for business process management, *Expert Systems with Applications*, Vol. 38, No. 5, pp. 6339-6350, 2011.

[14] United States Government Defense Acquisition University: *Contract Pricing Reference Guides*, Vol. 5, CreateSpace Independent Publishing Platform, 2018.

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Recognition of sustainable packaging by consumers of household chemicals

Michal Patak
University of Pardubice, Faculty of Chemical Technology, Studentska 95, 532 10 Pardubice, Czech Republic, EU, michal.patak@upce.cz
Lenka Branska
University of Pardubice, Faculty of Chemical Technology, Studentska 95, 532 10 Pardubice, Czech Republic, EU, lenka.branska@upce.cz (corresponding author)
Gabriela Hvezdova
University of Pardubice, Faculty of Chemical Technology, Studentska 95, 532 10 Pardubice, Czech Republic, EU, gabriela.hvezdova@upce.cz

Keywords: sustainability, sustainable packaging, sustainable packaging indicator, consumer recognition, household chemicals.
Abstract: The growing interest of companies in sustainability affects various areas of logistic activities, including packaging. There is a clear tendency among industrial companies to enhance the sustainability of packaging for their products. In doing so, companies contribute not only to the environmental behaviour of society but also to its overall well-being. However, for ultimate success in both business and society, it is important that consumers can recognise and appreciate these packaging efforts. The paper addresses the challenge of identifying sustainable packaging from the perspective of consumers, particularly in relation to the purchase of household chemicals such as detergents and cosmetics. Based on the literature review and focus group discussion, the paper reveals packaging indicators that enable consumers to identify sustainable packaging. A subsequent questionnaire survey involving 400 Czech consumers defines the relative importance of these indicators. Through exploratory factor analysis, the paper identifies six main factors in recognising sustainable packaging, namely graphic design, amount of material, type of material, brand, labelling, and reusability. Furthermore, the paper reveals differences in the perception of sustainable packaging based on the socio-demographic characteristics of consumers. Reusability, type of material, and labelling emerge as the most significant factors in packaging recognition within the Czech consumer market for household chemicals. While the impact of labelling and type of material factors varies depending on the education, age, and environmental inclination of consumers, the reusability factor equally influences all Czech consumers, regardless of gender, age, education, or lifestyle.

1 Introduction

Increasing environmental problems, such as global warming, have led to a growing awareness of the importance of sustainable development [1]. At present, sustainability has a significant impact on the direction of human society. It has become one of the main trends influencing corporate strategies in the last decade [2]. The principles of sustainability influence individual corporate strategies to varying degrees, and changes in these strategies also have a different impact on the sustainability of the company and society. One strategy with a significant effect on sustainability is the packaging strategy. Changes to this strategy concern the use of renewable materials, the reduction of materials [3], the rethinking of packaging structure [4], and the introduction of recyclable, returnable, and reusable packaging [5]. Each of these changes can significantly affect the amount and composition of municipal waste, a large part of which is packaging waste. In addition, appropriately designed packaging can make more efficient use of space during transport and storage or facilitate product handling. This can reduce waste during transport and reduce energy consumption and emissions [6]. For this reason, current packaging strategies focus specifically on the redesign of packaging to increase the sustainability of product packaging [5] and contribute to higher business performance. Higher business performance is based on both resource savings and higher sales.

However, if higher sales are to be generated, consumers must have access to these innovations. They need to be able to identify what sustainable packaging is, differentiate it from conventional packaging, and consider its benefits when making purchasing decisions [1]. Therefore, it is crucial for businesses to understand what indicators consumers look for when recognising sustainable packaging. However, this is still insufficiently clarified on a theoretical level. Current knowledge in this area of research is limited because previous research worked with selected features of sustainable products [4,7,8] and did not examine the significance of the considered indicators of product sustainability from the perspective of customers through quantitative research, for the possibility of some generalization. The issue of different perceptions of these indicators has also not been sufficiently explored, although some studies point to a specific perception of sustainable packaging depending on environmental concerns [8], lifestyle [9], the country in which consumers live [1], or the maturity of this country [10].

The paper aimed to identify the main factors contributing to consumer recognition of sustainable packaging and to evaluate their significance when purchasing household chemicals. This aim was achieved using mixed-methods research (a combination of focus group discussion and questionnaire survey) on the Czech consumer market. Therefore, the paper has the potential to contribute to the development of knowledge both in the importance of sustainable packaging features and in different perceptions depending on several factors, namely demographic factors and attitudes towards environmental protection. At the same time, it contributes to the understanding of the different perceptions depending on the origin of respondents, as it adds the perspective of Czech consumers.

2 Literature review

Sustainable packaging helps protect the environment by reducing waste and societal healthcare costs while reducing environmental health risks [1]. The sustainability of the packaging, and as a result, the environmental friendliness of the packaging, matters to a large group of consumers. For example, Martinho et al. [11] stated that 44.1% of respondents consider environmentally friendly packaging to be very important or important, while 35.6% have a neutral attitude. Prakash and Pathak [12] concluded that up to two-thirds of consumers are interested in environmentally friendly packaging for products intended for daily consumption.

When recognising sustainable packaging, consumers often look for simple ways to do it [1]. They often identify sustainable packaging by the feeling of environmental friendliness [4]. Herbes et al. [1] identified four main groups of indicators, namely:

- structural indicators (material, size, and shape of the packaging),
- visual indicators (colour, branding, and images)
- information provided (text and figures), and
- sensory indicators (texture and smell).

For a certain group of consumers, packaging material is the primary indicator of the degree of environmental friendliness [13]. Up to 83% of consumers consider it important for packaging to be made from recyclable materials [14]. Materials that are routinely sorted and recycled have received an incredibly positive response. Typical environmentally friendly materials include paper [1,15], glass [4,15] and cardboard [1]. According to research by Orzan et al. [16], paper was identified as a suitable material by 74.2% of respondents; in research by Lindh et al. [17], paper was spontaneously identified as the least environmentally negative packaging material by 79% of respondents. Glass was identified as an environmentally friendly material in a study by Orzan et al. [16] by 51.1% of respondents. In addition to recyclable materials, consumers are also interested in biodegradable or compostable packaging [18].

When assessing sustainability, it is not only about the type of packaging material but also about its quantity [1]. Sustainable packaging should be reasonably large, have a smart shape, and have a small footprint compared to the packaged product (optimisation of the free space in the packaging should be conducted). Inappropriately chosen shapes and sizes of the packaging may make consumers feel that the packaging is not sufficiently filled with the product [19]. Similarly, the optimisation of the one-off quantity of a product should be conducted in relation to the needs of consumers [7] to avoid product waste. However, the size and shape of the packaging (which also, for example, facilitates storage and transport) are not decisive when assessing the sustainability of the packaging [1,20]. A probable reason for this is that consumers do not sufficiently perceive the link between waste and packaging size, as suggested by studies by Boesen et al. [18].

The colour of the packaging [1] also helps consumers assess sustainability. This is one of the most distinctive features of packaging that drives purchasing decisions for organic products [21]. It attracts attention and can also signal naturalness and sustainability [22]. Earth-coloured packaging (e.g., brown, cream, or green) is a common indicator of sustainable products. Transparent packaging or packaging in colours that are associated with the naturalness of the product are also considered more sustainable options [22]. Lindh et al. [17] report that unbleached paper is often perceived by customers as an ideal form of packaging. However, consumers perceive sustainable packaging as less appealing because it tends to be simple and not as colourful [15].

Other indicators of the sustainability of packaging are brands, images, and other information in the form of numbers and text. Scott and Vigar-Ellis [10] report that 44% of respondents read the label on the packaging when evaluating the environmental friendliness of a product, and 30% of respondents rate the same based on an image or (e.g., recycle) logo on the packaging. According to a study by Herbes et al. [1], around 80% of consumers assess the sustainability of packaging based on labelling. Eco-labels provide consumers with information on the environmental performance of the product and packaging, which should facilitate the choice of sustainable products [23]. However, the current way of eco-labelling products on consumer markets is burdened by the fact that manufacturers use many eco-labels. Each of them is based on different evaluation criteria and often provides diametrically opposed information, which can be confusing for consumers [24]. According to Navas et al. [25], the impact of eco-labels on consumers is minimal.

Packaging information in various forms can also provide consumers with additional information regarding the sustainability of packaging. For example, recyclability of packaging (together with reusability) is one of the most frequently requested properties of sustainable packaging

[4,15,18]. Bech-Larsen [26] reports that 82% of consumers want them. These consumers need to be reassured of recyclability. According to Jerzyk [27], the information on the packaging about the possibility of recycling is one of the most important pieces of information for consumers. 83% of consumers believe that this information should be easy to find and 77% of consumers believe that it should be displayed directly on the packaging [14]. There may also be additional information on the packaging, such as a label or text describing the material or a number indicating the percentage of recycled material [1]. They also signal to customers the degree of sustainability of the packaging.

Consumers can also assess the sustainability of packaging based on other information, for example, information known or obtained from other sources, or only because of knowledge and trust in the manufacturer's brand. If consumers know and trust the manufacturer's brand, they are more likely to believe sustainability claims on packaging [28,29], which can influence their purchasing decisions.

Reusable or refillable packaging is particularly preferred by green consumers. In addition, they add a requirement to use one material type, namely glass or paper [22]. However, this requirement is not very widespread. According to Boesen et al. [18], only 9% of respondents say they consider it important that packaging is made of only one material. In any case, the reusability of packaging should be supported by packaging design, as according to Greenwood et al. [30], the consumer is willing to use the packaging more than once only if the packaging has a tasteful and timeless design.

It is therefore clear that consumers can recognise sustainable packaging based on several indicators or characteristics. The question is how deep their knowledge is to rigorously evaluate these characteristics and indicators. According to Otto et al. [22], consumers evaluate packaging primarily through their feelings. They most often associate sustainability with the recyclability or reusability of packaging, and their knowledge of other aspects of sustainable packaging is limited. For example, they do not perceive the facts that condition the recyclability of packaging, or these facts are not important to them. As a result, consumer behaviour may be much less sustainable than they anticipate [3].

According to El Oraiba and Kiygi-Calli [31], packaging design preferences are not influenced by demographic factors such as gender, age, education, income, and married life. According to Popovic et al. [9], consumer attitudes towards environmentally friendly packaging are influenced by two main factors, namely lifestyle and the ability to apply knowledge in the field of environmentally friendly packaging in their daily lives. Lifestyle can also be characterised by an inclination towards environmental protection.

Regarding the intensity of the inclination towards environmental protection, two main groups of consumers can be distinguished, namely consumers with an initiative-taking approach to the environment (eco-consumers) and traditional consumers (conventional consumers). Eco-consumers are people who try to reduce their environmental impact [32]. Over traditional products, they prefer products whose production saves energy, saves water, reduces water pollution, or generates their own contribution to improving the state of the environment [33]. Conventional consumers are highly influenced by consumerism. The main priority for them is to satisfy themselves through many products, often without regard for the waste that burdens the environment [34].

The perception of the sustainability of packaging can also be influenced by the country of origin of the consumers. For example, Herbes et al. [1] found that French consumers often rely on colour or perceived material. They rely on it more often than consumers in the United States and Germany, but they are much less inclined to search for more information, for example, on the Internet. For consumers from Germany and France, the quantity or size of packaging is a much more important indicator of sustainability than for US consumers.

3 Methodology

A mixed-methods approach that combines qualitative and quantitative research methods in a single research study was proposed to achieve the aim of the paper. The qualitative research aimed to reveal how consumers recognise sustainable packaging and then define potential indicators of sustainable packaging. The follow-up quantitative research aimed to measure the significance of these indicators when purchasing household chemicals in the population of Czech consumers and to identify the key factors in recognising sustainable packaging in consumer markets through subsequent analysis of the data obtained. At the same time, the validity of four research hypotheses was verified, which result from the literature review and verify the differences in the recognition of sustainable packaging depending on the socio-demographic characteristics of consumers. The hypotheses were formulated as follows:

H1: The way of recognising sustainable packaging depends on the gender of consumers.
H2: The way of recognising sustainable packaging depends on the age of consumers.
H3: The way of recognising sustainable packaging depends on the education of consumers.
H4: The way of recognising sustainable packaging depends on the lifestyle of consumers.

3.1 Data collection

The qualitative research was conducted using the focus group discussion, which included six Czech consumers of different genders (three men and three women) and ages (25-65 years). All participants in the discussion were united by their inclination towards a sustainable lifestyle and their preference for purchasing goods in sustainable

packaging. An audio-visual recording of the discussion was made, which was transcribed into written form and subjected to content analysis. The content analysis made it possible to define eighteen potential indicators of sustainable packaging, which were used in the creation of a questionnaire for follow-up quantitative research.

The quantitative research was conducted in the form of a questionnaire survey among 400 Czech consumers aged 18+ in the period from January to February 2023. The sample of respondents was compiled by quota sampling with bound quotas for gender and age according to data from the Czech Statistical Office [35]. The data were collected using personal questioning and a structured questionnaire. In the first part of the questionnaire, respondents assessed the extent to which they were able to recognise sustainable packaging when purchasing household chemicals according to eighteen pre-specified indicators. A four-point rating scale was used to measure the significance of the indicators (where 1 = no; 2 = rather no; 3 = rather yes; 4 = yes). During the interview, the basic demographic characteristics of the respondents (gender, age, and education) and their attitudes towards a sustainable lifestyle (willingness to adapt to trends in sustainable development, interest in information related to sustainable development, frequency of purchase of sustainable products, and waste sorting in the household) were also identified. A five-point frequency scale was used to measure respondents' attitudes towards a sustainable lifestyle (where 1 = never; 2 = sometimes; 3 = often; 4 = very often; 5 = always). Based on these attitudes, the sample of respondents was divided into two segments (eco-consumers and conventional consumers) using the two-step cluster analysis method.

The structure of the research sample is shown in Table 1. Based on the chi-square test, the research sample can be considered representative of gender ($\chi^2 = 0.002$; $p = 0.968$) and age of respondents ($\chi^2 = 0.002$; $p = 0.968$), but it is dominated by consumers with higher education ($\chi^2 = 150.248$; $p < 0.001$) compared to the structure of the Czech population.

Table 1 Structure of research sample

Characteristic	Segment	Frequency in the research (%)	Frequency in the population (%)[a]
Gender	Males	51.0	51.1
	Females	49.0	48.9
Age	18-34	23.3	23.2
	35-54	36.8	36.8
	55+	40.0	39.9
Education	Primary	17.3	44.9
	Secondary	41.8	34.0
	Tertiary	41.0	21.1
Lifestyle	Eco	32.3	.
	Conventional	67.8	.

a. Structure of the Czech population according to SLDB 2021 [35].

3.2 Statistical data processing and verification of research hypotheses

Methods of exploratory and inferential statistics were used in the IBM SPSS Statistics (version 24) software for processing quantitative data. To compare the significance of eighteen indicators, an average ranking on the measuring scale was determined for each indicator, and this ranking was subjected to the Friedman test at the 5% significance level. This made it possible to uncover the most important indicators of sustainable packaging.

To identify the main factors of sustainable packaging recognition and to verify the research hypotheses, exploratory factor analysis was used. The quality of the data for factor analysis was evaluated using the Bartlett test and the Kaiser-Meyer-Olkin criterion. The principal component method was used for the extraction of the factors, but the initial solution was orthogonally rotated by the Varimax method in order to improve the interpretation of the analysis results. The reliability of the analysis results was evaluated using *Cronbach's alpha*.

Based on the factor analysis model, each respondent was evaluated with a factor score, the value of which can be used to infer the degree of influence of factors in recognising sustainable packaging. Because the factor score has a standardised normal distribution of N (0;1), positive score values point to a more significant effect of the factor, while negative score values point to a less significant effect. This fact was used to verify the validity of the *H1–H4* research hypotheses. In each group of consumers (by gender, age, education, and lifestyle), the average values of factor scores were determined, and the differences between the averages were tested using the ANOVA test at a 5% significance level. This made it possible to decide on the validity of the research hypothesis and to evaluate how the way of recognising packaging differs between individual consumer segments.

4 Results and discussion

The first part of the analysis focused on revealing the indicators of sustainable packaging used by consumers

when purchasing household chemicals. The content analysis of the focus group discussion made it possible to identify 18 indicators (see Table 2) that do not differ fundamentally from the indicators described in previous research [1,7,10,22]. However, three new indicators have been identified, namely the brand of the product or the name of the manufacturer, the type of sales network that offers the product, and the placement of the product in the store. Conversely, the indicators we identify do not include sensory indicators of packaging sustainability, such as texture or smell, as reported by Herbes et al. [1]. However, it can be estimated that this difference is due to the nature of the products that were the subject of research.

Table 2 Relative importance of sustainable packaging indicators

Indicator	**Response rate[a] (%)**				**Average ranking**
	No	Rather no	Rather yes	Yes	
Returnability of packaging	2.3	12.5	48.3	37.0	12.76[b]
Recyclability of packaging	1.0	12.8	53.3	33.0	12.66[b]
Refillability of packaging	2.3	17.3	49.8	30.8	12.17[b]
Use of recycled materials	2.5	21.0	53.0	23.5	11.30[b]
Sustainability product certification label	3.0	21.0	51.5	24.5	11.29[b]
Type of material used	2.0	24.0	59.0	15.0	10.53
Rate of filling the packaging with the product	6.8	28.5	42.0	22.8	10.45
The number of types of material used and their easy separability	5.0	27.8	51.3	16.0	9.97
Amount of material used	6.8	29.5	46.5	17.3	9.84
Sustainable/eco-friendly claims on packaging	4.8	32.3	51.3	11.8	9.59
Product brand or manufacturer's name	12.5	29.3	44.8	13.5	9.20
Number of layers of the packaging	9.0	35.5	40.0	15.5	9.08
The type of sales network in which the product is offered	13.0	37.5	43.8	5.8	8.08
Used images and natural motifs on the packaging	20.0	37.3	35.3	7.5	7.49
Placement of the product in the store (or e-shop)	15.0	44.3	33.8	7.0	7.44
Packaging colour	21.5	43.5	27.8	7.3	6.75
Minimalist graphic packaging design	21.3	44.5	30.3	4.0	6.47
Packaging shape	28.3	45.5	20.8	5.5	5.93

a. Frequency of responses to the question of whether respondents are able to recognise that purchased goods are sustainably packaged according to the indicator.
b. There was no statistically significant difference between the values of the average rank (post hoc Friedman tests with Bonferroni correction).

In the next phase of the analysis, the significance of eighteen indicators was compared based on the analysis of data obtained from the questionnaire survey. Table 2 presents the results of the data analysis, including the value of the average ranking of the indicator (the significance of the indicator increases as the ranking value increases). The result of the Friedman test ($\chi^2 = 1419$; $df = 17$; $p < 0.001$) shows that the examined indicators are not comparably important in recognising sustainable packaging. Czech consumers most often orient themselves according to the information provided on the possibilities of reusing packaging (returnability of packaging, refillability of packaging), recyclability of packaging, use of secondary materials, and eco-labels. The importance of indicators in the field of recyclability of packaging corresponds to the revealed importance of this characteristic of packaging for consumers in previous research [1,4,15,18,26]. However, the revealed significance of eco-labels contradicts Navaz et al.'s [25] claim that the impact of eco-labels on consumers is minimal.

Regarding the fact that several indicators were evaluated by respondents in an analogous way, the main factors of packaging recognition using exploratory factor analysis were revealed in the subsequent step of the analysis. The adequacy of the use of factor analysis can be declared by the significant result of the Bartlett test ($\chi^2 = 2763$; $df = 153$; $p < 0.001$) and by the high value of the Kaiser-Meyer-Olkin criterion, which reached 0.851 in the research. The resulting solution of the rotated component matrix, presented in Table 3, explains 70.3% of the variability of the input data. All extracted factors achieve the required reliability (values of *Cronbach's alpha* are higher than 0.7).

Table 3 shows that six main factors influencing consumer recognition of sustainable packaging can be identified. These factors are as follows:

- graphic design,
- amount of material,
- type of material,
- brand
- labelling, and
- reusability.

Table 3 Results of exploratory factor analysis

Rotated component matrix	**Factor loading[a]**					
	Graphic design	Amount of material	Type of material	Brand	Labelling	Reusability
Minimalist graphic packaging design	0.821					
Packaging colour	0.809					
Packaging shape	0.721					
Used images and natural motifs on the packaging	0.686					
Number of layers of the packaging		0.865				
Amount of material used		0.820				
The number of types of material used and their easy separability		0.638	0.526			
Rate of filling the packaging with the product		0.632				
Use of recycled materials			0.766			
Type of material used			0.732			
Recyclability of packaging			0.711			
Product brand or manufacturer's name				0.791		
The type of sales network in which the product is offered				0.789		
Placement of the product in the store (or e-shop)				0.689		
Sustainable/eco-friendly claims on packaging					0.825	
Sustainability product certification label					0.767	
Returnability of packaging						0.808
Refillability of packaging						0.759
Cronbach's alpha	**0.806**	**0.822**	**0.746**	**0.740**	**0.711**	**0.706**

a. Factor loading values lower than 0.5 are hidden.

The above-mentioned finding expands on and refines already published conclusions, especially by Herbes et al. [1], who identified four groups of these indicators (structural, visual, sensory, and information). The difference was identified not only in the number of these groups but also in their structure and content. The graphic design factor identified by our research is closely related to the visual perception of packaging design. It therefore includes consumer reactions to the colours and motifs used, which evoke the sustainability of the packaging. The material aspects of packaging are recognised by consumers in two basic ways, namely the amount of material and the type of material factors. The amount of material factor represents the consumer's perception of the amount of material used and how it is used to package the product (including the division of products into batches and the use of excess packaging layers). On the other hand, the type of material factor is related to consumer perceptions of the type of material used and the possibility of its recycling. The brand factor is closely related to the purchasing orientation of consumers according to the sustainable image of the manufacturer, the brand of products, the placement in the store, or the specific classification of the product in the e-shop. The labelling factor involves consumer perceptions of the symbols, brands, and other claims on the packaging that are used to identify sustainable packaging. Finally, the reusability factor includes the consumer's perception of whether the packaging can be reused (returnability of packaging and refillability of packaging).

From the comparison of the results presented in Table 2 and Table 3, the key factors in recognising sustainable packaging among the population of Czech consumers are reusability, type of material, and labelling factors. When recognising sustainable packaging, consumers are therefore primarily guided by whether the packaging can be reused and recycled and whether the packaging is marked with appropriate symbols, claims, or eco-labels that declare the responsibility of producers for the sustainable management of packaging materials throughout the entire life cycle of the packaging.

The last part of the analysis verified the research hypotheses about differences in packaging recognition depending on the socio-demographic characteristics of the respondents. Tables 4-7 present the values of average factor scores (the degree of influence of sustainable packaging recognition factors) in respondent segments depending on their gender (Table 4), age (Table 5), education (Table 6) and lifestyle (Table 7). The tables also include the results of the analysis of variance (ANOVA) test, which verify the significance of the reported differences.

An analysis of differences in the recognition of sustainable packaging by gender of respondents revealed significant results only in the case of the brand factor (F = 4.922; p = 0.027). The values of the average factor scores in Table 4 show that women are more likely than men to

assess the sustainability of packaging by brand or manufacturer of the product, or the product distribution in consumer markets. The results support the H1 hypothesis (*the way of recognising sustainable packaging depends on the gender of consumers*).

Table 4 Gender differences in factor scores

Factor	Average Factor Score		ANOVA Test	
	Men	Woman	*F*	*p*
Graphic design	-0.079	0.076	2.393	0.123
Amount of material	-0.043	0.042	0.719	0.397
Type of material	-0.077	0.074	2.274	0.132
Brand	**-0.113**	**0.108**	**4.922**	**0.027**
Labelling	-0.059	0.057	1.343	0.247
Reusability	-0.051	0.049	0.983	0.322

In the case of the analysis of differences by age of respondents, significant differences were confirmed only in the case of the labelling factor ($F = 3.516$; $p = 0.031$). The values of the average factor scores in Table 5 show that with increasing consumer age, respondents' sensitivity to the symbols, brands, and claims used on packaging decreases in recognising their sustainability. The results support the *H2 hypothesis* (*the way of recognising sustainable packaging depends on the age of consumers*).

Table 5 Age differences in factor scores

Factor	Average Factor Score			ANOVA Test	
	18–34	35–54	55+	*F*	*p*
Graphic design	0.056	-0.070	0.031	0.581	0.560
Amount of material	0.020	0.123	-0.124	2.381	0.094
Type of material	0.159	-0.084	-0.015	1.718	0.181
Brand	-0.159	0.068	0.030	1.589	0.205
Labelling	**0.221**	**-0.006**	**-0.123**	**3.516**	**0.031**
Reusability	0.070	-0.021	-0.021	0.299	0.742

An analysis of the differences in recognising sustainable packaging according to respondents' education revealed significant results in the case of both factors, which are closely related to the material aspects of packaging. In the case of the amount of material factor ($F = 15.662$; $p < 0.001$), these differences are significantly more significant than in the case of the type of material factor ($F = 3.802$; $p = 0.023$). The values of the average factor scores in Table 6 show that as consumers become more educated, their ability to judge the sustainability of packaging by the amount of material used in the packaging and the type of material from which the packaging is made increases. The results support the *H3 hypothesis* (*the way of recognising sustainable packaging depends on the education of consumers*).

Table 6 Education differences in factor scores

Factor	Average Factor Score			ANOVA Test	
	Primary	Secondary	Tertiary	*F*	*p*
Graphic design	0.151	0.004	-0.068	1.164	0.313
Amount of material	**-0.440**	**-0.105**	**0.292**	**15.662**	**<0.001**
Type of material	**-0.103**	**-0.118**	**0.164**	**3.802**	**0.023**
Brand	0.192	-0.010	-0.070	1.692	0.186
Labelling	-0.018	0.032	-0.025	0.144	0.866
Reusability	0.013	0.007	-0.013	0.024	0.976

The confirmation of the H1-H3 hypotheses points to differences in the recognition of sustainable packaging depending on the demographic characteristics of the respondents. If we compare this finding with the conclusions of El Oraiba and Kiygi-Calli [31] regarding packaging design preferences, we can conclude that recognition and perceived preference are two different aspects of a consumer's perception. While there is an influence of demographic factors on recognition, the preference for sustainable packaging design may be independent of demographic factors.

The most significant differences were revealed when analysing the differences according to the lifestyle of the respondents. Consumer recognition of sustainable

packaging differs for amount of material factor (F = 10.449; p = 0.001), type of material factor (F = 10.329; p = 0.001), and brand factor (F = 9.632; p = 0.002). The values of the average factor scores in Table 7 show that eco-consumers are more likely to orient themselves to all material aspects of the packaging as well as the brand of the purchased product when recognising sustainable packaging. The results support the H4 hypothesis (*the way of recognising sustainable packaging depends on the lifestyle of consumers*).

Table 7 Lifestyle differences in factor scores

Factor	Average Factor Score		ANOVA Test	
	Eco	Conventional	*F*	*p*
Graphic design	0.135	-0.064	3.481	0.063
Amount of material	**0.194**	**-0.092**	**7.300**	**0.007**
Type of material	**0.230**	**-0.109**	**10.279**	**0.001**
Brand	**0.253**	**-0.120**	**12.514**	**<0.001**
Labelling	-0.067	0.032	0.862	0.354
Reusability	0.098	-0.047	1.833	0.177

The importance of the involvement of eco-consumers in the process of recognising sustainable packaging was expected in advance. Therefore, the surprising result of the research is the fact that graphic design, labelling, and reusability factors were not identified as more significant factors in the eco-consumer segment. At the same time, the results of the research showed that the factors of graphic design and reusability affect all consumers to the same extent, regardless of their gender, age, education, or lifestyle.

The conducted research also highlighted specificities depending on the country from which the research data originated. Comparing our results with those from Herbes et al. [1], it emerges that Czech consumers, like consumers from France, Germany, or the USA, base their orientation on the type of packaging material and the eco-labels used. However, unlike them, Czech consumers also place great emphasis on the reusability of packaging.

5 Conclusions

Our research focused on the area of recognising sustainable packaging. Based on the qualitative research, we have defined a wide portfolio of sustainable packaging indicators from the perspective of consumers buying consumer chemicals (detergents and cosmetics). This allowed us to expand the group of indicators described in the literature to include other indicators, namely the brand of the product or the name of the manufacturer, the type of sales network that offers the product, and the placement of the product in the store.

Based on the quantitative research, we have found that Czech consumers most often orient themselves according to the information provided on the possibilities of reusing packaging (returnability of packaging, refilling of packaging), recyclability of packaging, use of secondary materials, and eco-labels. Using factor analysis, we have grouped the individual indicators into six factors behind the recognition of sustainable packaging. These are graphic design, amount of material, type of material, brand, labelling, and reusability. This can be considered an extension of current knowledge, as previous studies worked directly with individuals and often only selected indicators. This approach also allowed us to understand that the most significant factors in recognising sustainable packaging among the population of Czech consumers are reusability, type of material, and labelling.

The analysis of differences in the impact of factors on consumers revealed significant variations depending on the socio-demographic characteristics of consumers. The results suggest that:

- Women are more likely than men to judge the sustainability of packaging by the brand or manufacturer of the product or how the product is distributed to consumers.
- As consumers age, respondents' sensitivity to the symbols, brands, and claims used on packaging decreases when recognising their sustainability.
- As consumers become more educated, their ability to judge the sustainability of packaging by the amount of material used in the packaging and the type of material from which the packaging is made grows.
- Eco-consumers are more likely than conventional consumers to look at all material aspects of the packaging as well as the brand of the purchased product when recognising sustainable packaging.

The results of the study can be generalised to a certain extent regarding the structure of the research sample, which was representative only by age and gender. Therefore, the results may be partially distorted, for example, by the fact that the sample contained more educated consumers than there are in the population. Nevertheless, we are convinced that our research contributes to the development of knowledge in the field of sustainable packaging indicators.

The study suggests that there are also regional differences in recognising sustainable packaging. Therefore, we would recommend further investigation of these regional differences for follow-up research. It would

seem useful to us to examine not only the differences themselves but also the factors influencing or causing these differences. We assume that the reason for these differences may not only be the culture or maturity of individual countries but also different attitudes towards environmental problems and ways of solving them, and within this also the form and maturity of the waste management systems.

References

[1] HERBES, C., BEUTHNER, C., RAMME, I.: How green is your packaging - a comparative international study of cues consumers use to recognize environmentally friendly packaging, *International Journal of Consumer Studies*, Vol. 44, No. 33, pp. 258-271, 2020. https://doi.org/10.1111/ijcs.12560

[2] NILASHI, M., RUPANI, P.F., RUPANI, M.M., KAMYAB, H., SHAO, W., AHMADI, H., RASHID, T.A., ALJOJO, N.: Measuring sustainability through ecological sustainability and human sustainability: A machine learning approach, *Journal of Cleaner Production*, Vol. 240, No. December, 118162, 2019. https://doi.org/10.1016/j.jclepro.2019.118162

[3] BOZ, Z., KORHONEN, V., KOELSCH SAND, C.: Consumer considerations for the implementation of sustainable packaging: A review, *Sustainability*, Vol. 12, No. 6, 2192, pp. 1-34, 2020. https://doi.org/10.3390/su12062192

[4] STEENIS, N.D., VAN HERPEN, E., VAN DER LANS, I.A., LIGTHART, T.N., VAN TRIJP, H.C.M.: Consumer response to packaging design: The role of packaging materials and graphics in sustainability perceptions and product evaluations, *Journal of Cleaner Production*, Vol. 162, pp. 286-298, 2017. https://doi.org/10.1016/j.jclepro.2017.06.036

[5] MATTIA, G., DI LEO, A., PRATESI, C.A.: Recognizing the key drivers and industry implications of sustainable packaging design: A mixed-method approach, *Sustainability*, Vol. 13, No. 9, 5299, pp. 1-18, 2021. https://doi.org/10.3390/su13095299

[6] GEORGAKOUDIS, E.D., TIPI, N.S., BAMFORD, C.G.: Packaging redesign - benefits for the environment and the community, *International Journal of Sustainable Engineering*, Vol. 11, No. 5, pp. 307-320, 2018. https://doi.org/10.1080/19397038.2018.1445789

[7] MAGNIER, L., CRIÉ, D.: Communicating packaging eco-friendliness, *Retail & Distribution Management*, Vol. 43, No. 4/5, pp. 350-366, 2015. https://doi.org/10.1108/IJRDM-04-2014-0048

[8] MAGNIER, L., SCHOORMANS, J.: Consumer reactions to sustainable packaging: The interplay of visual appearance, verbal claim and environmental concern, *Journal of Environmental Psychology*, Vol. 44, pp. 53-62, 2015. https://doi.org/10.1016/j.jenvp.2015.09.005

[9] POPOVIC, I., BOSSINK, B.A.G., VAN DER SIJDE, P.C., FONG, C.Y.M.: Why are consumers willing to pay more for liquid foods in environmentally friendly packaging? A dual attitudes perspective, *Sustainability*, Vol. 12, No. 7, 2812, pp. 1-14, 2020. https://doi.org/10.3390/su12072812

[10] SCOTT, L., VIGAR-ELLIS, D.: Consumer understanding, perceptions and behaviours with regard to environmentally friendly packaging in a developing nation, *International Journal of Consumer Studies*, Vol. 38, pp. 642-649, 2014. https://doi.org/10.1111/ijcs.12136

[11] MARTINHO, G., PIRES, A., PORTELA, G., FONSECA, M.: Factors affecting consumers' choices concerning sustainable packaging during product purchase and recycling, *Resources, Conservation and Recycling*, Vol. 103, pp. 58-68, 2015. https://doi.org/10.1016/j.resconrec.2015.07.012

[12] PRAKASH, G., PATHAK, P.: Intention to buy eco-friendly packaged products among young consumers of India: A Study on developing nation, *Journal of Cleaner Production*, Vol. 141, pp. 385-393, 2017. https://doi.org/10.1016/j.jclepro.2016.09.116

[13] KETELSEN, M., JANSSEN, M., HAMM, U.: Consumers' response to environmentally-friendly food packaging - A systematic review, *Journal of Cleaner Production*, Vol. 254, No. May, 120123, 2020. https://doi.org/10.1016/j.jclepro.2020.120123

[14] KOCH, J., FROMMEYER, B., SCHEWE, G.: Managing the transition to eco-friendly packaging - An investigation of consumers' motives in online retail, *Journal of Cleaner Production*, Vol. 351, No. June, 131504, 2022. https://doi.org/10.1016/j.jclepro.2022.131504

[15] NGUYEN, A.T., PARKER, L., BRENNAN, L., LOCKREY, S.: A Consumer definition of eco-friendly packaging, *Journal of Cleaner Production*, Vol. 252, No. April, 119792, 2020. https://doi.org/10.1016/j.jclepro.2019.119792

[16] ORZAN, G., CRUCERU, A.F., BĂLĂCEANU, C.T., CHIVU R.-G.: Consumers' behavior concerning sustainable packaging: An exploratory study on Romanian consumers, *Sustainability*, Vol. 10, No. 6, pp. 1-11, 2018. https://doi.org/10.3390/su10061787

[17] LINDH, H., OLSSON, A., WILLIAMS, H.: Consumer perceptions of food packaging: Contributing to or counteracting environmentally sustainable development?, *Packaging Technology and Science*, Vol. 29, No. 1, pp. 3-23, 2015. https://doi.org/10.1002/pts.2184

[18] BOESEN, S., BAY, N., NIERO, M.: Environmental sustainability of liquid food packaging: Is there a gap between Danish consumers' perception and learnings from life cycle assessment?, *Journal of Cleaner Production*, Vol. 210, pp. 1193-1206, 2019. https://doi.org/10.1016/j.jclepro.2018.11.055

[19] ZENG, T., DURIF, F.: The influence of consumers' perceived risks towards eco-design packaging upon the purchasing decision process: An exploratory study, *Sustainability*, Vol. 11, No. 21, 6131, pp. 1-29, 2019. https://doi.org/10.3390/su11216131

[20] ESCURSELL, S., LLORACH-MASSANA, P., RONCERO, M.B.: Sustainability in e-commerce packaging: A review, *Journal of Cleaner Production*, Vol. 280, 124314, pp. 1-17, 2021. https://doi.org/10.1016/j.jclepro.2020.124314

[21] LIEM, D.G., GROEN, A., VAN KLEEF, E.: Dutch consumers' perception of sustainable packaging for milk products, a qualitative and quantitative study, *Food Quality and Preference*, Vol. 102, No. December, 104658, 2022. https://doi.org/10.1016/j.foodqual.2022.104658

[22] OTTO, S., STRENGER, M., MAIER-NÖTH, A., SCHMID, M.: Food packaging and sustainability - consumer perception vs. correlated scientific facts: A review, *Journal of Cleaner Production*, Vol. 298, No. May, 126733, 2021. https://doi.org/10.1016/j.jclepro.2021.126733

[23] SHABBIR, M.S., BAIT ALI SULAIMAN, M.A., HASAN AL-KUMAIM, N., MAHMOOD, A., ABBAS, M.: Green marketing approaches and their impact on consumer behavior towards the environment - A study from the UAE, *Sustainability*, Vol. 12, No. 21, 8977, pp. 1-13, 2020. https://doi.org/10.3390/su12218977

[24] BRACH, S., WALSH, G., SHAW, D.: Sustainable consumption and third-party certification labels: Consumers' perceptions and reactions, *European Management Journal*, Vol. 36, No. 2, pp. 254-265, 2018. https://doi.org/10.1016/j.emj.2017.03.005

[25] NAVAS, R., CHANG, H.J., KHAN, S., CHONG, J.W.: Sustainability transparency and trustworthiness of traditional and blockchain ecolabels: A comparison of generations X and Y consumers, *Sustainability*, Vol. 13, No. 15, 8469, pp. 1-16, 2021. https://doi.org/10.3390/su13158469

[26] BECH-LARSEN, T.: Danish consumers' attitudes to the functional and environmental characteristics of food packaging, *Journal of Consumer Policy*, Vol. 19, No. 3, pp. 339-363, 1996. https://doi.org/10.1007/BF00411413

[27] JERZYK, E.: Design and communication of ecological content on sustainable packaging in young consumers' opinions, *Journal of Food Products Marketing*, Vol. 22, No. 6, pp. 707-716, 2016. https://doi.org/10.1080/10454446.2015.1121435

[28] RISKOS, K., DEKOULOU, P., MYLONAS, N., TSOURVAKAS, G.: Ecolabels and the attitude-behavior relationship towards green product purchase: A multiple mediation model, *Sustainability*, Vol. 13, No. 12, 6867, pp. 1-22, 2021. https://doi.org/10.3390/su13126867

[29] GRAPPE, C.G., LOMBART, C., LOUIS, D., DURIF, F.: Clean labeling: Is it about the presence of benefits or the absence of detriments? Consumer response to personal care claims, *Journal of Retailing and Consumer Services*, Vol. 65, No. March, 102893, 2022. https://doi.org/10.1016/j.jretconser.2021.102893

[30] GREENWOOD, S.C., WALKER, S., BAIRD, H.M., PARSONS, R., MEHL, S., WEBB, T.L., SLARK, A.T., RYAN, A.J., ROTHMAN, R.H.: Many happy returns: Combining insights from the environmental and behavioural sciences to understand what is required to make reusable packaging mainstream, *Sustainable Production and Consumption*, Vol. 27, pp. 1688-1702, 2021. https://doi.org/10.1016/j.spc.2021.03.022

[31] EL ORAIBY, M., KIYGI-CALLI, M.: The influence of packaging design visual elements on consumers' purchase intention: a comparison study on organic food and non-food products, *Organic agriculture*, Vol. 14, pp. 143-165, 2024. https://doi.org/10.1007/s13165-023-00446-1

[32] SINGH, G., PANDEY, N.: The determinants of green packaging that influence buyers' willingness to pay a price premium, *Australasian Marketing Journal*, Vol. 26, No. 3, pp. 221-230, 2018. https://doi.org/10.1016/j.ausmj.2018.06.001

[33] KLAIMAN, K., ORTEGA, D.L., GARNACHE, C.: Consumer preferences and demand for packaging material and recyclability, *Resources, Conservation and Recycling*, Vol. 115, pp. 1-8, 2016. https://doi.org/10.1016/j.resconrec.2016.08.021

[34] KILBOURNE, W., PICKETT, G.: How materialism affects environmental beliefs, concern, and environmentally responsible behavior, *Journal of Business Research*, Vol. 61, No. 9, pp. 885-893, 2008. https://doi.org/10.1016/j.jbusres.2007.09.016

[35] Czech Statistical Office, www.vdb.czso.cz: *Public Database: Population and Housing Census*, [Online], Available: https://vdb.czso.cz/vdbvo2/faces/cs/index.jsf?page=statistiky [01 Jan 2024], 2022.

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Logistic-information system based on object-oriented approach

Peter Trebuna
Technical university of Košice, Faculty of Mechanical Engineering, Department of Industrial and Digital engineering, Park Komenského 9, 042 00 Košice, Slovak Republic, EU, peter.trebuna@tuke.sk
Miriam Pekarcikova
Technical university of Košice, Faculty of Mechanical Engineering, Department of Industrial and Digital engineering, Park Komenského 9, 042 00 Košice, Slovak Republic, EU, miriam.pekarcikova@tuke.sk (corresponding author)
Matus Matiscsak
Technical university of Košice, Faculty of Mechanical Engineering, Department of Industrial and Digital engineering, Park Komenského 9, 042 00 Košice, Slovak Republic, EU, matus.matiscsak@student.tuke.sk

Keywords: logistics, information, system.
Abstract: The article deals with the issue of creating an information system through an object-oriented approach, which is suitable for ensuring an efficient and properly functioning logistics network. An object-oriented approach to the creation of a business information system pays attention to a set of cooperating objects and reacts more flexibly to events in the environment. The main effort within the object-oriented approach is the reuse of created objects for a new system, which significantly contributes to shortening the development of new systems. For this fact and based on practical experience, the mentioned approach was chosen by the authors of the article. The overall design and functionality of the information system were influenced by the strategic direction of the company, which was also necessary to consider when preparing the article. In the end, a comparison of specific and object-oriented approaches to the creation of information systems for the company is processed.

1 Introduction

Managing business processes using information support means connecting and cooperating with people in a virtual environment to achieve the desired result in the highest possible quality. The connection of PLM/Product Lifecycle Management and ERP/Enterprice Resoure Planning enables selected work processes (repetitive or based on a common algorithm of solutions) to be automated and thus speed up their course, to improve its quality by reducing the error rate and to make the processing of large volumes of data more efficient. Such a change in the way business processes are managed makes it possible to simplify the implementation of even the most complex processes, to ensure the correct distribution of tasks, the correct distribution of data to the right person and at the right time [1-3].

While increasing competitiveness and customer orientation of services in the form of added product value, logistics has undergone major modernization periods. The role of logistics is to integrate, regulate and generally control the material flow, including semi-finished and finished parts. By monitoring and reacting to information in the course of simple logistics operations (transport, packaging handling, etc.), it optimizes their conduct in order to reduce costs and satisfy customer requirements. Logistics does not stand out as a separate process but interferes with every area of the company's functions in accordance with the established company strategy. Logistics represents a complex system of management, monitoring, and regulation of company flows.

Logistics generally has a clearly set objective, which is to reduce the costs associated with logistics and to streamline the use of its activities. The result of having such an objective is an increase in company profit over logistics costs. Therefore, long-term strategic planning also includes improvements in operational areas such as the supply chain. Just as it is difficult to characterize logistics in general terms, it is equally difficult to determine the division of logistics. In terms of the extent of its complexity, applicability and arrangement in practice, it will be used a division into three main groups: supply logistics (also called procurement logistics), production logistics and distribution logistics.

1.1 Object-oriented approach to the establishment of business information systems

The first step of the object-oriented approach to the establishment of business information systems is the identification of all objects of interest, as well as the knowledge of relations between these objects. Every object represents a structure that has a defined identity, behaviour, and state. Objects can be material matters, interactions, various events, etc. Object identity ensures the differentiation of an object from other objects, i.e. its identification. Object behaviour is the ability of an object to react to environmental events at state changes (Figure 1). Object state is defined by persistent properties and their values throughout the life of the object [4-7].

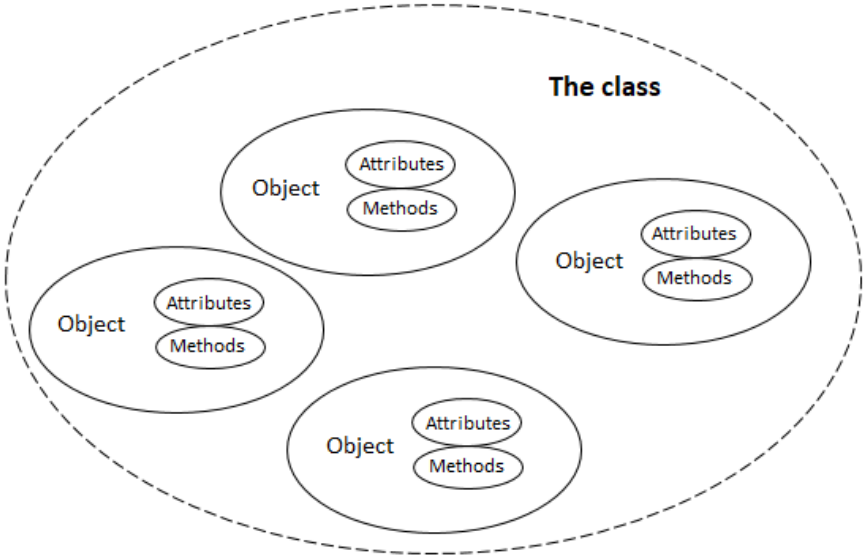

Figure 1 Structure of an object-oriented approach

Basic principles of the object-oriented approach to business information systems include [1-3,8,9]:

- Encapsulation – a state when objects keep their status inside classes, while other objects do not have access to this status. Objects manage their status through methods. As long as there is a requirement for communication with an object, this communication is possible only through available methods, while the object's status cannot be changed or affected.
- Abstraction – within the object-oriented approach, in many cases, extremely large programs are generated. Implementation of the abstraction feature ensures that internal implementation details are hidden, while only operations relevant to other objects are displayed.
- Heredity – ensures the principle of repeated use within the object-oriented principle of business information system establishment. In the case of heredity, a subclass is generated by derivation from another class, i.e. mother class. In this way, hierarchy arises. The created subclass takes over all methods and objects from the mother class and can implement its unique elements.
- Polymorphism – enables the use of the subclass in the same way as the mother class is worked with, while the subclass keeps its unique characteristic. It emphasizes the most frequently used methods which can be consequently implemented by sub-classes in a suitable way. In case of polymorphism, while applying one method, different behaviour or reaction of multiple objects might occur.
- Within the object-oriented approach to the creation of information systems, a great number of techniques and methodologies is developed nowadays. These techniques and methodologies are dedicated to modelling of future software solutions. Their development is, however, based on object-oriented design and object modelling technique.

In object-oriented programming, objects are grouped into classes that generalize objects according to similar or identical properties and behaviour models. An object class is characterized by certain attributes which are common to all objects in the class and by methods that represent object behaviour. A class generally represents a pattern for the creation of a specific object.

1.2 Comparison of object-oriented approach to the creation of information systems of the company

Based on the foregoing analysis of theoretical basis for object-oriented approaches, it is possible to state the following [1-3,8,9]:

- A typical feature of a structured approach is the segregation of data structures into a single module and processes into another module. In the case of the object-oriented approach, a combination of data and processes applies. It can therefore be concluded that by using the object-oriented approach a greater consensus between reality and business information system can be achieved.
- The model within the object-oriented approach enables an analysis of internal relations between objects, which leads to the design and establishment of the information system precisely according to the requirements of the future user.
- Ready software applications within the object-oriented approach can be used repeatedly ability, which shortens the development time of the future information system.
- In comparison to the structured approach, the object-oriented approach provides possibilities for more flexible adaptation of the ready system to changes. This enables quicker reactions to user requirements.

- The structured approach, considering its concept, glossary, and expressions, belongs exclusively to the field of information technologies. The object-oriented approach is a more comprehensible tool that is suitable for the establishment of business information systems even by the general public. Through the involvement of the general public in information systems it is possible to avoid mistakes that result from a misunderstanding between the author or requirements and the programmer.
- In comparison to the structured approach, the object-oriented approach requires greater computing time and memory space.

The implementation stage or the stage of business information system integration, in our case the Kanban system, follows the design stage. The above-stated comparison shows that for these purposes and under existing conditions it is more appropriate to use the object-oriented approach with its methods and tools.

1.3 Architecture of Integrated Information Systems

The architecture of integrated information systems represents a hardware and software infrastructure that offers tools for process analysis, creates a holistic view of the creation and management of processes and the flow of values. It is a general methodological framework and tools for modelling business processes in the PLM interface, with ERP support. If the main task of a PLM solution is product innovation and development, monitoring and management of information and product configurations throughout their life cycle, management of production processes, and cooperation between engineering departments, then we can say that PLM is data-driven [10-14].

In contrast to business information systems that manage finances, contracts, production order processes, production planning, logistics, and warehouse management, here we can say that information systems are transactionally managed. PLM and ERP play different, complementary roles in product innovation and execution, and therefore their mutual integration helps companies to be more efficient in their activities related to the development and management of the manufacturing portfolio of products. An example of this cooperation is attached in Figure 2, where we can see the mutual sharing of information about the structure of products, items, changes, production information, technological procedures, etc. The construction of such infrastructure will be provided by the company:

- digitize, optimize, and standardize your processes,
- reduce costs by executing processes with less manual effort,
- minimize cycle times with process automation,
- improve productivity for all stakeholders with the right information at the right time,
- ensure consistency and completeness by standardizing best practices.

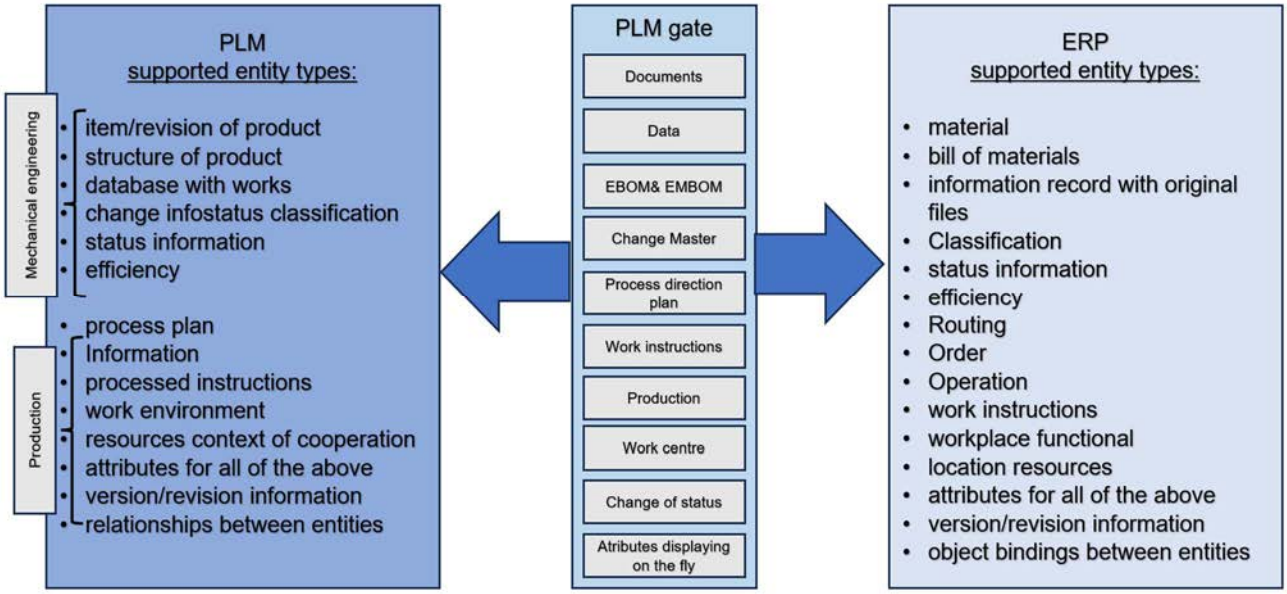

Figure 2 Interface between PLM and ERP data models

This integration must of course be parametric to be able to connect different data models of PLM and ERP databases and thus enable the sharing of monitored attributes, including the possibility of defining which system is the controlling system for which attribute and which only shares information. Among the key suppliers of PLM solutions that set the long-term direction and trend in PLM software development include:

- Siemens Industry Software - software PLM product Teamcenter.
- Dassault Systemes: software PLM product Enovia, software cPDM product SmarTeam.
- PTC- software PLM product Windchill.

All the solutions mentioned above are fully modular and cover the entire application portfolio of modern PLM.

2 Case study

Below are the outputs from the implemented case studies, which are related to the object-oriented approach in solving logistics. case studies were handled through the workplace of the authors of the article.

2.1 Dynamic production scheduling

Production Scheduling can be considered as a usually demanding discipline at the production level due to the possibility of different combinations even in the case of only a few products that the production produces. Scheduling can also be considered one of the most important processes for every manufacturing company. Schedules are usually presented in Gannt Charts. Scheduling processes have a short duration and must be rerun for each change. The average accuracy time of the schedule is very short, and therefore most authors report a continuous scheduling process in the literature. Scheduling is usually thought of as an iterative scheduling process that varies. Scheduling methods:

- Capacity planning (forward, backward, combined).
- According to the running time (to front, back, combined).
- Weighted planning (for example, for resources such as technologist, designer).
- Planning according to production bottlenecks.
- Operational planning common.

The APS/Advanced Planning and Scheduling solution itself communicates bilaterally between the ERP System and production. For each new schedule, he needs to get the status of new orders from the ERP system and the status of production equipment and work-in-progress directly from the factory. In most cases, this horizontal communication is enabled by the MES/Manufacturing Execution System solution, as described in Figure 3 [15-18].

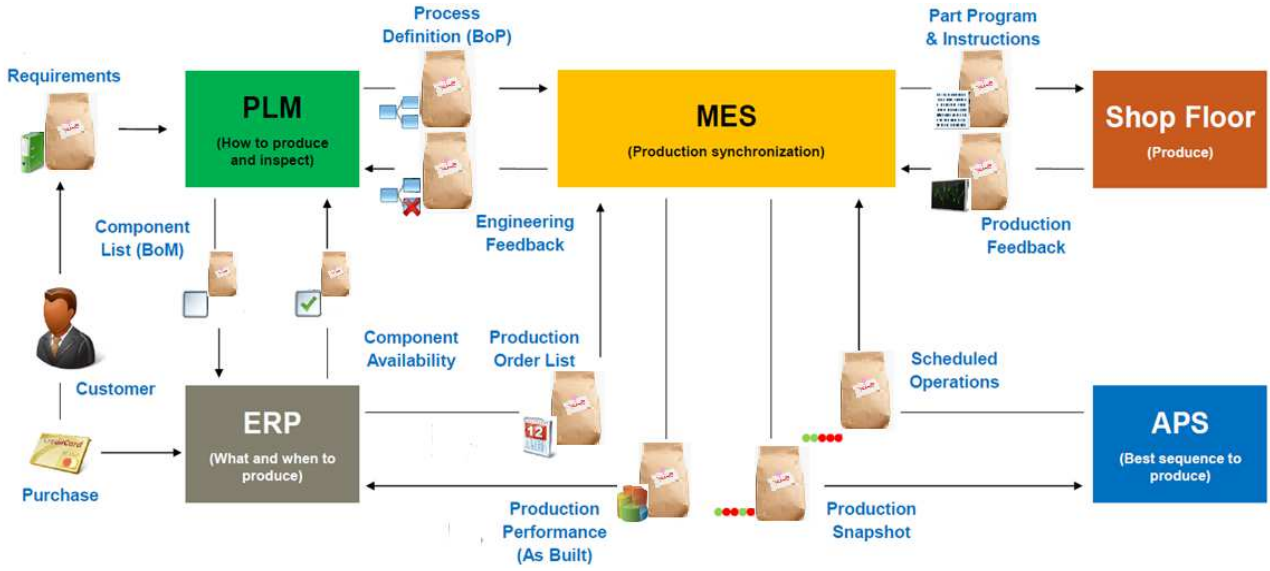

Figure 3 Interface MES + PLM + ERP + APS position [15-18]

Grouping work orders by material

Combining production orders according to the material that enters the production process can also be a method to optimize production and overall results. Consolidation of production orders improves the overall downtime caused by changing tools when changing from one type to another and also improves the results of failures. Figure 4 describes a Gantt chart in which production orders are connected. If we compare it with the first optimization method - forward scheduling, the difference is in the improvement of delayed orders and also the improvement of downtime when switching from one product to another.

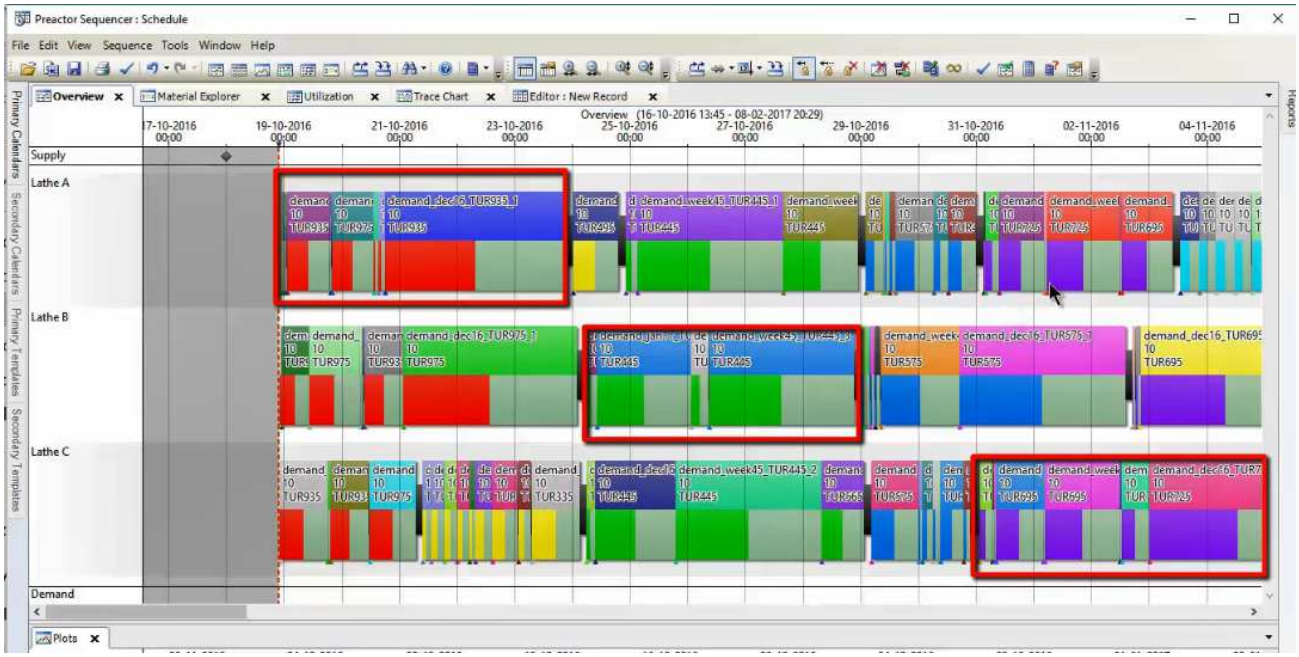

Figure 4 Optimization by combining work orders based on material - Opcenter APS Gantt Chart [15-18]

Forward scheduling is production in the forward direction from a defined starting point. The goal of such scheduling is to complete the process of each production order as soon as possible when the resource assigned to it is available with little or no waiting between individual processes. Planning logic: If the resource is available (the device itself, a specific role) the process is finished, but if the resource is not available at a given time, the process is waiting until the point when the resource is available again. Forward scheduling does not allow us to generate unfinished work orders but assigns them a delayed status.

2.2 Online Kanban implementation

With manual Kanban system the demand information is transferred through physical Kanban cards. Production launch signals are also sent manually from the customer to the supplier. However, this traditional Kanban system has its limits. Production continuity is endangered through incorrect manipulation with cards, either by their movement in incorrect time, or by their loss or duplication. As production times are constantly shortening and production volumes are constantly increasing, the amount of Kanban cards and, as a result, the amount of related problems with Kanban system maintenance and transparency is rising. Technical progress enables gradual replacement of the physical Kanban system through an electronic system, where signals are generated after demand and are automatically sent based on current needs. These signals are transmitted electronically. Every signal is recorded and kept which enables the comparison of historical data. The implementation of an electronic Kanban system may bring [3,6,10]:

- Kanban data management,
- increase of data rate,
- greater system transparency,
- support for the existing Kanban system,
- continuous improvement in the Kanban system.

The electronic Kanban system must follow the same principles as the traditional manual Kanban system. These principles include mainly the creation of a smooth flow of materials, synchronisation of production operations, elimination of bottlenecks and the establishment of a turn-based production system. The electronic Kanban system, similarly to the manual system, must continuously support improvement which is generally considered the most important sign of the Kanban system. The objective is to minimise stocks and production batches, which uncovers shortcomings in the production process and removes them after corrective measures are taken. The electronic Kanban system provides data collection, reporting on production operations and the flow of material and reserves and, in this way, contributes to the improvement as possible for data archiving. Working environment of the online Kanban system should be intuitive and easy to use properly. The electronic Kanban system should be user friendly as much as possible to meet possibilities of all users in the organization.

In comparison to the traditional approach, electronic Kanban system brings solutions in many areas, mainly [3,6,10]:

- elimination of card manipulations,
- elimination of problems related to a frequent loss of cards,
- better visibility of signals for the launch of production,

- improved communication with suppliers within the manufacturing process,
- analysis of supplier effectiveness within the manufacturing process,
- delivery of required material, ongoing production or ready-made products at the right time,
- minimisation of downtimes caused by the lack of material,
- improvement of supply chain transparency.

The electronic Kanban system solves many problems which occur when using physical Kanban cards. The process is more transparent, quicker and more reliable. It helps with solving problems associated with an error rate of production devices, manufactured production quality or the flow of materials and values within the manufacturing process. An indisputable advantage of the electronic Kanban system is the access to the system even outside the manufacturing process or even outside the manufacturing plant. Users and management staff can track and evaluate current data on the manufacturing process in real time.

The online Kanban system enables mediation of information on the status of every production station. The electronic Kanban system enables the implementation of the turn-based production system even in places where the traditional Kanban system often fails. Such places are production facilities with frequently changing customer demand. In such a case the electronic Kanban system within a computer application reacts to changes more flexibly and adapts the production accordingly. Electronic Kanban is currently also able to evaluate the impact of errors and failures on machines and equipment in the production process, thus minimizing the negative impact on the production plan.

The following Table 1 records main differences between the traditional Kanban system, which uses Kanban cards and Kanban boards for the transmission of information, and the electronic Kanban system, which runs as a programme in a personal computer.

Table 1 Comparison of the the traditional and the electrical Kanban system [3,6,10]

Traditional Kanban	**Electronic Kanban**
Useally chaotic data management – Acces, Excel or other general system	A specific system developed for Kanban
Difficult handing or large quantilies of Kanban cards	A large number of items are not a problem
Limited ability to send Kanban cards over lond distances	Automatic sending of data worldwide
Low order and stock transparency – not in real time	An up-to-date view fo orders and inventory in real time
Problematic definition of priorities	Priorities generated automatically
No record of historical data	Data is archived and evaluated using various tools
Manual transmission of data to the master system	Automatic data and report transfer

Contrary to the traditional manual Kanban system, the online Kanban system in many cases works using bar codes or RFID chips which mark materials, ongoing production and ready products. The RFID technology applies mainly internally within an organisation. Bar codes are suitable for the introduction of the Kanban system in the entire production chain, i.e. from material and component suppliers up to the final customer. These technologies also help record material movement in the production, either through bar-code scanning or through data collection by means of RFID readers. Data are displayed on an electronic Kanban dashboard. This board can be visualised on personal computers and various mobile devices such as tablets, mobile phones, etc. The tendency during last decades is to continuously increase flexibility and effectiveness of manufacturing processes. This trend also applies in the area of production planning and management. In view of the fundamental principle of the Kanban system, which is a continuous improvement, the establishment of the electronic Kanban system is a natural step.

2.3 RTLS technology use in TestBed

The practical example shown below was implemented in the specialized TestBed 4.0 laboratory, which is part of the KPaDI laboratories in cooperation with the SOVA Digital company, see Figure 5. To simulate the processes that can be implemented in the laboratory, a model was developed in the TX Plant Simulation software, which made it possible to test variant options during teaching.

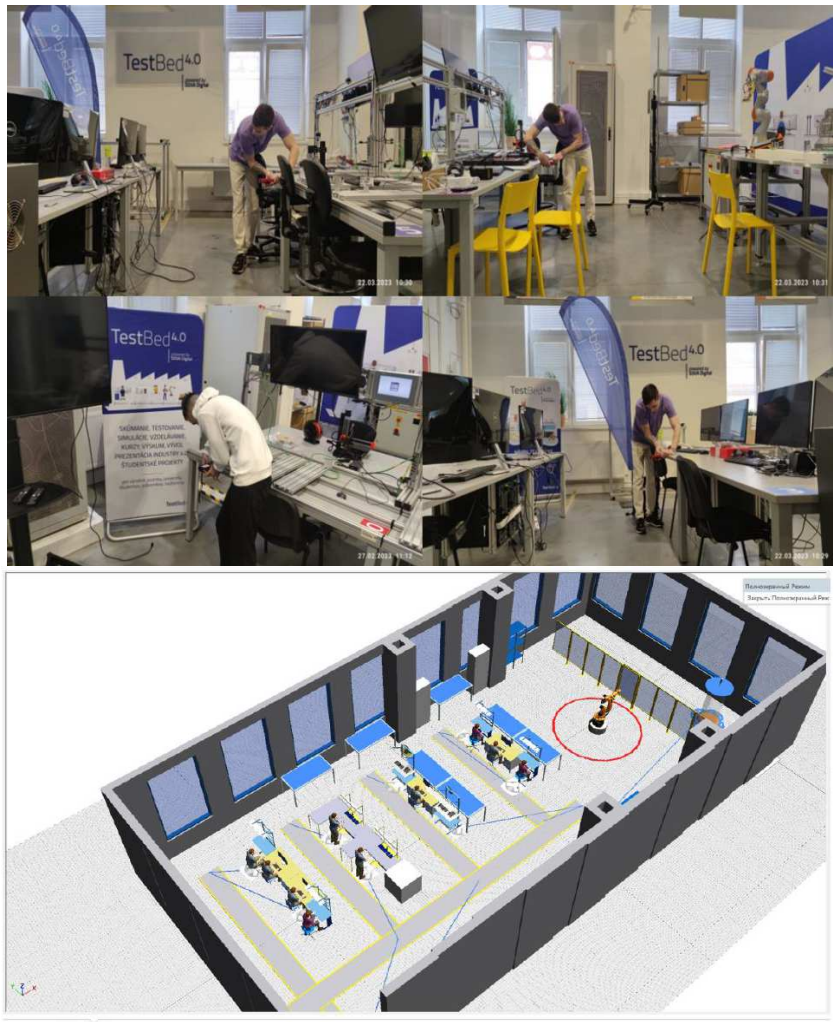

Figure 5 Project activity with RTLS technology in TestBed and 2D model in TX Plant Simulation

2D model was processed for tracking movement using RTLS/Real Time Location System software, Figure 5. By tracking the movement of the students through the tags they were wearing, it was possible to process the movements in the form of the above-mentioned graphic outputs. The collection of data on the movement of students around the floor plan of the laboratory was carried out, with the identification of activities within the laboratory and the identification of the most popular equipment of the workstations located in the laboratory from the student's point of view. With the help, it was possible to control and view the activity of students during their presence in the laboratory in real time. The outputs are shown in Figure 6.

The implementation of RTLS technology together with the simulation model and its 3D display will make it possible to create a more realistic and accurate model of the TestBed 4.0 training laboratory in order to further find new potential for increasing the efficiency of the educational process. Today's manufacturing companies and plants are subject to constant modernization, which is essential for success. The digitization of production data using industrial localization elements such as RTLS systems is increasingly recognized. This is due to the results of these systems in the area of workers' health protection, but mainly for saving production time, protecting property and products, and last but not least, for saving business finances. Managing business processes using information support means connecting and cooperating with people in a virtual environment with the aim of achieving the desired result in the highest possible quality [19]. The connection of PLM and ERP enables selected work processes (repetitive or based on a common algorithm of solutions) to be automated and thus speed up their course, to improve its quality by reducing the error rate and to make the processing of large volumes of data more efficient. Such a change in the way business processes are managed makes it possible to simplify the implementation of even the most complex processes, to ensure the correct distribution of tasks, the correct distribution of data to the right person and at the right time.

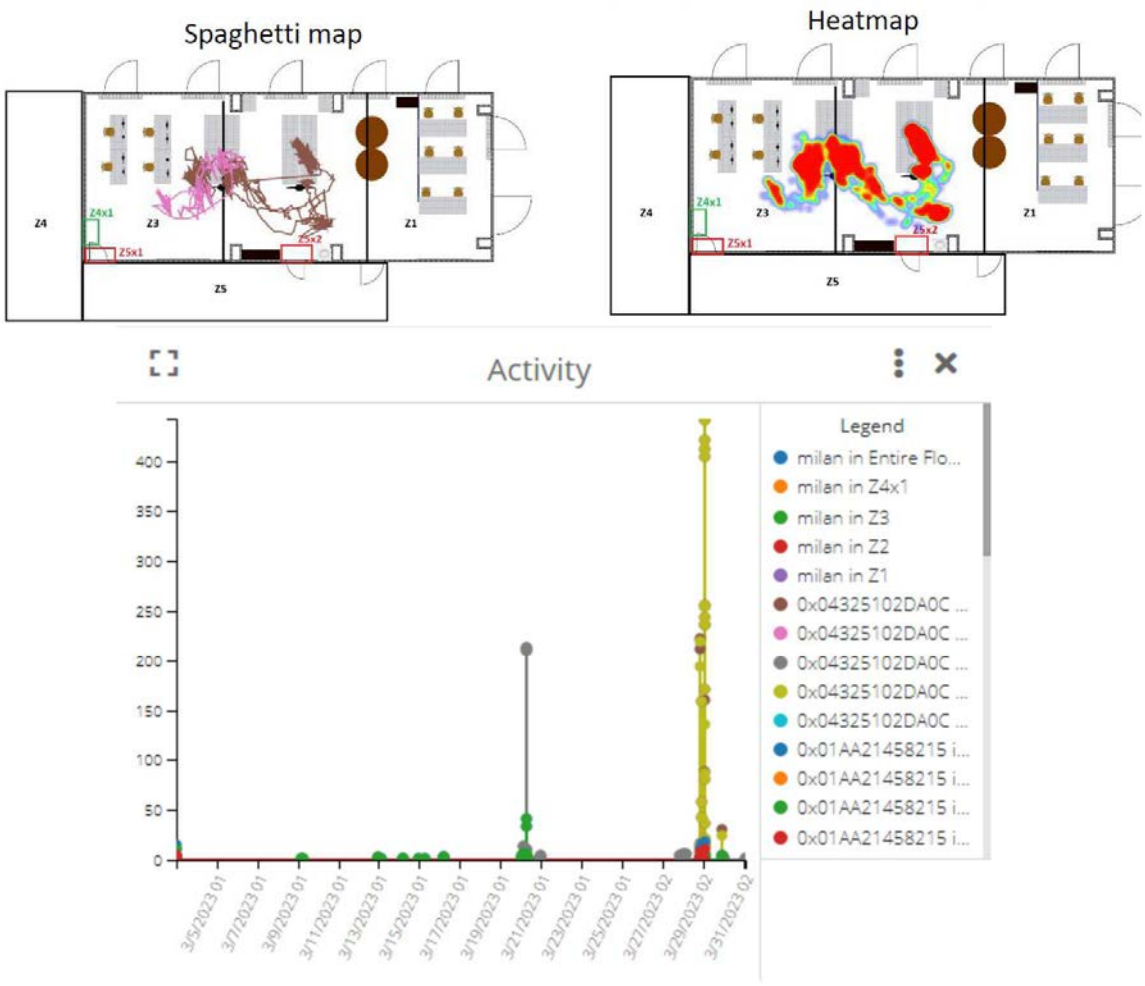

Figure 6 Previews the analysis from the RTLS software

The spaghetti diagram determines the continuity of the material flow for the possibilities of further optimization of processes and identification of inefficiencies in the organization of work, as well as wasteful transport and unjustified reduction of activity.

Heatmaps in general can provide a relatively high level of process clarity in that they can reveal the distribution and density of in-house operations as well as vulnerabilities that ultimately cause delays.

The activity can optimize the overall efficiency of use, e.g. fleet, employee, etc. Elements such as an inactive renewal and repair period are used. The data can be compared with each other.

3 Conclusions

Result of a logical sequence of steps that lead to the optimization of logistics processes through ERP collaboration with the business information system are processed in the algorithm presented in Figure 7. The goal of the created algorithm is:

- optimize the portfolio with a holistic view of information,
- effectively coordinate company resources,
- clearly understand impacts across projects,
- implement changes quickly, accurately, and comprehensively,
- maximize the visibility of work progress, resources, costs, and project status,
- simplify all types of processes in the company,
- digitize, optimize, and standardize production and non-production processes.

It is a sequence of steps, the aim of which is to effectively implement the customer's requirements into the desired output through the interactive cooperation of the concerned entities. In addition to a high-quality form of data analysis, it includes digitalization of models, simulation, evaluation of results, and standardization of processes. It enables interactive cooperation in the development of the proposal and the implementation of the selected proposal with entities that have access rights to the system anytime and anywhere, which is an indisputable advantage of this system, thereby increasing the quality

and flexibility of work and reducing the costs associated with project implementation.

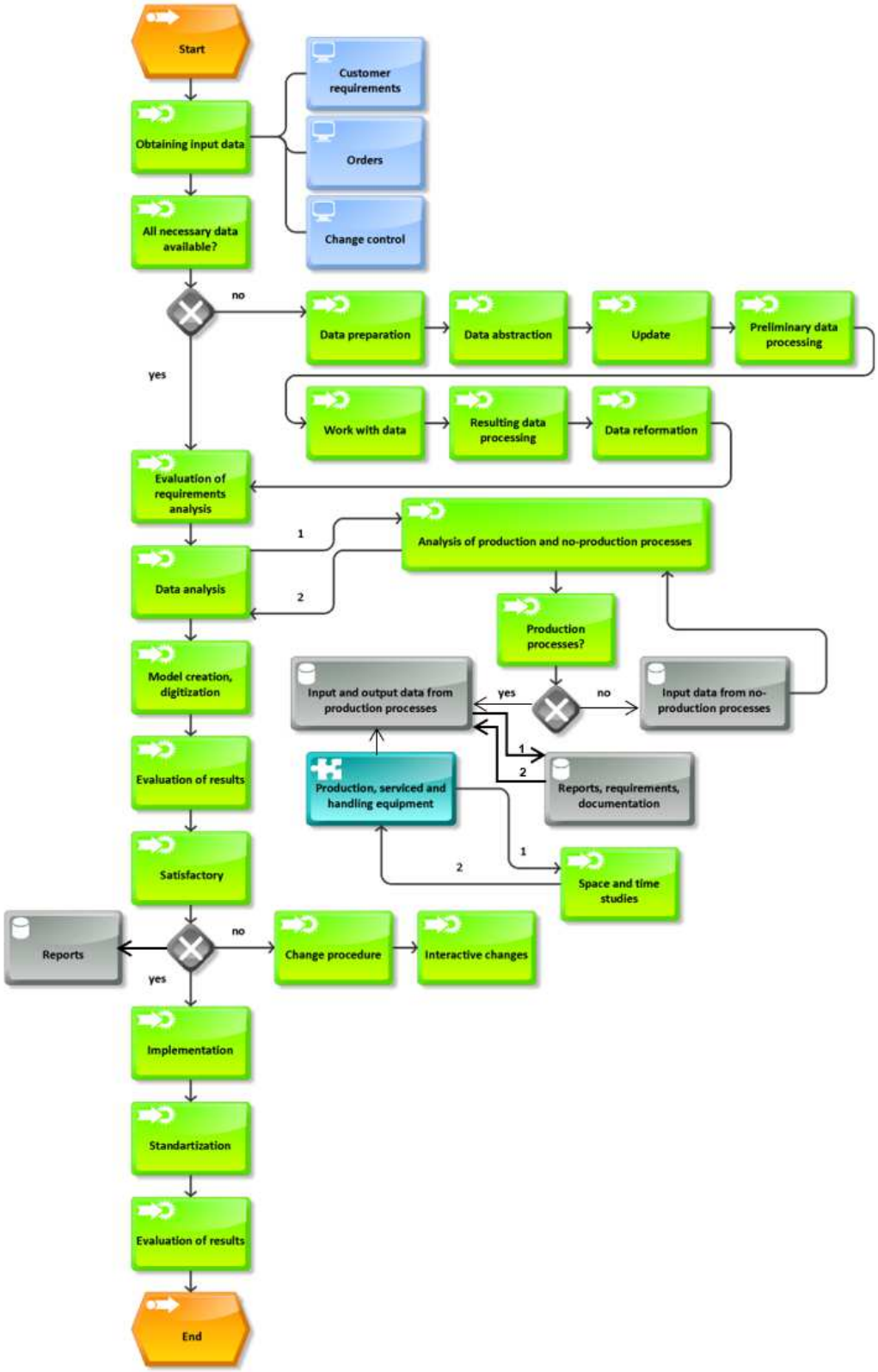

Figure 7 Algorithm for optimizing logistics processes through a business information system [used ARIS [20]]

The goal of the logistics information system is to achieve the interaction of physical processes with simulations in the digital model. This provides more detailed information into the functionality of production and logistics processes. The synergy between production practice and simulation technologies based on the principles of the digital twin enable complex analyzes of the cyber physical system, i.e. the physical device connected to its digital twin. The scope of these analyzes is not only the proposal of possible production situations and conditions, but also the backward applicability of the design output to the physical model. It is the area of analysis or the causality of change that brings about the development of areas of use of digital twins in the area of sophisticated algorithms for solving specific situations in production processes. The great benefit of the digital twin lies in solving complex logistical tasks and in the construction of e.g. electronic kanban, implementation of RTLS for real-time motion tracking, and other examples given in the article.

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References

[1] GRZNAR, P., GREGOR, M., GOLA, A., NIELSEN, I., MOZOL, S., SELIGA, V.: Quick workplace analysis using simulation, *International Journal of Simulation Modelling*, Vol. 21, No. 3, pp. 465-476, 2022.

[2] STRAKA, M., SOFRANKO, M., GLOVA, J., VEGSOOVA, O., KOVALCIK, J.: Simulation of homo-geneous production processes, *International Journal of Simulation Modelling*, Vol. 21, No. 2, pp. 214-225, 2022.

[3] BANGSOW, S.: *Tecnomatix Plant Simulation—Modeling and Programming by Means of Examples*, 2nd ed., Springer: Cham, Switzerland, 2020.

[4] PRESTER, J., BUCHMEISTER, B., PALČIČ, I.: Effects of advanced manufacturing technologies on manufacturing company perfor-mance, *Strojniski vestnik – Journal of Mechanical Engineering*, Vol. 64, No. 12, pp. 763-771, 2018. https://doi.org/10.5545/sv-jme.2018.5476

[5] TEPLICKÁ, K., KHOURI, S., MUDARRI, T., FRENÁKOVÁ, M.: Improving the Quality of Automotive Components through the Effective Management of Complaints in Industry 4.0, *Applied Sciences*, Vol. 13, No. 14, pp. 1-16, 2023. https://doi.org/10.3390/app13148402

[6] EDL, M., LERHER, T., ROSI, B.: Energy efficiency model for the mini-load automated storage and retrieval systems, *International Journal of Advanced Manufacturing Technology*, Vol. 70, No. 1-4, pp. 1-19, 2014. https://doi.org/10.1007/s00170-013-5253-x

[7] KNAPCIKOVA, L., BEHUNOVA, A., BEHUN, M.: Using a discrete event simulation as an effective method applied in the production of recycled material, *Advances in production engineering & management*, Vol. 15, No. 4, pp. 431-440, 2020. https://doi.org/10.14743/apem2020.4.376

[8] MALKUS, T., KOZINA, A.: The features of negotiations within reverse logistics cooperation, *Acta logistica*, Vol. 10, No. 1, pp. 111-119, 2023. https://doi.org/10.22306/al.v10i1.364

[9] KRAJČOVIČ, M., GABAJOVÁ, G., MATYS, M., GRZNÁR, P., DULINA, Ľ., KOHÁR, R.: 3D Interactive Learning Environment as a Tool for Knowledge Transfer and Retention, *Sustainability*, Vol. 13, No. 14, 7916, pp. 1-22, 2021. https://doi.org/10.3390/su13147916

[10] FEDORKO, G., MOLNÁR, V., HONUS, S., NERADILOVA, H., KAMPF, R.: The application of simulation model of a milk run to identify the occurrence of failures, *International Journal of Simulation Modelling*, Vol. 17, No. 3, pp. 444-457, 2018.

[11] SANIUK, S., GRABOWSKA, S., STRAKA, M.: Identification of Social and Economic Expectations: Contextual Reasons for the Transformation Process of Industry 4.0 into the Industry 5.0 Concept, *Sustainability*, Vol. 14, No. 3, pp. 1-20, 2022.

[12] HNILICA, R., JANKOVSKY, M., DADO, M., MESSINGEROVA, V.: *Experimental evaluation of combined effects of risk factors in work environment*, 12th Interantional scientific konference engineering for rural development, May 23-24, 2013, Jelgava, Latvia, pp. 577-583, 2013.

[13] GLOVA, J., MRAZKOVA, S., DANCAKOVA, D.: Measurement of intangibles and knowledge: an empirical evidence, *AD Alta-Journal of interdisciplinary research*, Vol. 8, pp. 76-80, 2018.

[14] HERZOG, I., GRABOWSKA, M.: Quality Cost Account as a Framework of Continuous Improvement at Operational and Strategic Level, *Management and Production Engineering Review*, Vol. 12, No. 4, pp. 122-132, 2021. https://doi.org/10.24425/mper.2021.140000

[15] Schedule optimization, [Online], Available: https://optimoroute.com/schedule-optimization [24 Sep 2023], 2023.
[16] Siemens DISW ebook – Manufacturing Operations Management - Software portfolio that helps you realize innovation in the Digital Enterprise, Siemens, 2023.
[17] Siemens, Advanced Planning and Scheduling, White papers, [Online], Available: https://www.plm.automation.siemens.com/global/en/products/manufacturing-operations/advanced-planning-scheduling.html [24 Sep 2023], 2023.
[18] Siemens, Manufacturing Operations Transformation, White papers, [Online], Available: https://www.plm.automation.siemens.com/global/en/products/manufacturing-operations/manufacturing-execution-system.html [24 Sep 2023], 2023.
[19] What Is an Industrial RTLS?, [Online], Available: https://www.sewio.net/rtls-in-industry [24 Sep 2023], 2023.
[20] ARIS community, Software AG, [Online], Available: https://www.ariscommunity.com/ [24 Sep 2023], 2022.

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Logistics impact on business management and firm competitiveness – 15 years of experience
Rafal Matwiejczuk

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Logistics impact on business management and firm competitiveness – 15 years of experience

Rafal Matwiejczuk
University of Opole, Institute of Economics and Finance, Chair of Logistics and Strategic Management, 46a Ozimska St., 45-058 Opole, Poland, EU, rafal.matwiejczuk@uni.opole.pl

Keywords: logistics, logistics concept, business management, competitive advantage, firm competitiveness.
Abstract: Logistics plays a very significant role in contemporary management. The aim of the article is to present the results of the research regarding the impact of logistics on business management and the overall firm competitiveness. The research started in 2009 and was conducted in the Chair of Logistics and Strategic Management at University of Opole, Poland, EU. The most important research findings show that logistics concept, logistics capacities (i.e. logistics resources, logistics capabilities, logistics competences) and logistics strategies have significant impact on business management and the overall firm competitiveness. The most distinctive characteristic of firm competitiveness is its competitive advantage. The pillars of the firm competitive advantage creation as well as the overall firm competitiveness building and strengthening are the market outcomes as well as economic outcomes achieved by the firm. Thanks to these outcomes firms are able to reach the desired financial performance and market position compared to the competitors. The research results were presented based on two projects named: (1) Logistics Determinants of Business Management, carried out in the Chair of Logistics and Strategic Management in years 2009-2011, and (2) Logistics Competences Affecting Business Competitive Advantage Creation, carried out in this chair in years 2012-2014. Several detailed issues, in particular the impact of logistics resources as well as logistics capabilities on business management as well as the overall firm competitiveness, have been the topic of the further, in-depth research carried out in the abovementioned chair in the next years.

1 Introduction

The development of logistics can be observed within the worldwide literature as well as business practice since the mid-20th century. The most important outcome of the logistics development is growing significance of logistics especially in the practice of business management [1-7]. It concerns both the changes in the internal conditions of business management as well as the changes in the external conditions of firm activities. A very special place and role is assigned to the logistics concept.

Logistics, whose inherent feature is the integration of flows and processes, plays a very important role in contemporary business management. Logistics as the materials, goods and information flow management concept affects the efficiency, effectiveness, success and the overall performance of a firm, as well as the building and strengthening the competitive advantage and the overall competitiveness of a firm.

The most significant symptoms of firm success are both market as well as economic outcomes reached by the firm. These outcomes are also the basis for creating sustainable, long-term firm competitive advantage and, as a final result, the overall firm competitiveness.

The basic condition to achieve market outcomes (e.g. customer satisfaction, customer loyalty, market share) as well as economic outcomes (e.g. profit, profitability, return on invested capital) by a firm is the proper identification and use of the firm's most important strategic capacities comprising: (1) resources, (2) capabilities, and (3) competences. In striving to achieve the abovementioned outcomes a very important role is also played by the firm strategy.

The aim of the article is to present the results of the research concerning logistics impact on business management and firm competitiveness conducted in Chair of Logistics and Strategic Management at University of Opole, Poland, EU. The research started fifteen years ago, in 2009 within the project named *Logistics Determinants of Business Management*, carried out in years 2009-2011. The research results concerned primarily the impact of the logistics (in particular logistics concept) and its instruments, especially logistics strategies, on the overall business management. The next stage of the research was the second project named *Logistics Competences Affecting Business Competitive Advantage Creation* carried out in years 2012-2014, concerning the impact of logistics competences on the firm competitive advantage creation. In the next years the above issues were expanded, including the influence of logistics resources as well as logistics capabilities on business management as well as the overall firm competitiveness.

2 Literature review

2.1 Logistics concept and its impact on business management and firm competitiveness

In the development of logistics, especially in the recent years, there is a very significant shift from logistics understood as the transformation of tasks and activities in the field of the flow of goods, towards logistics seen as a holistical, integrated concept concerning the materials,

goods and information flow management within the firm and the entire supply chain (supply network).

In general, the concept of logistics means a decision-making model comprising four basic parts: (1) strategic analysis, (2) logistics goals, (3) logistics strategies, and (4) logistics tools [8].

The concept of logistics has a multidimensional and often very significant impact on the business management system as well as its parts (subsystems). During the last several years logistics is more and more often understood and conducted as one of the most significant, efficient and effective business management tools that allow firms to reach success and create their long-term competitive advantage. Both, such a success as well as competitive advantage are the pillars of widely understood firm competitiveness.

Logistics understood as the materials, goods and information flow management concept, and consequently logistics management, can be considered in two basic dimensions: strategic and operational [9].

Within the strategic dimension logistics is perceived first of all as a business management concept. As a result, from that point of view logistics management plays an equally important role at the highest levels of business management comparing to other functional areas like marketing or finance. Within the strategic dimension logistics is also implemented as a cross-sectional function of the firm in relation to the basic areas of flows, i.e. supply/purchases, production and distribution/sales. Moreover, together with research and development (R&D), supply/purchases, production and distribution/sales, logistics as a cross-sectional function determines the framework conditions for shaping and forming logistics systems and processes.

In turn, within the operational dimension logistics often plays a subordinate role for the highest levels of business management and is not implemented as a cross-sectional function comparing to marketing or finance. Individual logistics systems and processes are then formed and shaped separately in the case of R&D, supply/purchases, production and distribution/sales [9].

The most significant requirement for the concept of logistics understood as the materials, goods and information flow management is the proper and systemic integration of logistics and logistics management with the overall and holistical logic as well as the entire business management system. This is already manifested in the definition of the firm (corporate) mission, which concerns all stages of the logistics management process, in particular the stage of strategic analysis of logistics and the stage of strategic logistics planning.

The first stage of the logistics management process, i.e. strategic analysis of logistics, serves primarily analytical, diagnostic and forecasting functions. The most significant role is assigned to the analysis of the logistics system of a firm and its parts (subsystems), taking into considerations trends and circumstances concerning the environment of a firm, as well as the strategic firm capacities comprising resources, capabilities, and competences.

The most significant outcome of the logistics strategic analysis is a comprehensive, systemic and strategic concept of logistics. Based on the assumed logistics goals, it leads to the development of logistics strategies. Simultaneously, both, logistics goals and logistics strategies should be consistent and integrated with the overall firm goals and the overall firm strategy, as well as with the long-term directions of the firm (corporate) development.

The strategic logistics concept is the pillar for specifying further management decisions as well as processes and activities. This is primarily related to the formulation of the operational logistics goals, as well as the selection and use of logistics tools referred to as logistics-mix.

The last stage of the logistics management, related to the implementation of logistics operational plans and programs, includes organizational and implementation solutions, as well as control processes and activities. The most important role is assigned to logistics controlling. Logistics controlling has both diagnostic and prognostic functions. It is closely related to the arrangements adopted at the planning stage and allows for the assessment of the implementation of the assumed goals.

2.2 Logistics resources affecting firm competitiveness

Logistics resources are the first group of the firm strategic capacities affecting business management and the broadly understood competitiveness of the firm.

Within the resource-based theory (RBT) of the firm it is assumed that gaining a long-term, sustainable competitive advantage by a firm depends, among others, on the ability for using resources to achieve the assumed goals. According to the assumptions of this theory, resources are understood as tangible and intangible assets used to carry out tasks that result in achieving the assumed goals. However, not all resources are of an equal importance in firms' efforts to gain a long-term, sustainable competitive advantage. Resources of a particular importance in building and strengthening of the firm competitive advantage are referred to as key resources. According to J. Barney, key resources can be considered when they meet the following criteria (the so-called VRIN criteria): (1) they are valuable, (2) they are rare, (3) they are difficult to copy by competitors, and (4) they have no substitutes [10].

Appropriate involvement of the firm resources in achieving the firm goals is a basis for achieving the firm long-term competitive advantage. Among the resources that can significantly contribute to building such an advantage as well as widely understood firm competitiveness an important role is assigned to logistics resources.

Permanently growing importance of logistics resources results from – among others – the fact that in recent years logistics itself as a concept of materials, goods and information flow management is increasingly perceived as a systemic and holistic factor affecting the overall firm competitiveness. Logistics understood in such a way is also perceived as the basis for achieving firm success and building a sustainable, long-term competitive advantage by a firm. At the same time, logistics strategy and logistics-mix are used as effective and efficient tools for the firm competitive advantage creation.

Logistics as the capacity of the firm competitiveness concerns the creation of the value systems more effectively and efficiently than competitors. It can be said that strategic management of logistics resources involves their use in such a way that the firm gains a competitive advantage by offering a unique value for the customer, which is significantly different from the values delivered and served by the market rivals.

There are three basic strategic options in logistics resources management: (1) development of the own firm logistics resources through investments in logistics systems, (2) acquiring logistics resources by taking them over from the competitors, (3) development of logistics resources in cooperation with business partners within the supply chain or even supply network.

The first of the above-mentioned solutions often involves the need to incur quite significant expenditures to expand the firm logistics resources base. It is important to select the types of resources that are most desirable to carry out the designated tasks. The basic selection criterion is the assessment regarding the efficiency and effectiveness of the use of logistics resources within the implementation of tasks.

The second solution also requires incurring the necessary expenditures, i.e. taking over resources from the competitors. The main issue, apart from the difficulties of acquiring resources, may be the adequacy assessment of these resources in relation to the tasks that the firm should perform. Logistics resources successfully used to carry out the designated tasks by one firm do not have to meet this criterion in the case of another firm.

The third solution to expand the logistics resources base is to develop it jointly with the market partners. It is then possible to determine not only the ways in which resources are involved in the implementation of tasks by the firm, but also the ways in which they can be used, taking into account the capabilities of suppliers, intermediaries, and other partners in the supply chain (network).

2.3 Logistics capabilities affecting firm competitiveness

Logistics capabilities are the second group of the firm strategic capacities affecting business management and firm competitiveness.

The firm logistics resources are supposed to be involved in several goals concerning – among others – offering logistics services accordingly to the customers' expectations, or ensuring the level of logistical service demanded by the customers. On the road to achieve such goals firm have to develop the effective and efficient logistics capabilities, enabling customers to be offered the right goods, at the right place and time, in the right quantity and quality, at the right costs and with the right information.

Logistics capabilities are the "tools" for the identification of customer preferences and the presentation of the market offer solving the customers' problems and adapting logistics services to customers' preferences and expectations, as well as ensuring the level of service required by customers, delivering products on terms that are adequate from the customers' point of view, etc.

The firm capabilities are a "set" of its individual abilities used to perform activities and/or tasks. The basic feature (determinant) of the firm capabilities is the orientation leading to achieving expected (i.e. planned, not e.g. accidental) outcomes, obtained in purposeful as well as coordinated ways of actively engaged resources [11].

The firm capabilities are oriented towards the effective and efficient use of the resources in achieving the planned goals [12,13]. The active nature of resource involvement means that they are assigned to specific tasks in the implementation of which they may be useful. The effectiveness and efficiency of the use of the resources concern the creation of the products and services offer for customers (customer value creation) and reaching the planned market and economic outcomes by the firm. This, in turn, may constitute a premise for achieving success as well as competitive advantage by the firm, and – as a result – the creation and strengthening the firm competitiveness.

Logistics capabilities can be defined and developed in two major areas: (1) the real area, and (2) the regulatory area. Capabilities related to the real area are related to processes such as transport, warehousing, storage, transshipment, manipulation, packaging, commissioning, packaging and labeling. In turn, capabilities related to the regulatory area concern processes related to the flow management of goods and information within the firm as well as the entire supply chain.

Logistics capabilities comprise two major types: (1) operational capabilities and (2) dynamic capabilities. Operational capabilities concerning logistics area include several routine activities related to the day-to-day implementation of logistics tasks, usually related to short-term guidelines for the firm activities such as "registration" of the amount and structure of revenues from the provided logistics services, assessment of the size and structure of inventories held, or assessment of the effectiveness and efficiency of current warehouses use. So it may be said, that logistics operational capabilities allow the firm to use current success capacities, especially the firm resources.

In turn, dynamic logistics capabilities are oriented not so much towards the use of the firm existing success capacities, but rather towards their long-term forming,

shaping and development. These capabilities are therefore a certain "carrier" of changes taking place both in business management systems and on the market. Dynamic logistics capabilities make possible more effective and efficient – compared to operational capabilities – use of the firm logistics resources by creating their new, innovative configurations, allowing for better adaptation to changes taking place on the market, and leading to building and strengthening the overall firm competitiveness.

2.4 Logistics competences affecting firm competitiveness

Logistics competences are the third group of the firm strategic capacities affecting business management and the competitiveness of the firm.

Basically, the issue of competences can be considered in two main approaches: (1) in the managerial approach, and (2) in the personal approach.

Within the managerial approach competences include bundles (compositions) of capabilities enabling the use of resources owned by the firm. The condition for using the opportunities inherent in resources is the development of appropriate capabilities of the firm. We can then talk about the resources and capabilities integration and coordination in the development of the firm competences.

In turn, within the personal approach competences are related to the human characteristics thanks to which people can effectively and efficiently perform the tasks entrusted to them. The topic of personal competences has been considered within the area of human resources management for many years, where it has a number of modern and advanced concepts and extensive models [14,15].

Competences, especially the distinctive competences introduced by P. Selznick, I. H. Ansoff and K. R. Andrews, have evolved towards significant strategic capacities of the firm, playing the key role in the value chain and influencing the forming and shaping the firm competitiveness, as well as building its competitive advantage [16].

It can be said that competences are the compositions of the long-term capabilities to use resources engaged in the firm goals and tasks implementation, leading to the expected market and economic outcomes achievement by the firm, and – as a result – to the forming and strengthening the overall firm competitiveness. The basis for the competences development is the integration and coordination of the firm resources and capabilities, taking also into account the significant type of the firm resources that is knowledge.

Within the firm competences the very significant role is assigned to the logistics competences. In addition to logistics resources and logistics capabilities, logistics competences are the third type of strategic firm capacities related to the logistics area that affect the firm competitive advantage as well as the overall firm competitiveness [17].

According to D. Bowersox and P. Daugherty, firms highlighting the strategic aspects of logistics, implementing the strategic logistics management concept within both forming and shaping their business models as well as formulating and developing business strategies, are mainly looking for the opportunities conditioning the effective and efficient use of the unique (distinctive) competences related to the area of logistics [18].

The most significant condition for the effective and efficient development of logistics competences is the prior identification of the appropriate logistics capabilities, based on logistics resources [19]. Thus, logistics competences are embedded and underpinned on the logistics resources owned by the firm and the logistics capabilities to use such the resources effectively and efficiently.

Logistics competences are the compositions of the long-term logistics capabilities conditioning the use of the logistics resources, actively involved in the implementation of the set goals and tasks, leading to the expected market and economic outcomes achievement by the firm, which are the basis for reaching business success and firm competitive advantage. The logistics competences are developed as a result of the integration and coordination of logistics resources and logistics capabilities. Moreover, knowledge, perceived as a special type of resources, related to logistics processes and activities carried out by the firm, plays a crucial role in the formation and development of logistics competences.

A significant complement to the logistics capacities influencing business management and the overall competitiveness of a firm is logistics strategy.

2.5 Logistics strategies and their impact on business management and firm competitiveness

The comprehensive involvement of logistics resources, capabilities and competences in firms' efforts to build a competitive advantage and strengthen the overall firm competitiveness requires the development of the proper strategies that could take into account the logistics systems capabilities in meeting the needs and wants of customers as well as ensuring the effective and efficient level and structure of costs. Trying to achieve the most efficient relations between the results obtained from the use of resources and the costs incurred, it is necessary to effectively integrate the logistics strategy within the overall corporate strategy. In a situation where logistics, especially logistics capacities play a key role in building a firm competitive advantage and its overall competitiveness, logistics may constitute the core of the strategy influencing achieving and sustaining this advantage, as well as strengthening the overall firm competitiveness. It can be said that then a specific transformation takes place, consisting in a transition from perceiving logistics as a functional strategy to treating logistics as a key component of the overall strategy of a firm.

One of the first studies on logistics strategies and their impact on business management as well as the firm competitiveness showed that logistics strategy is a functional strategy, being the composition of the long-term, internally and externally coordinated decisions as well as activities within the areas of location, transport, storage, inventory control and customer service, leading to achieve the competitive advantage by a firm [20]. Despite the logistics strategy often being assigned to the group of functional strategies, it was already perceived as an important factor affecting the firm competitive advantage creation, as well as building and strengthening the overall firm competitiveness.

The significance of logistics strategies in building and strengthening firm competitive advantage, as well as broadly understood firm competitiveness has been confirmed by the results of many world-wide studies. One of the most important and innovative research was the studies conducted by D. Bowersox and P. Daugherty, who defined three basic orientations which are the pillars for the logistics strategy development, based on the resources and capabilities of a firm. These orientations are [21]: (1) process orientation, (2) market orientation and (3) information orientation.

Process orientation assumes that all logistics processes and activities are the parts of the value added creation system. The logistics strategy plays a crucial role in firm competitiveness building and strengthening, mostly by the concentration on the effectiveness and efficiency of logistics processes concerning purchasing, manufacturing, delivery scheduling and physical distribution.

In turn, in market orientation the coordinated implementation of all logistics processes as well as logistics activities in the area of physical distribution is of a key importance. It enables achieving the synergic effects by a firm. The most effective logistics strategy conditioning the overall firm competitiveness building and strengthening is the strategy embedded on the customer service.

Finally, the information orientation is based on the integration and coordination of the logistics processes as well as logistics activities within the entire supply chain. Such an orientation require the wide and deep cooperation between supply chain partners, which is based on the integrated goods and information flow management, conditioning building and strengthening the overall firm competitiveness.

The growing significance of logistics strategies in building and strengthening widely understood competitiveness of a firm emphasizes G. Persson [22]. In his opinion, logistics plays the crucial role in the process of the business strategies formation and development, taking into account first of all the strategic aspects of logistics concept concerning logistics systems as well as logistics processes and activities.

M. Christopher also draws attention to the constantly growing importance of logistics, according to logistics strategies as well as logistics tools playing the crucial role in achieving business competitive advantage by a firm [23]. The most significant outcomes performed by the firms and supply chains, conditioning the creation of the competitive advantage should be related both to costs as well as customer service.

Logistics strategies which are the pillars of the firm competitive advantage building and strengthening are often classified taking into account the criterion of competition and competitiveness. Based on this criterion, K. Rao, J. Steenger and R. Young distinguish three basic logistics strategies: (1) strategy for cost minimization, (2) strategy for additional value maximization, and (3) strategy for achieving flexibility and control of the logistics system [18]. The abovementioned logistics strategies primarily concern the most significant development directions within the strategic management of business logistics. In particular, it relates to the identification of the main sources of the firm competitive advantage achieved thanks to logistics.

Logistics strategies are also classified taking into consideration the type of logistics concept implemented in a firm. Taking into account the challenges regarding the market environment, as well as the long-term firms' goals regarding the performed market and economic outcomes, two main logistics strategies can be defined: (1) logistics strategies concerning the entire supply chain management, and (2) logistics strategies concerning time compression [24]. The abovementioned logistics strategies should widely and deeply consider the set firm goals, as well as the firm strategic capacities comprising resources, capabilities and competences. Such logistics strategies go beyond the classical functional framework, playing the significant role in strategic management decisions related to the building and strengthening of the firm competitive advantage as well as the overall competitiveness of the firm.

3 Methodology

The growing significance of logistics concerns mainly its crucial influence on changes in the entire firm management system as well as on the overall firm competitiveness. These changes contribute first of all to the more effective and efficient market outcomes as well as economic outcomes achievied by the firms. As it was mentioned above, logistics is perceived as a comprehensive factor afecting the entire business management system and its subsystems, conditioning and stimulating several significant changes within the specific business management subsystems, including planning, organizing, motivating and controlling. Such changes also significantly affect the key parts of business management concept, including strategic analysis, goals, strategies and tools, as well as business management levels, i.e. normative level, strategic level, tactical level and operational level.

The key importance within the research concerning logistics impact on business management and firm competitiveness is assigned to the logistics determinants of business management.

Logistics determinants of business management affect not only the expected changes concerning the entire business management system and its subsystems, but influence on the overall firm competitiveness as well. These determinants fulfill the following criteria [8]:

1) They influence the changes of forms, parameters, features and/or structure of "object" on which they have an impact,
2) They form and determine the expected change directions of the "object" and its parameters, features and structure,
3) They generate the expected effects of changes, i.e. market and economic outcomes.

The scope and symptoms of logistics determinants impact on business management system were the subject of the research project named *Logistics Determinants of Business Management*, conducted in years 2009-2011 by the Chair of Logistics and Strategic Management at University of Opole, Poland, EU. The aim of the abovementioned research project was to identify the most important multidimensional relationships between logistics and business management system, as well as the possibilities of expected market and economic outcomes achievement by a firm, concerning the overall firm competitiveness. As a result the following logistics determinants of business management have been identified [8]:

1) Flow orientation,
2) Logistics and supply chain competences,
3) Logistics strategies,
4) Logistics management tools,
5) Logistics planning,
6) Organizational solutions related to logistics and supply chain management,
7) Logistics controlling.

Within this research project it was assumed that logistics determinants of business management are the specific factors related to logistics and supply chain management areas, affecting business management system and its subsystems, as well as providing the opportunities for the expected market and economic outcomes achievement by the firm.

Logistics determinants of business management are specific factors affecting the planned changes occuring in business management system as well as in the overall firm competitiveness. Such changes concern first of all the transformation within the specific business management subsystems including planning, organizing, etc. The transformation is related to the shift from up-to-now solutions to solutions conditioning the achievement of the expected market and economic outcomes. Apart from this, such a transformation also concerns the overall firm competitiveness, including firm competitive advantage as well as firm competitive position on the market.

4 Results and discussion

Logistics determinants of business management are of a key importance within the research carried out by the Chair of Logistics and Strategic Management at University of Opole, Poland, EU, related to the impact of logistics on business management and the competitiveness of the firm. The basis of the research was the concept of logistics and the identification of its most important characteristics. The concept of logistics is primarily related to the flow orientation in business management and the degree of its implementation.

Based on the logistics determinants of business management, the most important logistics capacities influencing business management and the competitiveness of the firm were defined. Among these capacities the most important role is assigned to logistics resources, logistics capabilities and logistics competences. At the same time, the condition for the proper use of logistics capacities is the identification and development of appropriate logistics strategies, allowing the achievement of planned goals and obtaining the expected market and economic outcomes, which are the basis for the firm success and its competitive advantage, as well as for building and strengthening the overall competitiveness of a firm.

P. Daugherty, H. Chen, D. Mattioda and S. Grawe point that logistics resources can be treated as the firm strengths, used in the development of competitive strategies that determine the achievement of a long-term, sustainable competitive advantage of a firm [25]. Key logistics resources are the significant parts of the logistics systems that are of the greater value compared to other resources. This value is manifested not only in the level of expenditures that must be incurred on their acquisition and/or development, but also in the level of logistics services that can be offered. As a result, the key logistics resources may constitute the core of the firm strategy related to forming, shaping and developing a sustainable, long-term competitive advantage on the market, and – as a final result – the overall firm competitiveness.

In addition to logistics resources, logistics capabilities play a key role in building and strengthening the firm competitiveness. The original concept of logistics capabilities embedded on the firm competitiveness capacities has been proposed by Mentzer et al. [26]. Within this concept is was assumed that the basis for the expected market and economic outcomes achievement by the firm is the active, effective and efficient involvement as well as use of the logistics resources and logistics capabilities in building and strengthening the firm competitiveness. As a result, logistics resources as well as logistics capabilities affect the changes within the entire business management system, as well as leads to the expected market outcomes and economic outcomes achievement by the firm.

Mentzer et al. defined three groups of logistics capabilities concerning the firm competitiveness building and strengthening [26]:

1) Capabilities concerning the firm competitiveness building and strengthening based on customer needs, wants, preferences, and expectations – these capabilities are referred to as demand-oriented capabilities,
2) Capabilities concerning the firm competitiveness building and strengthening based on costs, referred to as supply-oriented capabilities,
3) Capabilities concerning information flow management.

The demand-oriented capabilities relate to the customer orientation. These capabilities are also named and/or described as customer-centric capabilities, customer value adding capabilities, or customer integration capabilities. This group of logistics capabilities allow to acquire customers and meet or even exceed their expectations, offering them unique values compared to the competition. These capabilities are also characterized by multidimensionality concerning customer service capabilities as well as logistics quality shaping capabilities, and long-term perspective related to pre-sales, sales and after-sales service capabilities. As a result, demand-oriented capabilities significantly affect building and strengthening the firm competitiveness embeded on customers' needs and preferences.

In turn, supply-oriented capabilities relate to total cost minimization, being the key premise for the superior performance concerning logistics systems, processes and activities. This group of logistics capabilities contribute to defining methods allowing for solving specific customer problems. It requires the effective and efficient implementation of such the solutions as just-in-time deliveries, quick response to customer needs, or vendor managed inventories. Supply-oriented logistics capabilities concern the optimization of all activities that ensure that logistics processes carried out within the entire supply chains lead to the minimization of total costs, as well as to building and strengthening the firm competitiveness based on costs.

Finally, the information flow management capabilities are related to the area of information technology, including the exchange and sharing of the information. These capabilities contribute to balancing demand and supply within the supply chain nodes and, as a result, to improving the processes of goods exchange. Information technology plays a crucial role in logistics capabilities development as well as determines the information flow effectiveness and efficiency both within the firm and the entire supply chain. Logistics capabilities concerning information flow management are very often implemented together with capabilities related to materials and goods flow management.

Apart from logistics resources and logistics capabilities, also logistics competences play a very significant role in building firm competitive advantage and strengthening the overall competitiveness of the firm. Within the research carried out by the Chair of Logistics and Strategic Management at University of Opole, Poland, EU, a significant role is assigned to the original concept of logistics competences, being the result of the research project named *Logistics Competences Affecting Business Competitive Advantage Creation*, conducted in years 2012-2014, related to the impact of logistics competences on business competitive advantage creation as well as the overall firm competitiveness.

Within the above research project three main topics were examined [8]:

1) Competencies of logistics managers concerning human resources (people) responsible for the logistics objectives reaching, as well as for the logistics tasks implementation,
2) Logistics competences related to logistics goals as well as logistics strategies positioning within firm and businesses' goals and strategies,
3) Logistics competences concerning the cooperation and integration with all partners in supply chain, in particular with suppliers, distribution companies, wholesalers, retailers, customers, etc.

The most significant result of the abovementioned research is the original model of firm success capacities and symptoms, comprising a very important role of logistics competences affecting the firm competitive advantage creation and the overall firm competitiveness strengthening. This model comprises four groups of the key (superior) logistics competences [8]:

1) Competences concerning the logistics concept embedding within business management, particularly in relation to goals, strategies, tactical programs and operational tasks, as well as to planning and organizational structure development – these competences are referred to as "logistics positioning and integration within business management",
2) Competences concerning the integration perceived as an inherent feature of the logistics concept, which can apply to processes carried out within the entire value chain as well as within the firm – these competences are referred to as "vertical and internal integration",
3) Competences concerning: (a) the adaptability and flexibility regarding relationships with suppliers, distribution companies and customers, (b) the coordination of materials and goods flow, (c) the logistics processes and activities carried out by the firm, as well as (d) the execution of customer orders – these competences are referred to as "flow management",

4) Competences concerning ERP systems, as well as EDI and RFID technologies – these competences are referred to as "information systems and technologies".

Additionally, in the area of logistics competences named "vertical and internal integration" the following competences may be specified [8]:

1) Integration with suppliers,
2) Integration with distribution companies,
3) Integration with customers,
4) Internal integration (integration within the firm).

In turn, in the area of logistics competences named "flow management", the following competences may be specified [8]:

1) Agility, including adaptability and flexibility,
2) Flow leaness and transparency,
3) Logistics processes,
4) Order management.

Research concerning the concept of logistics as well as the key logistics capacities (resources, capabilities and competences), should be supplemented with the research on logistics strategies, linking all the above logistics topics related to the firm competitiveness building and strengthening.

The results of the several research carried out in world as well as in Poland point that logistics strategies are very often supposed to go beyond the functional level, having an important share in the process of business strategies formulation and implementation. Logistics strategies are also a significant part of the comprehensive, global strategies of the firm (corporate strategies), strongly affecting a sustainable, long-term competitive advantage of the firm [27,28].

Strategic aspects of logistics concerning the logistics strategy influence on the expected market and economic outcomes achivement by the firm, and – as a result – on the creation of the firm competitive advantage are also presented by A. Stainer. As he points, the logistics strategy is very strongly related to the firm environment, as well as to the measures and indicators presenting the achievement of the expected market and economic outcomes by the firm [29]. Such a comprehensive look at the logistics strategy not only goes significantly beyond the classical functional approach concerning logistics strategy, but also shows that logistics strategy can be a key part of the business strategy and even the overall, logistically oriented strategy of the firm.

5 Conclusions

The aim of the article was to present the research results related to logistics impact on business management and firm competitiveness carried out in Chair of Logistics and Strategic Management at University of Opole, Poland, EU. The research outcomes confirmed a very significant role as well as the growing importance of the logistics concept, logistics capacities **(**resources, capabilities and competences**)**, and logistics strategies in building and strengthening the firm competitiveness. Within two projects: (1) *Logistics Determinants of Business Management*, and (2) *Logistics Competences Affecting Business Competitive Advantage Creation* it was examined that logistics not only strongly influences business management system and its subsystems, but also significantly affects the overall firm competitiveness.

The research results also highlighted the crucial importance of the strategic aspects of logistics. D. Bowersox and P. Daugherty point that firms which particularly value the strategic aspects of logistics, implementing the concept of the strategic logistics management in forming and shaping their business models as well as formulating and developing business strategies, are primarily looking for opportunities to use unique (distinctive) competences related to the area of logistics [18]. This is why logistics competences play a crucial role in contemporary business management, and – together with logistics resources and logistics capabilities – create the "capacity base" for building and strengthening the firm competitiveness.

The possibilities for the creation of the firm competitive advantage as well as firm competitiveness embedded on widely understood logistics, including in particular logistics strategies, also points J. Heskett [30]. In his opinion, the significantly growing role of logistics, especially the concept of logistics in business management, makes the logistics strategy more and more important in the formulation and development of the overall firm (corporate) strategy. A logistics strategy perceived in such a way is more and more often defined as a "logistically oriented firm strategy", influencing the building and sustaining of the firm competitive advantage and – as a result – strengthening the overall competitiveness of the firm, taking into account the capacities comprising logistics resources, logistics capabilities and logistics competences.

Nowadays, logistics concept, logistics capacities and logistics strategies became not only the most important pillars of widely understood firm competitiveness, but more and more significant drivers for the development of the mentioned above modern business models in logistics. Such models play a key role in contemporary logistics management, influencing the entire business management system and its subsystems, as well as leading to strengthening widely understood firm competitiveness.

References

[1] BLAIK, P.: Tendencje rozwojowe i integracyjne logistyki, *Gospodarka Materiałowa i Logistyka*, Vol. 2012, No. 6, pp. 4-10, 2012. (Original in Polish)

[2] DEHLER, M.: *Entwicklungsstand der Logistik. Messung – Determinanten – Erfolgswirkungen*, Wiesbaden, DU-Verlag, 2001. (Original in German)

[3] MIKUS, B.: *Strategisches Logistikmanagement. Ein markt-, prozess- und ressourcenorierties Konzept*, Wiesbaden, Deutscher Universitäts Verlag/GWV Fachverlage, 2003. (Original in German)
[4] GÖPFERT, I.: *Logistik der Zukunft – Logistics for the Future*, Wiesbaden, Verlag Gabler, 2006. (Original in German)
[5] PROCKL, G.: *Logistik-Management im Spannungsfeld zwischen wissenschaftlicher Erklärung und praktischer Handlung*, Wiesbaden, Deutscher Universitäts Verlag/GWV Fachverlage, 2007. (Original in German)
[6] KLAUS, P.: Logistics Research: A 50 Years' March of Ideas, *Logistics Research*, Vol. 1, No. 1, pp. 53-65, 2009.
[7] DELFMANN, W., DANGELMAIER, W., GÜNTHNER, W., KLAUS, P., OVERMEYER, L., ROTHENGATTER, W., WEBER, J., ZENTES, J.: Towards a Science of Logistics: Cornerstones of a Framework of Understanding of Logistics as An Academic Discipline, *Logistics Research*, Vol. 2, No. 2, pp. 57-63, 2010.
[8] MATWIEJCZUK, R.: *Logistyka w zarządzaniu strategicznym*, Warszawa, Polskie Wydawnictwo Ekonomiczne, 2021. (Original in Polish)
[9] BLAIK, P.: *Logistyka. Koncepcja zintegrowanego zarządzania*, Warszawa, Polskie Wydawnictwo Ekonomiczne, 2017. (Original in Polish)
[10] BARNEY, J.: Firm Resources and Sustained Competitive Advantage, *Journal of Management*, Vol. 17, No. 1, pp. 99-120, 1991.
[11] SIMON, A., BARTLE, A., STOCKPORT, G., SMITH, B., KOLBAS, J., SOHAL, A.: Business leaders' views on the importance of strategic and dynamic capabilities for successful financial and non-financial business performance, *International Journal of Productivity and Performance Management*, Vol. 64, No. 7, pp. 908-931, 2015.
[12] TEECE, D., PISANO, G., SHUEN, A.: Dynamic capabilities and strategic management, *Strategic Management Journal*, Vol. 18, No. 7, pp. 509-533, 1997.
[13] EISENHARDT, K., MARTIN, J.: Dynamic capabilities: What are they?, *Strategic Management Journal*, Vol. 21, No. 10-11, pp. 1105-1121, 2000.
[14] ILLERIS, K.: *International Perspectives on Competence Development: Developing Skills and Capabilities*, Abingdon – New York, Routledge, 2009.
[15] SANGHI, S.: *The Handbook of Competency Mapping: Understanding, Designing and Implementing Competency Models in Organizations*, New Dehli, Sage Publications India Pvt. Ltd., 2010.
[16] MAHONEY, J., PANDIAN, J.: The Resource-Based View within the Conversation of Strategic Management, *Strategic Management Journal*, Vol. 13, No. 5, pp. 363-380, 1992.
[17] MOLLENKOPF, D., DAPIRAN, P.: The Importance of Developing Logistics Competencies: A Study of Australian and New Zealand Firms, *International Journal of Logistics: Research and Applications*, Vol. 8, No. 1, pp. 1-14, 2005.
[18] BOWERSOX, D., DAUGHERTY, P.: Logistics paradigms: The impact of information technology, *Journal of Business Logistics*, Vol. 16, No. 1, pp. 65-80, 1995.
[19] SENNHEISER, A., SCHNETZLER, M.: *Wertorientiertes Supply Chain Management*, Berlin – Heidelberg – New York, Springer Verlag, 2008.
[20] WITKOWSKI, J.: *Strategia logistyczna przedsiębiorstw przemysłowych*, Wrocław, Wydawnictwo Akademii Ekonomicznej we Wrocławiu, 1995. (Original in Polish)
[21] BOWERSOX, D., DAUGHERTY, P.: Emerging patterns of logistical organization, *Journal of Business Logistics*, Vol. 8, No. 1, pp. 46-60, 1987.
[22] PERSSON, G.: Achieving competitiveness through logistics, *The International Journal of Logistics Management*, Vol. 2, No. 1, pp. 1-11, 1991.
[23] CHRISTOPHER, M.: *Logistics and Supply Chain Management*, Financial Times Prentice Hall, Pearson Education Limited, London, 2011.
[24] LA LONDE, B., MASTERS, J.: Emerging logistics strategies: Blueprints for the next century, *International Journal of Physical Distribution & Logistics Management*, Vol. 24, No. 7, pp. 35-47, 1994.
[25] DAUGHERTY, P., CHEN, H., MATTIODA, D., GRAWE, S.: Marketing/Logistics Relationships: Influence on Capabilities and Performance, *Journal of Business Logistics*, Vol. 30, No. 1, pp. 1-18, 2009.
[26] MENTZER, J., MIN, S., BOBBITT, L.: Toward a Unified Theory of Logistics, *International Journal of Physical Distribution and Logistics Management*, Vol. 34, No. 8, pp. 606-627, 2004.
[27] AUTRY, C., ZACHARIA, Z., LAMB, CH.: A logistics strategy taxonomy, *Journal of Business Logistics*, Vol. 29, No. 2, pp. 27-51, 2008.
[28] McGINNIS, M., KOHN, J., SPILLAN, J.: A longitudinal study of logistics strategy: 1990-2008, *Journal of Business Logistics*, Vol. 31, No. 1, pp. 217-235, 2010.
[29] STAINER, A.: Logistics – a productivity and performance perspective, *Supply Chain Management*, Vol. 2, No. 2, pp. 53-62, 1997.
[30] HESKETT, J.: Logistics: Essential to strategy, *Harvard Business Review*, Vol. 55, No. 6, pp. 85-96, 1977.

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An innovative decision-making method for choosing a bus fleet based on logistics and sustainability aspects
Vince Kruchina, Peter Tamas, Bela Illes

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An innovative decision-making method for choosing a bus fleet based on logistics and sustainability aspects

Vince Kruchina
Institute of Logistics, University of Miskolc, HU-3515 Miskolc-Egyetemváros, Hungary, EU,
kruchina.vince@gmail.com (corresponding author)
Peter Tamas
Institute of Logistics, University of Miskolc, HU-3515 Miskolc-Egyetemváros, Hungary, EU,
peter.tamas@uni-miskolc.hu
Bela Illes
Institute of Logistics, University of Miskolc, HU-3515 Miskolc-Egyetemváros, Hungary, EU,
bela.illes@uni-miskolc.hu

Keywords: battery degradation, decision-making method, sustainability, public transportation.
Abstract: The widespread adoption of electric vehicles (EVs) has played a significant role due to their much smaller carbon footprint compared to their internal combustion engine counterparts. This trend also applies to public transportation in Hungary, where battery electric buses (BEBs) are gradually being incorporated into the fleets of major passenger transport operators. In assessing the total cost of ownership (TCO) of these vehicles, factors such as the expected daily mileage, the current price, capacity, lifecycle, and degradation of the integrated drive train batteries—typically lithium-ion based—play a significant role. This is also considered, if the batteries' second life and reuse can significantly improve the TCO value. Based on the examination of domestic and international literature, it can be established that the selection of the appropriate vehicle fleet exclusively considers the TCO value, which disregards neither the significant benefits arising from the batteries' secondary life cycle, nor considering various quality indicators. This deficiency in fleet selection could result incorrect decisions. In our opinion, the consideration of both logistical and sustainability aspects is indispensable in the decision-making process. To prove this, the paper presents an innovative decision-making method developed by us, which considers the effects of battery degradation related to the secondary life cycle and key quality indicators when selecting the ideal fleet meeting the expected mileage performance. To validate the theoretical background, a case study was also prepared, which is included in the paper. The article also contains considerations related to the topic by Volánbusz Zrt.

1 Introduction

Although buses appeared in road transport much earlier, electric vehicles (EVs) really burst into public transport fleets in the early 2020s. An important element in their uptake has been the fact that their carbon footprint is much smaller comparing to internal combustion engine counterparts, and thus they comply with the legislation and environmental protection requirements resulting from the European Union's climate protection efforts.

Battery electric buses (BEBs) are being progressively integrated into the fleets of major passenger transport operators [1,2], typically leading to mixed fleets [3]. The retention of fossil fuel buses in mixed fleets is primarily related to the driving range of electric vehicles, which determines the types of timetabling that - taking into account the capacity of the batteries and the way they are charged - allow for the safe covering of route distances.

Volánbusz Zrt., which plays a dominant role in suburban and local public transport in addition to domestic intercity bus transport, has been gradually increasing the number of electric buses in its fleet since the early 2000 s [4]. Due to a significant increase in the number of lithium-ion based batteries and their role in the sustainability of the fleet, the rest of this paper will analyse literature on the degradation and second life cycle of electric bus batteries, and then present our research results in this field. Considering this, an innovative decision-making method will be presented that takes into account the positive effects of the second life cycle resulting from battery degradation, and the relevant quality indicators for the selection of the optimal fleet. The results of the calculations based on this decision-making method are presented in the final section of the paper.

2 Thematic literature review

In relation to the objectives stated in this article, a thematic review of literature on batteries for electric buses focused on the following areas:

- types and characteristics of batteries,
- the degradation process in batteries,
- optimal operation and charging of batteries for a long battery life,
- application of reverse logistics in the second life cycle of batteries,
- integration of battery electric buses into mixed fleets.

2.1 Typical types of batteries for battery electric buses (BEB)

As in all areas of life, lithium-ion batteries have also found applications in electric vehicles. As the technology has evolved, competition has started in the following parameters: energy consumption measured in kWh/km; the reduction of overall battery weight; and achievement of the highest energy density.

The acronyms for the three most popular types of lithium-ion technologies are derived from the abbreviations of the minerals used in cell chemistry: LTO (lithium titanium oxide), LFP (lithium iron phosphate) and NMC (nickel manganese cobalt). Figure 1 is based on BMZ Poland's analysis, showing that NMC leads in terms of energy density, but also in unit weight and volume [5].

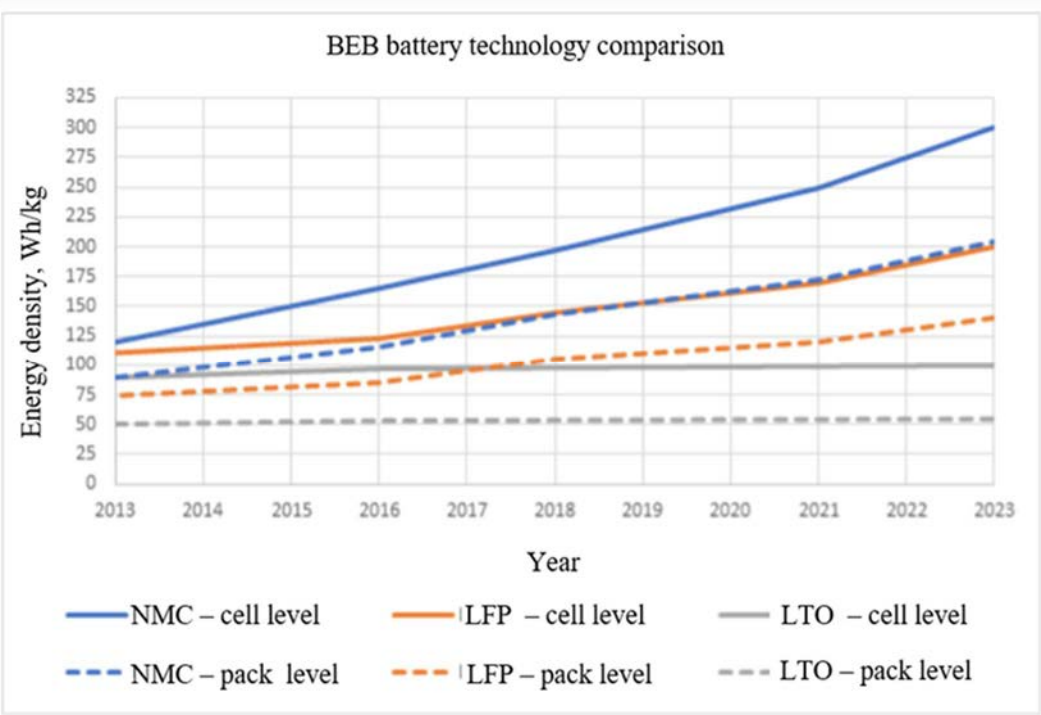

Figure 1 Comparison of the evolution of NMC, LFP and LTO technologies in terms of energy density at the levels of cells and battery packs [5]

2.2 Degradation of batteries

Battery degradation is the result of a number of complex processes, in which cyclic aging and calendar ageing play a combined role, leading to an increase in internal resistance. During cyclic ageing the capacity of the battery decreases, mainly due to an increase in the frequency of charging and discharging cycles. This is due to an increase in the internal solid electrolyte interphase layer, degradation of the electrodes, and cyclic lithium loss. Conversely, calendar ageing - which also leads to loss of capacity - refers to self-discharge reactions influenced by charge state, time and temperature. These phenomena are particularly relevant for electric vehicles, as significant degradation of batteries can increase the total energy consumption of electric vehicles and their greenhouse gas emissions per kilometre on a given driving cycle.

2.3 Optimal operation and charging of batteries for a long battery life

Some studies suggest that battery life can vary between 2,500 and 9,000 charge/discharge cycles [6]. The geographical location of buses can also have an impact on this, as one of the main causes of battery degradation is unfavourable ambient temperature, with lifetime significantly dependent on local temperature - i.e. climatic – conditions. Geography affects not only the lifetime of vehicles, but also their operating costs. Charging costs can vary depending on the time of year and time of day, and the carbon emissions of buses also depend on the energy mix of the power grid in a given country [7]. The lifetime guarantee of batteries is between 5 and 10 years, depending on the manufacturer. The guarantee is defined by manufacturers as a function of chemical composition, operation and charging.

Studies aimed at optimising the operation and charging of battery electric buses estimate battery lifetimes of 8 to 12 years, however, this is closely related to the charging process, and also the development of battery manufacturing technologies can undoubtedly increase the lifetime outlook [8].

But for assessing the long-term return on investment and fleet operational efficiency, a detailed analysis of the

effects of degradation is essential. All this is influenced by a number of factors, such as charging rate, temperature, depth of discharge and time/discharge cycle, as well as battery design, manufacturing and operating conditions.

If we want to look at the degradation of a whole battery system and not just one cell, we have to note that the performance of the system is determined by the performance of the individual cells. Ageing of the cells can lead to ageing of the system, but the performance of the battery system is greatly affected by inconsistencies and disparities between cells [9].

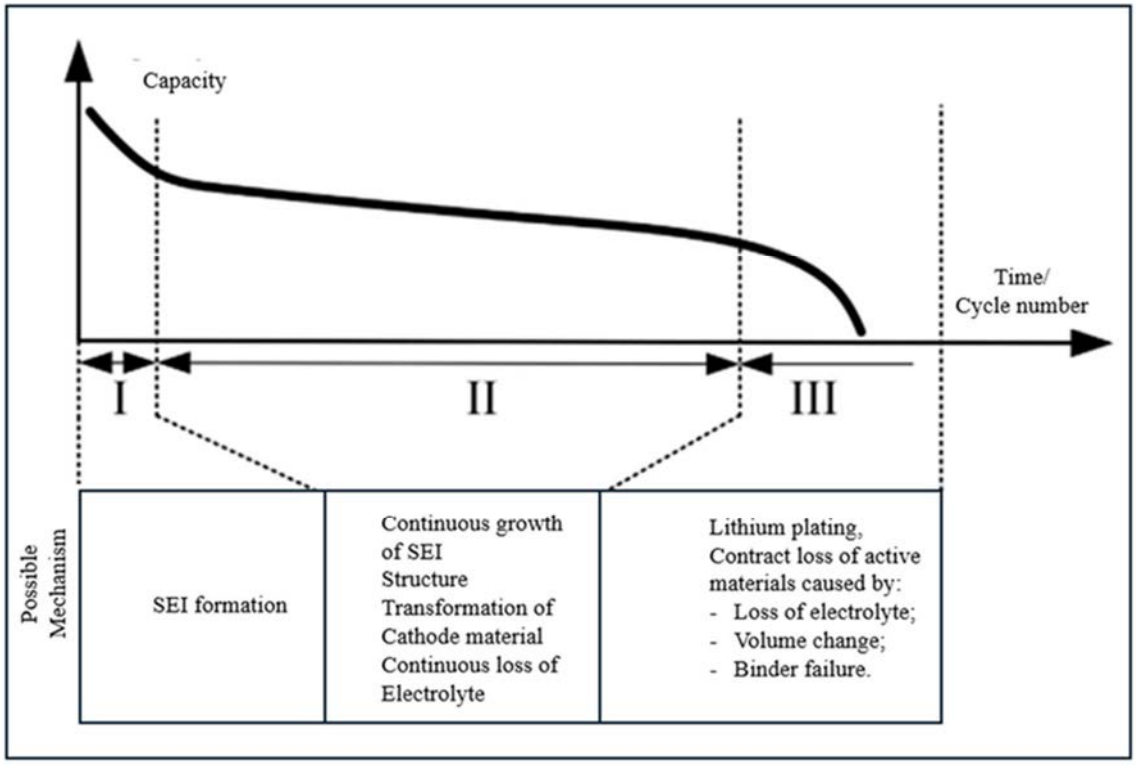

Figure 2 Mechanism of degradation [9]

The non-linear ageing of batteries can be divided into three stages:

- Stage I: solid electrolyte interface formation; sudden, rapid degradation.
- Stage II: further solid electrolyte interface formation, structural change in cathode material, electrolyte loss; linear stage.
- Stage III: lithium plating, continuous loss of material; sudden, rapid degradation.

Generally speaking, most batteries currently used in electric vehicles exhibit the characteristics of non-linear ageing, which can basically be divided into the three phases shown in Figure 2. In the first stage, the battery capacity decreases rapidly during the first few charging cycles. In the second stage, the battery performance decreases continuously due to the different reactions taking place inside the battery. In the third stage, a rapid decrease in capacity and increase in resistance occurs towards the end of the battery's life. This may be due to a rapid loss of lithium-ion supply and/or a loss of active material due to loss of electrolyte, failure of the binder and volume changes.

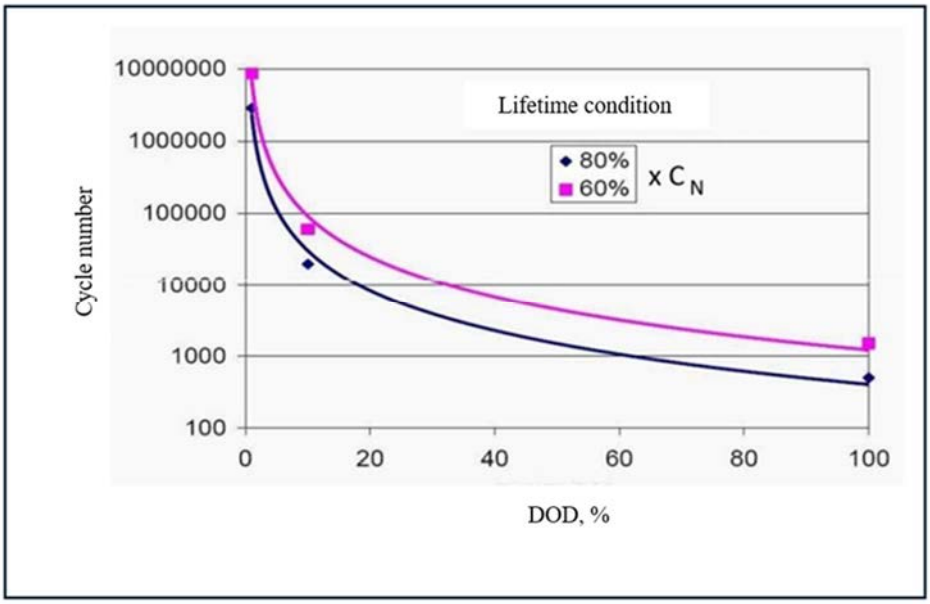

Figure 3 Effect of charging on battery degradation [10]

The state of charge (SOC) of a battery has a significant impact on battery life. The SOC value indicates the amount of available capacity stored in the battery. It is important to note that the SOC and the voltage of the battery are interdependent values. The battery voltage can be derived from the battery SOC and current. In general, a higher SOC results in higher terminal voltage, which means lower anode potential and higher cathode potential. This can accelerate the ageing process of the battery. A lower SOC, on the other hand, means higher anode potential and lower cathode potential, which is generally beneficial for battery life. If the SOC is too low, however, corrosion of the copper current collector of the anode and decomposition of the active material structure of the cathode can negatively affect battery life.

DOD (depth of discharge) also has a complex effect on battery life. According to professional opinion, there is an optimum DOD for battery life, but this DOD is generally too small to meet driving range requirements.

In scientific publications there has been analysis of several other aspects of the degradation of lithium-ion batteries typically used in electric buses. Chen et al. (2015) established a prediction model by analysing discharge characteristics, [11] while Tseng et al. (2015) [12] carried out an in-depth investigation into the effect on battery condition of voltage and internal resistance variation. O'Kane et al. (2022) were the first to publish a model linking two degradation mechanisms [13].

Degradation measurements make it clear that the life cycle of batteries is shorter than the designed service life of electric buses, so that when a battery is no longer suitable for its original function but still has significant value, environmental and economic considerations support the need to address its second life.

2.4 Application of reverse logistics in the second life cycle of batteries

The process known in the literature as reverse logistics [14] can play a significant role in creating a second life for batteries. The reverse logistics network design of Hao et al. (2021) for electric vehicle batteries focused on recall risks [15]. Yükseltürk et al. (2021) discussed the design of a reverse logistics centre for end-of-life electric vehicle batteries based on fleet size prediction [16]. Azadnia et al. (2021) analysed the barriers to the application of reverse logistics using the TISMA-MICMAC approach [17].

Harris at al, (2018) developed a novel framework to assist decision-makers in assessing the uncertainty of the life cycle impacts of alternative bus technologies, [18] while Jefferies at al. (2018) presented a comprehensive TCO evaluation method for electric bus systems based on discrete-event simulation including bus scheduling and charging infrastructure optimisation [19].

2.5 Findings from a review of the literature

Published material on the degradation of electric bus batteries has been associated with a number of sub-disciplines. The results acquired can be used in a more holistic operational model, in which an accurate knowledge of battery degradation allows for planning the second life of batteries in order to optimise the whole life cycle cost of a fleet. A key element in the second life cycle planning of batteries is precise knowledge of the degradation and charging characteristics of the batteries in a fleet, which can be achieved by having actual measurement results from the operator. A degradation study carried out by the company and its results are presented below

3 Degradation measurements for Volánbusz Zrt.

As a public transport bus operator, Volánbusz Zrt. has developed a concept for the development of electric vehicles as a strategic alternative, and has set itself the objective of significantly rejuvenating and upgrading its bus fleet. In line with this vehicle development, the company is already operating 102 purely electric buses.

Among the main driving forces behind the development of electromobility are the need to improve technology and service levels, to improve energy efficiency and reduce emissions. A further aim is to produce electricity as a fuel for the company itself, thereby reducing its use of fossil fuels and increasing its energy security and independence.

Alongside exploration of the development of its own energy generation capacity, the company has launched a research project in cooperation with market players and universities. The project's purpose is to investigate how, based on the principle of circular operation, batteries from electric buses can further serve the company's operations and interests by being used as storage in the infrastructure for secondary use. The benefits of this re-use are manifold. The purchase costs of batteries used in buses are substantial. Based on experience from manufacturers and users, in principle batteries should be replaced every 10 years, due to capacity loss. By using functioning batteries as storage units beyond this manufacturer's warranty period, the company can keep them in service for a number of additional years, thus preserving their usability for the company and improving return on investment. In the previous chapter we saw that if batteries are used optimally for 15 years, there is still potential for other uses, which will facilitate use of the circular economy model. The degradation measurements on batteries carried out by Volánbusz Zrt. led to the following results.

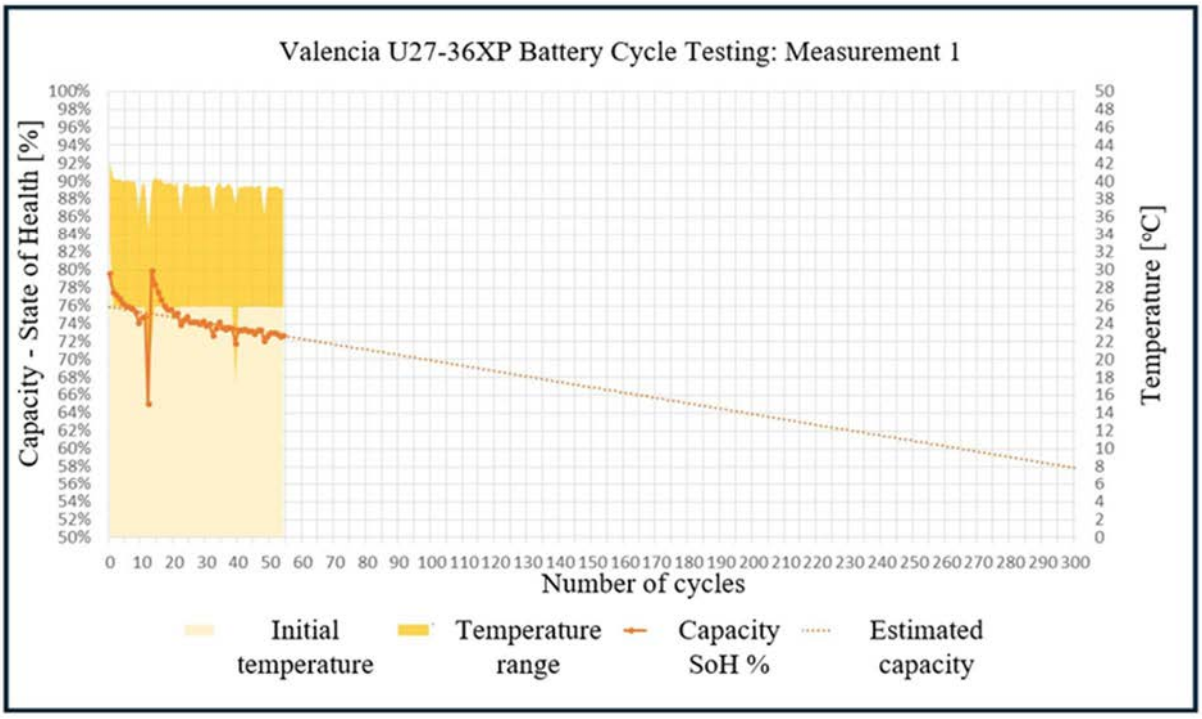

Figure 4 Valencia U27-36XP battery cyclic test: Measurement 1

Figure 4 summarises Valencia U27-36XP used battery test results from Volánbusz Zrt. The X-axis represents the total number of cycles. The cycles were performed with a 0.5C charge rate and a 1.0C discharge rate. On the left, the Y-axis shows the remaining capacity of the battery relative to its original capacity, i.e. the percentage of capacity remaining, with measurement points represented by orange dots. The broken orange line shows a linear extrapolation of the data, i.e. an estimate of the further capacity loss that can be expected for the same rates of charge and discharge. (The capacity loss of batteries under the same conditions can be said to be linear.)

In our experience, this linearity is true up to about 60% of remaining capacity, after which the capacity loss becomes progressively more severe (battery ageing), and then at a certain level collapses completely. So in general vigilance is advisable when capacity drops below 60%.

Figure 5 summarises the battery measurements of the battery test in a refrigerated medium. The axis descriptors and diagram elements are the same as in Figure 4, but the measured values are different.

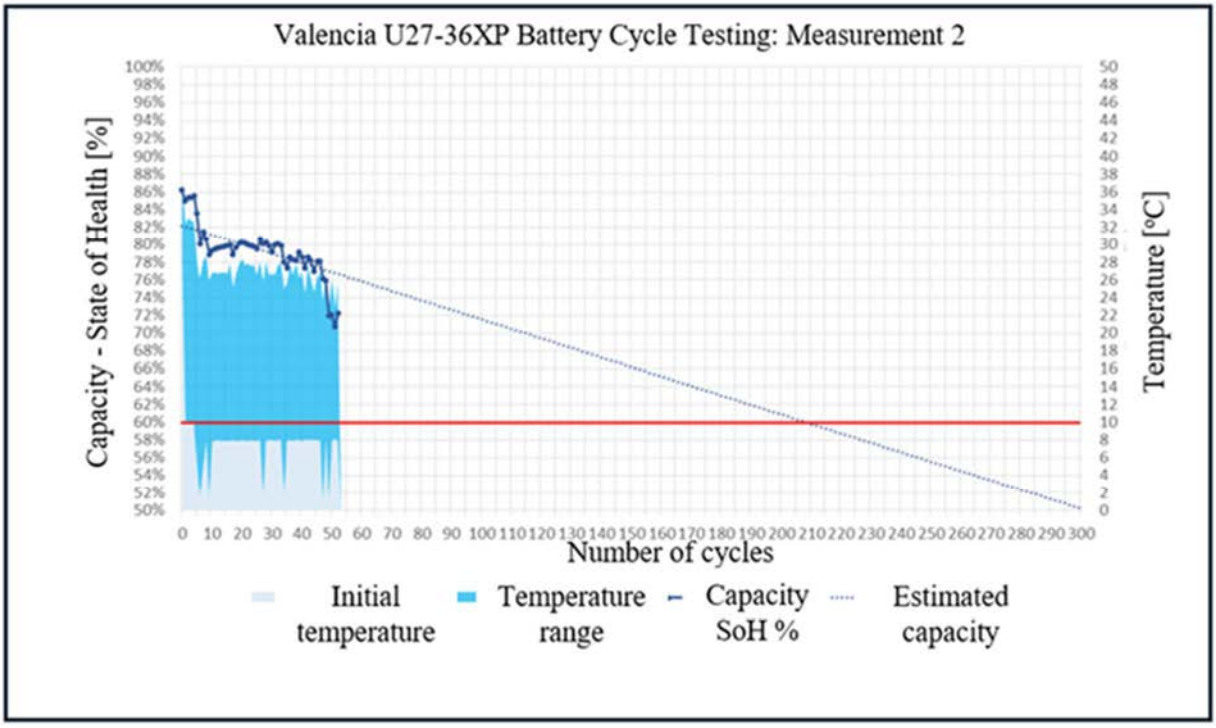

Figure 5 Valencia U27-36XP battery cyclic test: Measurement 2

The measurements clearly demonstrated the need to measure degradation under specific operating conditions for the use of batteries in vehicles and for second life cycle planning

4 An innovative decision-making method for bus fleet selection taking battery degradation into consideration

The selection of the right fleet for the operating company requires the consideration of a number of decision criteria and the application of a normalisation-based decision-making method which takes all relevant aspects into account. This chapter will describe the system variants that can be considered and the criteria and decision-making method for selecting the appropriate fleet.

4.1 Description of the system variants that can be tested

The decision-making method developed can be applied to all companies involved in public transport bus services, regardless of the type of fleet being assessed and the way in which batteries are managed and used. The examination possibilities are contained in Figure 6. During the examination, the optimal selection of a fleet consisting of a given vehicle type - suitable for achieving the expected daily mileage performance - is carried out. If the study includes an electric fleet, then only the first, and first and second life cycle impacts of batteries can be considered. In the first life cycle of batteries, the possibility to operate vehicles and sell spare capacity to the electricity supplier can also be examined. If the capacity of batteries falls below a predefined limit and they are longer capable of performing the required tasks, i.e.,daily mileage, secondary use becomes necessary. The latter may involve the following: sale of the battery on the market, for example for storage; as a captive reserve, for instance, storage of energy generated by captive solar or wind power, storage of peak-period electricity in order to power vehicles during peak periods, etc.; or a combination of these.

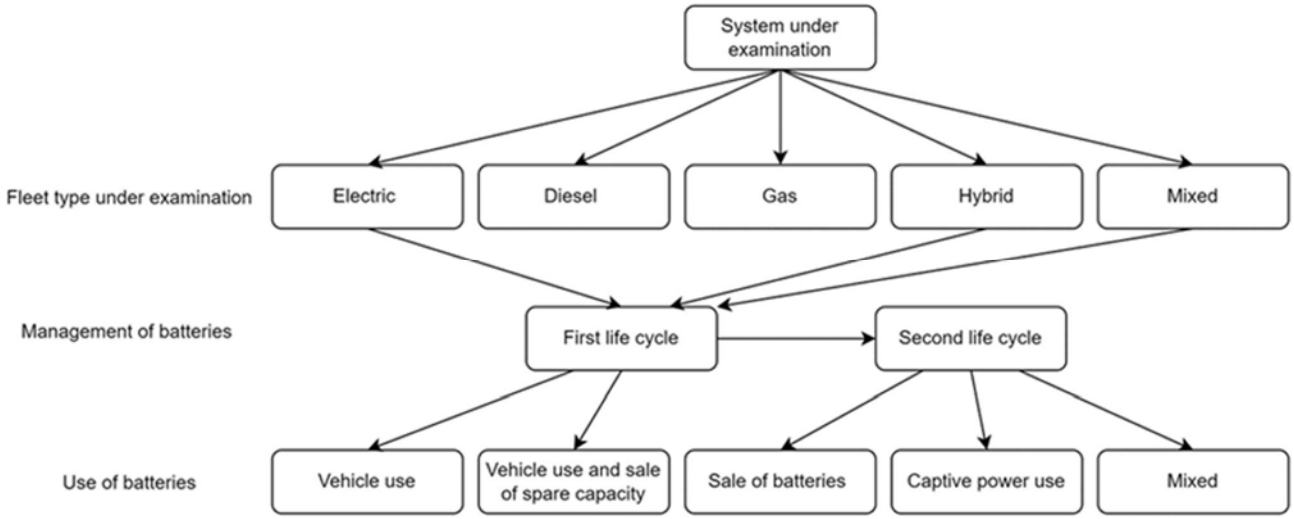

Figure 6 Description of testable system variants

4.2 Description of the decision-making method

The decision-making method is used to determine the type of fleet to be operated under predefined conditions, in the following steps:

1. Determining requirements for fleet utilization

In this section the requirements to be met in the operation of the fleet are specified, the most important of which are the following:

- average ambient temperature and fluctuations in it,
- the expected average speed of vehicles,
- expected mileage,
- available resources,
- environmental requirements,
- infrastructure available and capable of being developed for operation.

2. Determining the number of vehicles to be purchased

Determination of the number of vehicles needed to cover the forecast mileage and to provide an adequate level of service.

3. Determining the types of vehicles to be tested

In this step, the types of fleet that meet the requirements in Step 1 are selected. In essence, the analysis will select the variant most suitable for the company's needs.

4. Determining the decision criteria

A fundamental problem with many assessment methods is that they only make cost-based comparisons, without taking into account other factors such as quality and subjective considerations. When applying the decision-making method we have developed, the following aspects may need to be considered:

- Total Cost of Ownership (TCO),
- Carbon footprint indicator,
- Customer satisfaction factor.

5. Normalisation of objective function values

6. Selection of the type of fleet to be purchased

4.2.1 Total Cost of Ownership

This is the sum of the capital expenditure (CAPEX) used to acquire the vehicle, and its associated operating expenses (OPEX). The model does not take inflation and depreciation into account, as these two factors impact equally on the economic rates of return for both electric buses and diesel buses. The definitions in the literature do not take into account the potential second life cycle of batteries, which in business practice is increasingly becoming a cost-reducing factor. Accordingly, the TCO for the fleet type under consideration should be defined as follows.

Capital expenditure for the period under examination (1):

$$C_i^{CAP} = C_i^{AM_v} + C_i^{AM_I} - R_i^{II} - R_i^{O} \qquad (1)$$

in which:

- $C_i^{AM_v}$: the present value of the amortised cost of vehicles in fleet type *i*,
- $C_i^{AM_I}$: the present value of the amortised cost of the infrastructure for fleet type *i*,
- R_i^{II}: present value of the additional revenue from the second life cycle of the batteries of the vehicles in fleet type *i*,
- R_i^{O}: present value of the revenue from the sale of vehicles in fleet type *i* and related infrastructure.

Operating expenses for the period under examination (2):

$$C_i^{OP} = C_i^{OP_M} + C_i^{OP_F} + C_i^{OP_S} + C_i^{OP_o} \quad (2)$$

in which:

- $C_i^{OP_M}$: the present value of the maintenance costs for fleet type *i*,
- $C_i^{OP_F}$: the present value of the fuel costs for fleet type *i*,
- $C_i^{OP_S}$: the present value of the wage costs associated with fleet type *i*,
- $C_i^{OP_M}$: the present value of other costs (road tolls, parking fees, etc.) associated with fleet type *i*.

Total life cycle cost for the period under consideration (3):

$$C_i^{TCO} = C_i^{CAP} + C_i^{OP} \quad (3)$$

4.2.2 Carbon footprint indicator

This indicator expresses the amount of carbon dioxide equivalent greenhouse gases associated with the production and subsequent operation of a fleet associated with a given vehicle type over the period under examination. This is an important indicator from a sustainability point of view, and is denoted as CF_i for fleet type *i*.

4.2.3 Customer satisfaction factor

This is a subjective indicator that expresses the expected customer satisfaction for a given fleet type, for example, amenities provided, reliability of vehicle type. The indicator is defined on the basis of a survey of service users, and is denoted by CS_i for fleet type *i*. For this indicator, values range from 1 to 10 (10 being the best rating).

4.2.4 Normalisation of objective function values

In this step, the values of the decision criteria relevant to the decision are determined and then normalized. During normalisation, the defined values are transformed so that they fall between 0 and 1, allowing them to be included in the objective function.

Full life cycle cost normalisation (4), (5):

$$C^{TCO(max)} = \max_i \{C_i^{TCO}\} \quad (4)$$

$$\alpha_i^1 = C_i^{TCO} / C^{TCO(max)} \quad (5)$$

Normalization of carbon footprint indicator (6), (7):

$$CF^{(max)} = \max_i \{CF_i\} \quad (6)$$

$$\alpha_i^2 = CF_i / CF^{(max)} \quad (7)$$

Customer satisfaction factor normalization (8), (9):

$$CS^{(max)} = \max_i \{CS_i\} \quad (8)$$

$$\alpha_i^3 = 1 - CS_i / CS^{(max)} \quad (9)$$

4.2.5 Selection of the types of fleet to be purchased

In this step, the experts from the company under consideration need to determine the weighting of each of the assessment criteria in order of importance (the sum of these should be 1, as shown in the following). Following this, the weighted sum of the components of the normalised objective function is formed, whereby the fleet type with the minimum value is the most appropriate choice for the company's criteria.

Determination of the weights of the objective function components (10), (11):

$$0 \leq \partial_h \leq 1 \quad (10)$$

$$\sum_{h=1}^{3} \partial_h = 1 \quad (11)$$

Determination of objective function (12):

$$F = \min_\gamma \sum_{h=1}^{3} \partial_h \cdot \alpha_\gamma^h \quad (12)$$

4.3 Application of the decision-making method

The system under examination relates to the operation of a mixed fleet of electric and diesel buses in Hungary's largest public transport bus company. The aim of the study is to select the fleet that best fits the company's criteria for the future under the given circumstances. Based on a preliminary assessment, the company's requirements are met by two types of fleet: one diesel and one electric.

For the purposes of the decision-making method described in the previous section, only the whole life cycle cost was considered, assuming that, based on this indicator alone, the electric bus is the better choice (the carbon footprint for the electric bus is clearly better, and in terms of customer satisfaction there is no significant difference between the options). For reasons of company confidentiality, a large amount of factual data cannot be published, but the following general conclusions can be drawn:

- the cost of batteries accounts for almost 50% of the price of the electric buses to be purchased, but this is expected to decrease in the future,
- the expected daily mileage performance for the vehicles is 300 km, for which a capacity of about 300-320 kW is necessary. Thus, in the case of a 400 kW battery, a maximum degradation of 25% is acceptable.
- empirical measurements show that the average consumption of electric buses is 1 kWh/km,
- the second life cycle of batteries after degradation is a significant factor in reducing costs/increasing revenue,
- degradation measurements show that batteries are being phased out of vehicles after 6–8 years due to capacity loss, while the significant remaining capacity can be used in the second life cycle,

- maintenance costs for electric buses are about half those of diesel buses.

The TCO value for the second life cycle of batteries has been determined for the two fleet types, and is shown in Figure 7.

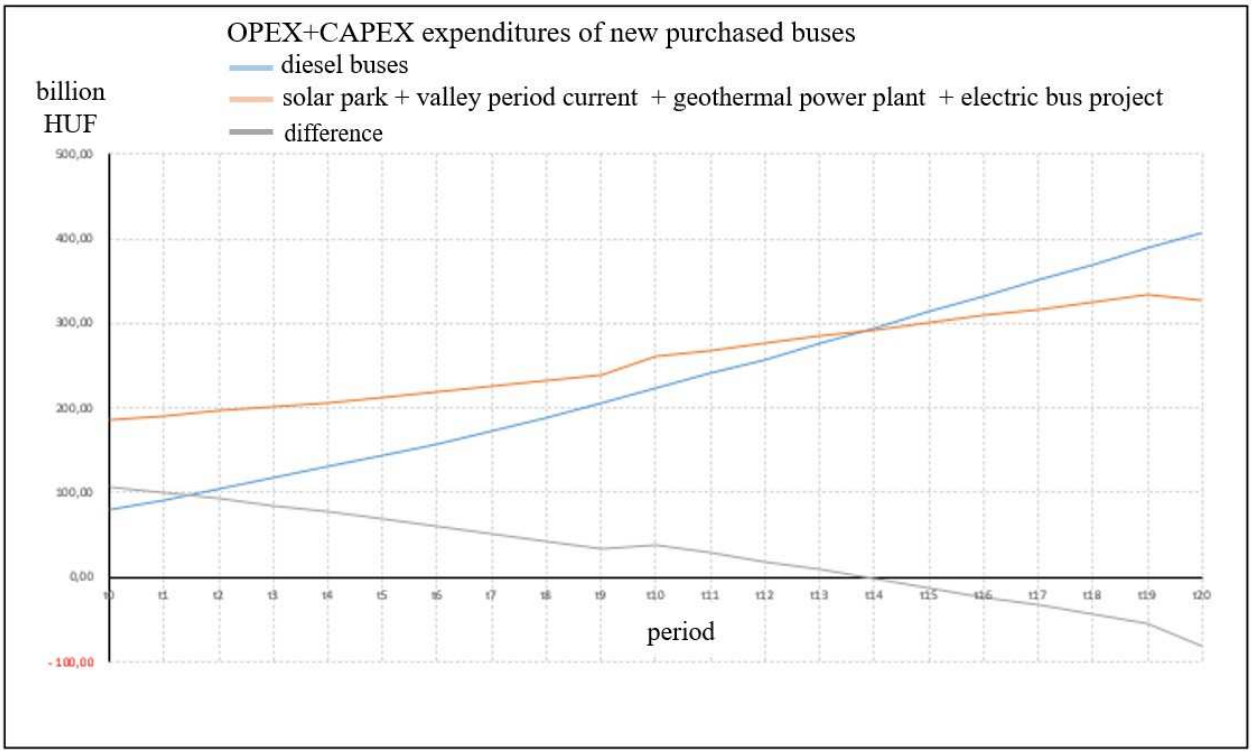

Figure 7 TCO comparison of electric and diesel buses (source Volánbusz Zrt.)

It can be seen, that for the fleet types studied, the use of electric buses is more advantageous for the company after 12.4 years. Of course, the fact, that the carbon footprint of electric buses is preferable to their diesel counterparts and that there is no significant difference in terms of customer satisfaction, adds weight to the decision.

5 Conclusion

The proliferation of electric vehicles in transportation can be considered a lasting and irreversible trend, reinforced by legislation and environmental expectations formed in the wake of the European Union's climate protection efforts. The bus fleet of Volánbusz Zrt., operating in Hungary, is already considered a so-called mixed fleet. The proportion of electric buses used in scheduled services, currently at 0.9%, is expected to reach 50% by 2032. The operation of electric buses increasingly emphasizes the importance of batteries' capacity, lifespan, and aging process (degradation). Therefore, Volánbusz Zrt. is already focusing on implementing a recycling strategy that significantly affects sustainable operation, including the planning of the second life cycle of lithium-ion batteries. As a result of a detailed literature analysis in the paper, we determined that the ideal fleet selection process lacks several relevant components, leading to erroneous decision-making. Among these factors are the consideration of batteries' secondary life cycle, sustainability, and logistics. A general and innovative decision-making method have been developed that addresses these deficiencies in selecting the appropriate fleet type. The method's correctness was verified through a case study using data from Volánbusz Zrt. In the next phase of our research, it is planned to develop innovative operational models related to the secondary life cycle of batteries.

References

[1] VALENTI, G., LIBERTO, C., LELLI, M., FERRARA, M.: *The impact of battery electric buses in public transport*, 2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe), 2017. http://dx.doi.org/10.1109/EEEIC.2017.7977517

[2] VERBRUGGE, B., HASAN, M.M., RASOOL, H., GEURI, T., EL BAGHDADI, M., HEGAZY, O.: Smart Integration of Electric Buses in Cities: A Technological Review, *Sustainability*, Vol. 13, No. 21. p. 12189, pp. 1-23, 2021. https://doi.org/10.3390/su132112189

[3] LI, L., LO, H.K., XIAO, F.: Mixed bus fleet scheduling under range and refueling constraints, *Transportation*

Research Part C: Emerging Technologies, Vol. 104, pp. 443-462, 2019. https://doi.org/10.1016/j.trc.2019.05.009

[4] KRUCHINA, V.: The possibility of electrification in public transport bus services, *Acta Technica Jaurinensis*, Vol. 16, No. 4, pp. 158-166, 2023. https://doi.org/0.14513/actatechjaur.00713

[5] Editorial: Lithium-ion battery technology in e-buses, according to BMZ Poland, *Sustainable Bus*, [Online], Avalilable: https://www.sustainable-bus.com/news/bmz-poland-lithium-ion-battery-technology-electric-buses/ [13 Mar 2024], 2021.

[6] PREGER, Y., BARKHOLTZ, H.M., FRESQUEZ, A., CAMPBELL, D.L., BENJAMIN, W.J., ROMÀN-KUSTAS, J., FERREIRA, S.R., CHALAMALA, B.: Degradation of commercial lithium-ion cells as a function of chemistry and cycling conditions, *Journal of the Electrochemical Society*, Vol. 167, No. 12, p. 120532, pp. 1-9, 2020. https://doi.org/10.1149/1945-7111/abae37

[7] MCGRATH, T., BLADES, L., EARLY, J., HARRIS, A.: UK battery electric bus operation: Examining battery degradation, carbon emissions and cost, *Transportation Research Part D: Transport and Environment*, Vol. 109, p. 103373, pp. 1-19, 2022. http://doi.org/10.1016/j.trd.2022.103373

[8] WANG, Y., HUANG, Y., XU, J., BARCLAY, N.: Optimal recharging scheduling for Urban Electric Buses: A case study in Davis, *Transportation Research Part E: Logistics and Transportation Review*, Vol. 100, pp. 115-132, 2017. http://doi.org/10.1016/j.tre.2017.01.001

[9] HAN, X., LU, L., ZHENG, Y., FENG, X., LI, Z., LI, J., OUYANG, M.: A review on the key issues of the lithium ion battery degradation among the whole life cycle, *eTransportation*, Vol. 1, No. August, p. 100005, 2019. http://doi.org/10.1016/j.etran.2019.100005

[10] HOMAN, J.: Description of a S-N Curve, *Fatec Engineering*, [Online], Avalilable: https://www.fatec-engineering.com/2018/02/20/description-of-a-s-n-curve/ [11 Mar 2024], 2018.

[11] CHEN, L., TIAN, B., LIN, W., JI, B., LI, J., PAN, H.: Analysis and prediction of the discharge characteristics of the lithium–ion battery based on the Grey System theory, *IET Power Electronics*, Vol. 8, No. 12, pp. 2361-2369, 2015. http://doi.org/10.1049/iet-pel.2015.0182

[12] TSENG, K.-H., LIANG, J.-W., CHANG, W., HUANG, S.-C.: Regression models using fully discharged voltage and internal resistance for state of health estimation of lithium-ion batteries, *Energies*, Vol. 8, No. 4, pp. 2889-2907, 2015. http://doi.org/10.3390/en8042889

[13] O'KANE, S.E.J., AI, W., MADABATTULA, G., ALONSO-ALVAREZ, D., TIMMS, R., SULZER, V., EDGE, J.S., WU, B., OFFER, G.J., MARINESCU, M.: Lithium-ion battery degradation: How to model it, *Physical Chemistry Chemical Physics*, Vol. 24, No. 13, pp. 7909-7922, 2022. http://doi.org/10.1039/D2CP00417H

[14] HUSCROFT, J.R., HAZEN, B.T., HALL, D.J., SKIPPER, J.B., HANNA, J.B.: Reverse logistics: past research, current management issues, and future directions, *The International Journal of Logistics Management*, Vol. 24, No. 3, pp. 304-327, 2013. https://doi.org/10.1108/IJLM-04-2012-0024

[15] HAO, H., SUN, Y., MEI, X., ZHOU, Y.: Reverse Logistics Network Design of Electric Vehicle Batteries considering Recall Risk, *Mathematical Problems in Engineering*, Vol. 8, pp. 1-16. 2021. http://doi.org/10.1155/2021/5518049

[16] YÜKSELTÜRK, A., WEWER, A., BILGE, P., DIETRICH, F.: Recollection center location for end-of-life electric vehicle batteries using fleet size forecast: Scenario analysis for Germany, *Procedia CIRP*, Vol. 96, No. 27, pp. 260-265, 2021. http://doi.org/10.1016/j.procir.2021.01.084

[17] AZADNIA, A.H., ONOFREI, G., GHADIMI, P.: Electric vehicles lithium-ion batteries reverse logistics implementation barriers analysis: A TISM-MICMAC approach, *Resources Conservation and Recycling*, Vol. 174, No. 1, pp. 1-15, 2021. http://doi.org/10.1016/j.resconrec.2021.105751

[18] HARRIS, A., SOBAN, D., SMYTH, B.M., BEST, R.: Assessing life cycle impacts and the risk and uncertainty of alternative bus technologies, *Renewable and Sustainable Energy Reviews*, Vol. 97, pp. 569-579, 2018. https://doi.org/10.1016/j.rser.2018.08.045

[19] JEFFERIES, D., GÖHLICH D.: A Comprehensive TCO Evaluation Method for Electric Bus Systems Based on Discrete-Event Simulation Including Bus Scheduling and Charging Infrastructure Optimisation, *World Electric Vehicle Journal*, Vol. 11, No. 3, pp. 1-43, 2020. https://doi.org/10.3390/wevj11030056

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Effects of material master data management on supply chain performance at FLSmidth: the moderating role of PiLog external service provider
Elmarie V. D. Merwe, Noleen N. Pisa, Enock Musau Gideon, Chengete Chakamera

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Effects of material master data management on supply chain performance at FLSmidth: the moderating role of PiLog external service provider

Elmarie V. D. Merwe
University of Johannesburg, Department of Transport and Supply Chain Management, PO Box 524-2600, South Africa, elnarnia@gmail.com
Noleen N. Pisa
University of Johannesburg, Department of Transport and Supply Chain Management, PO Box 524-2600, South Africa, noleenp@uj.ac.za
Enock Musau Gideon
University of Johannesburg, Department of Transport and Supply Chain Management, PO Box 524-2600, South Africa, emusau@uj.ac.za (corresponding author)
Chengete Chakamera
University of Johannesburg, Department of Transport and Supply Chain Management, PO Box 524-2600, South Africa, cchakamera@uj.ac.za

Keywords: supply chain performance, logistics, service provider, material master data management, moderating role.
Abstract: In the dynamic landscape of industrial operations, the effective management of material master data within the supply chain is paramount for organizational success. This study investigates the challenges and solutions associated with Material Master Data Management (MMDM) at FLSmidth (FLS), a leading supplier in the cement and mining sectors. FLS operates within a complex and diverse supply chain environment, serving global clientele across various sectors. The study aims to understand the impact of MMDM implementation on supply chain performance at FLS, specifically focusing on performance metrics such as inventory turnover, order fulfillment accuracy, and lead time reduction. The moderating role of PiLog, an External Service Provider (ESP), is explored in this context. Employing a mono-qualitative approach, the study delves into MMDM implementation through in-depth interviews with 18 FLS employees and 4 PiLog customers. Thematic analysis reveals that well-implemented MMDM systems enhance visibility, planning, and inventory management, leading to improvements in supply chain performance. Challenges in stakeholder persuasion and infrastructure access are identified as common implementation hurdles. PiLog emerges as a crucial moderator, providing structured frameworks, emphasizing standardization, and addressing governance challenges. The findings underscore the importance of strategic partnerships between organizations and ESPs in successfully implementing and sustaining MMDM initiatives. Recommendations include strategies for overcoming infrastructure challenges, leveraging ESP expertise, and aligning with best practices in standardization and governance. This study contributes to the academic discourse on MMDM implementation and offers practical insights for organizations seeking to enhance supply chain performance through meticulous MMDM practices.

1 Introduction

In industrial operations, the management of material flows, information flows, and financial flows within the supply chain is the foundation of organizational triumph, ensuring a smooth flow of materials, information, and services from suppliers to end-users in enhancing value addition [1]. Supply chain performance (SCP) refers to how effectively and efficiently a supply chain achieves its goals, including metrics such as inventory turnover, order fulfillment accuracy, and lead time reduction. The Resource-Based View (RBV) theory emphasizes that organizations can achieve superior competitive advantages by effectively managing their internal resources, including material master data (MMDM), alongside their capabilities and competencies [2]. Material master data (MMDM) consists of critical information related to materials, such as specifications, inventory levels, and procurement details, which are essential for smooth supply chain operations and overall performance. FLSmidth (FLS), a prominent supplier offering engineering, equipment, and services to the global cement and mining sectors, operates within a notably intricate and diverse supply chain environment [3]. Given its expansive operations and extensive range of industrial products and services, including centrifugation, classification, crushing, filtration, and milling, the RBV theory underscores MMDM as a crucial resource for maintaining supply chain performance and enhancing overall operational performance, thereby reinforcing FLS's competitive advantage [4].

Inconsistencies or inefficiencies in MMDM can disrupt procurement, production, and distribution activities, impacting organizational performance [5]. The lack of integrated MMDM practices due to historical mergers and acquisitions has led to fragmented product information management, disrupting procurement, production, and distribution activities. This disarray manifests in duplicate data records, increased risk of fraud, suboptimal inventory

control, and reduced operational efficiency, particularly in FLS's logistics operations. However, a critical challenge underlying this complexity is the efficient management of material master data (MMDM). The relevance of MMDM is underscored by the challenges FLS faces in harmonizing material master data across its global operations. From an RBV perspective, the fragmentation of MMDM due to historical mergers and acquisitions represents a missed opportunity to leverage this strategic resource effectively, leading to inefficiencies in procurement, production, and distribution activities [6].

This study addresses the critical challenge of managing MMDM within FLS's complex supply chain**.** The absence of a unified MMDM framework at FLSmidth has led to significant inefficiencies in supply chain performance, negatively impacting the company's competitive edge in the global market. By applying the RBV framework, this research explores how MMDM can be optimized to strengthen FLS's internal capabilities, resulting in enhanced supply chain performance and sustained competitive advantage. The theoretical contribution of this study lies in its application of the RBV theory to MMDM within a complex industrial setting like FLSmidth, filling a gap in the literature on how strategic internal resources, such as MMDM, can be harnessed to improve supply chain performance. Practically, it guides the implementation of MMDM practices that align with FLS's broader organizational goals, ensuring that the company remains competitive in the global market. This study also extends the RBV theory by illustrating how external service providers, like PiLog, can moderate the relationship between internal resources and competitive advantage, thereby offering a more comprehensive understanding of how organizations can optimize their resource management strategies.

Organizations must diligently monitor and evaluate their integration strategies to ensure effectiveness and maximize their benefits [7]. Firms must focus on developing innovative manufacturing models and accessing capabilities for managing new technologies to enhance value creation, including financial management aspects such as cost and profit [8]. The emphasis creates the necessity of this broad and deep understanding to gain economic benefits within the logistics chain [9].

Consequently, the supply chain performance within FLS are marred by inefficiencies stemming from poor material master data management. Duplicate data records, increased risk of fraud, suboptimal inventory control, and reduced operational efficiency have become common challenges in logistics. The complexity of logistics increases the risks faced by enterprises, exposing them to various challenges such as natural disasters, geopolitical tensions, operational issues, and cybersecurity threats. This highlights the urgent need for stability and reliability across all levels of logistics. To achieve this, a comprehensive framework is essential for identifying, assessing, and mitigating risks, with a focus on proactive strategies to address potential disruptions and reduce their impact [10]. These challenges not only affect profits but also diminish customer satisfaction and loyalty in the context of market competitiveness [11]. From this standpoint, these processes necessitate enhanced logistics service management alongside an integrated approach, merging process integration for assessing satisfaction and identifying potential risks that could hinder the delivery of satisfactory logistics services. In this complex scenario, the importance of thoroughly understanding (MMDM) implementation and its influence on supply chain performance applied in logistics becomes a crucial concern.

This urges the investigation of efficient solutions to improve FLS's supply chain efficiency and overall operational effectiveness. Therefore to improve supply chain performance, companies should implement sustainable methods that reduce logistics expenses while increasing financial returns, specifically by decreasing lead times and boosting inventory turnover. This approach will significantly enhance the profitability of firms [12].

Implementing robust MMDM practices is akin to administering a precise remedy to the challenges faced by organizations like FLSmidth (FLS) in their supply chain performance. A well-coordinated MMDM strategy guarantees the uniformity, precision, and thoroughness of material master data, thereby addressing the inconsistencies and inefficiencies that disrupt supply chain operations [13]. By establishing clear naming conventions, such as standardizing the format for product codes, and codification standards, like adopting a universal coding system for materials, as well as data governance policies, which include regular audits and data validation procedures**,** help organizations harmonize their material master data across disparate systems. This fosters seamless communication and collaboration between various departments [14,15].

Automation of data cleaning processes and part description creation further eliminates manual errors, reducing delays and streamlining supply chain workflows. Through MMDM, organizations can optimize inventory management, enhance procurement accuracy, and minimize the risk of errors in production and distribution processes [16]. A comprehensive and accurate material master data repository is crucial for organizations to make informed decisions, enhance customer service, and secure a competitive advantage in a highly competitive market. In recent years, many organizations have increasingly focused on quality as a sustainable competitive strategy to stay ahead [17].

Globally, several approaches have been adopted to tackle material master data management challenges and enhance organizational supply chain performance by addressing the primary obstacles organizations face when integrating master data to achieve successful MDM adoption [18]. One prevalent approach involves the implementation of standardized data quality frameworks

such as ISO 8000. ISO 8000, the international data quality standard developed by organizations like PiLog, provides guidelines and best practices for data quality management, ensuring that material master data adheres to globally accepted standards [19]. By aligning with ISO 8000, organizations can establish a common language for data quality, enabling seamless data exchange and integration across supply chain partners. This standardization promotes interoperability, reduces data discrepancies, and fosters collaboration, thereby optimizing supply chain performance [20].

Moreover, use of technologies such as Machine Learning (ML) and Artificial Intelligence (AI) has revolutionized MMDM practices and acts as a transformative force, influencing diverse aspects of contemporary society by allowing systems to learn and evolve from data [21]. AI-powered algorithms can automatically cleanse, enrich, and classify material master data, detecting patterns and inconsistencies that might be missed by manual processes [22]. These technologies not only enhance data accuracy but also enable predictive analytics, allowing organizations to foresee demand patterns, optimize inventory levels, and enhance supplier relationships. Blockchain technology is another innovative solution that enhances transparency and traceability in the supply chain. By implementing Blockchain-based MMDM systems, organizations can create an immutable record of material master data transactions, ensuring data integrity and authenticity throughout the supply chain [23]. This heightened level of transparency reduces the risk of counterfeit products, enhances trust between supply chain partners, and improves overall supply chain performance. Blockchain-based models can provide a secure and transparent record of all supply chain transactions and activities. This transparency allows participants to identify potential issues and inefficiencies, minimize waste and delays, and enhance collaboration and communication [24].

Additionally, the adoption of cloud-based MMDM solutions has gained traction in recent years. Cloud platforms offer scalable and flexible MMDM services, allowing organizations to centralize their material master data in secure, easily accessible repositories and have emerged as an approach to improving the operations of manufacturing organizations [25]. Cloud-based MMDM systems facilitate real-time data updates, collaboration, and data sharing among geographically dispersed teams and supply chain partners [26]. The flexibility of these solutions enables organizations to adapt swiftly to changing market demands and scale their logistic operations without the constraints of traditional on-premise systems by facilitating the production flow of various items employed in discrete batch manufacturing processes, such as those found in the aerospace sector [27]. Cloud-based MMDM solutions enhance supply chain agility, enabling organizations to respond promptly to market trends, customer demands, and supply chain disruptions.

Moreover, fostering a culture of continuous improvement and data stewardship within organizations is integral to effective MMDM. Training human capital, suppliers, and other stakeholders on the importance of information management quality, governance, and compliance encourages proactive data management practices [28]. Defining the distinct contribution of logistics elements and responsibilities for data stewardship ensures consistent review, updates, and validation of material master data. Regular financial management audits and performance metrics enable organizations to gauge the efficacy of their MMDM initiatives, pinpoint areas for enhancement, and adapt strategies accordingly [29]. Encouraging a culture centered on information flow management and equipping individuals with the expertise and tools for proficient material master data management fosters sustained high logistic information quality. This approach optimizes supply chain performance, fostering enduring operational excellence.

Meanwhile, MMDM external service providers (ESPs), like PiLog, offer expertise in post-merger data harmonization. PiLog, a global provider established in 1978, specializes in data cleaning, classification, governance, and material criticality analysis. These providers offer specialized expertise and advanced tools tailored to the unique challenges faced by organizations like FLSmidth (FLS). By leveraging their knowledge and industry best practices, MMDM ESPs help establish robust frameworks aligned with international standards such as ISO 8000, ensuring that material master data is consistent, accurate, and compliant. For instance, PiLog, a reputable MMDM ESP, has developed tools and processes compliant with ISO 8000 standards, offering services like data cleaning, classification, and material criticality analysis [30].

Additionally, MMDM ESPs often provide sophisticated software solutions powered by AI and ML. These tools automate data cleaning, classification, and enrichment processes, enhancing the accuracy and completeness of material master data. Automation reduces manual errors, optimizes inventory levels, and improves demand forecasting, leading to more efficient material flow processes. Standardized data models, as advocated by ISO 8000, promote interoperability, reduce data discrepancies, and foster collaboration, enhancing supply chain efficiency and communication across international boundaries among logistics organizations [31].

Continuous support and maintenance provided by MMDM ESPs are instrumental in ensuring the longevity and effectiveness of MMDM implementations. Regular updates, training sessions, and consultations empower logistics organizations to adapt swiftly to market changes. This ongoing support ensures that supply chain performance remain agile and responsive to dynamic market demands, response to consumer needs enhancing overall operational efficiency [32,33]. However, organizations must carefully assess the selected ESP's

solutions and certifications to mitigate concerns about logistics data security and confidentiality. Adequate data protection measures are crucial to maintaining the integrity essential to guarantee the safety of the increasing use of ICT systems across various elements of logistics [34]. Logistics operations involve the entire process of producing and distributing a product or service, beginning with the acquisition and flow of raw materials and culminating in the final flow to the ultimate customer [35]. Therefore Measures for data protection and information security should be implemented throughout all supply chain activities. The transparency and traceability at each stage determine the achievable level of security [36].

In the competitive landscape of the cement and mining industries, FLSmidth has emerged as a global leader, providing innovative engineering solutions, equipment, and services to its clients worldwide. The company's expansive growth is evident through its presence in more than 50 offices globally, catering to the demands of the ever-evolving market. FLSmidth's success can be attributed to its dedication to providing sustainable productivity to its clientele is attained through an extensive range of industrial products and services in its portfolio. With expertise in key areas such as centrifugation, crushing, milling, and grinding, Tumbling mills are extensively used across various industries for grinding bulk materials [37]. FLSmidth has demonstrated performance excellence in the sectors it serves.

However, alongside its successes, FLSmidth, like many companies in the engineering and mining sectors, faces challenges inherent to these industries. Fluctuating commodity prices, economic uncertainties in different regions, and evolving environmental regulations pose ongoing challenges [38]. Additionally, managing a global supply chain in these sectors demands precision, safety, and efficiency. Sustaining uniformity and precision in material master data (MMD), incorporating descriptions and qualities of all acquired, manufactured, and stocked materials is crucial. Material Master Data refers to all the core information required to manage specific items within a supply chain, such as part numbers, descriptions, technical specifications, and stock codes. This data is central to logistics processes in a firm’s basic information management system Inadequate management of material master data can lead to inefficiencies, errors, and disruptions within the supply chain, impacting the company's overall operational performance. It can result in product returns and customer complaints, reduce the efficiency of supply chain operations, and endanger the level of stock [39,40].

The significance of addressing these challenges is underscored by the complexity of modern business operations. In this context, the implementation of Material Master Data Management (MMDM) practices becomes pivotal. MMDM involves standardizing and centralizing material master data elements, ensuring accuracy, consistency, and completeness. Effective MMDM practices streamline supply chain performance, optimize inventory management, and enhance operational efficiency.

Furthermore, integrating an external service provider like PiLog, an established player in the field, can significantly enhance the impact of MMDM implementation. PiLog, with its expertise in data cleaning, classification, master data governance, and material criticality analysis, aligns its services with international data quality standards such as ISO 8000. In today's data-driven world, organizations are increasingly acknowledging the crucial importance of Master Data Management (MDM) and Data Quality for improving business performance [41].

Considering the challenges faced by FLSmidth in its supply chain performance and the potential benefits offered by robust MMDM practices, studying how the management of MDM is implemented as the ability of the system to handle huge volumes of data as the business expands [42], and evaluating the moderating role of PiLog as an external service provider becomes imperative. Such a study can provide valuable insights into enhancing supply chain performance, ensuring data accuracy, completeness, and fostering sustainability in FLSmidth's logistics operations [43]. Additionally, understanding the dynamics of this implementation within the specific context of FLSmidth can contribute to broader knowledge in the field, offering practical implications for similar companies in the engineering and mining sectors.

2 Literature review

2.1 Master Data and Master Data Management

Master data, as outlined by [44], comprises vital entities within an organization, encompassing not just the entities themselves but also their definitions, classifications, and terminology that serve as the foundation of business information. Effectively gathering, managing, and utilizing data has become a crucial determinant of business success [45]. These essential reference data, such as the customers, chart of accounts, materials, and vendors play a critical role in preserving transactional integrity, aiding analysis, and ensuring compliance. Historically, master data management (MDM) evolved alongside advancements in technology, transitioning from flat data files to centralized computing systems [46]. Organizations began recognizing the significance of MDM, storing critical business data, including customer information, products, services, and supplier details [47].

Gartner Group's contributions, emphasizing MDM as both a technical and organizational challenge, underscored the multifaceted nature of MDM [48]. MDM, as a technology-driven discipline, aims to establish distinct identifiers for data entities like customers, suppliers, and products, facilitating unified data management [49]. The core of MDM lies in establishing an authoritative, precise, and singular source of organizational information assets [50,51]. This emphasis on data quality and governance is

crucial for ensuring supply chain performance**,** particularly in terms of operational efficiency and agility. The MDM model outlined by [52] includes content, systems, processes, governance, and establishing a strategic framework for proficient master data management.

The Resource-Based View (RBV) theory provides a robust theoretical foundation for understanding how master data and MDM can serve as valuable resources contributing to a firm's competitive advantage. According to RBV, resources that are valuable, rare, inimitable, and non-substitutable (VRIN) are crucial for sustaining a competitive edge. In the context of MDM, accurate and well-maintained master data can be seen as a strategic asset that enhances supply chain performance through metrics such as inventory turnover, order fulfillment accuracy, and lead time reduction. Previous research has applied RBV to explore how organizations leverage their data management capabilities to achieve superior performance. For instance, [54] examined the impact of master data management (MDM) on organizational performance through the Resource-Based View (RBV) theory. It posited that accurate master data is a critical resource characterized by value offering the strategic role of MDM in improving decision-making and operational efficiency.

Similarly, [55] investigated the impact of master data management (MDM) in enhancing supply chain performance, employing the Resource-Based View (RBV) theory. The study revealed how effective management of master data can influence supply chain efficiency and effectiveness. The study highlighted that well-managed master data serves as a critical resource, contributing to superior supply chain performance and providing a competitive edge.

However, there is a gap in the literature regarding the specific mechanisms through which MDM contributes to competitive advantage, particularly in the context of global supply chains. This study aims to address this gap by examining the role of MDM as a strategic resource in enhancing supply chain performance, drawing on the principles of RBV.

2.2 Material Master Data and MMDM in supply chain

Material master data management (MMDM) focuses specifically on materials an organization procures, produces, and stocks. Effective MMDM ensures standardized, accurate, and consistent material data, laying the foundation for streamlined supply chain operations. However, challenges in MMDM, especially within complex organizations like FLSmidth, require a nuanced approach. Implementing MMDM systems and addressing these challenges have far-reaching implications for supply chain performance.

The discussion on MMDM provides a comprehensive overview of its importance within modern business operations, especially within the domain of supply chain management. The authors aptly underline the critical role of well-maintained material master data in optimizing inventory, understanding material expenditure, and ultimately, ensuring efficient supply chain performance. The clear articulation of the historical evolution of Master Data Management (MDM) and its transition from flat data files to centralized computing systems adds depth to the discussion, establishing a solid foundation for understanding the complexities of MDM implementation.

2.3 The impact of MMDM on supply chain performance: the moderating role of PiLog external service provider

PiLog, an external service provider specializing in master data management, plays a crucial moderating role in the implementation of MMDM within organizations like FLSmidth. Their expertise and tools provide essential guidance, ensuring that MMDM practices align with industry standards and best practices. By moderating the implementation process, PiLog enhances the effectiveness of MMDM in optimizing supply chain performance. Investigating this moderating role in the context of FLSmidth is paramount, as it sheds light on how external service providers influence the outcome of MMDM initiatives, shaping the landscape of the supply chain performance within the organization.

Applying the RBV theory, PiLog's involvement can be interpreted as a strategic partnership that enhances the firm’s resource base. By providing specialized knowledge and technology, PiLog augments FLSmidth’s capabilities in managing material master data, thereby contributing to the firm’s competitive advantage. However, the literature has yet to thoroughly examine how such external collaborations influence the strategic value of MMDM. This study aims to address this gap by exploring the moderating role of PiLog in enhancing the strategic impact of MMDM within FLSmidth's supply chain, using RBV as a theoretical framework. The study also emphasizes how PiLog's involvement contributes to performance metrics such as lead time reduction, accurate order fulfillment, and inventory optimization, critical indicators of supply chain performance

However, while the importance of MMDM and the involvement of external service providers like PiLog are highlighted, the critique here lies in the lack of specific examples or case studies demonstrating the impact of MMDM, particularly within the context of FLSmidth. Providing concrete instances or real-life applications of MMDM implementation in organizations, especially in complex industrial settings like FLSmidth, would have strengthened the argument. Real-world examples would not only add credibility to the discussion but also offer practical insights into the challenges faced and the solutions implemented.

Furthermore, the moderating role of PiLog as an external service provider is briefly mentioned, but the nuances of their involvement are not elaborated upon. How exactly does PiLog navigate the unique challenges faced

by FLSmidth? What specific tools or strategies do they employ to moderate the implementation process effectively? These questions remain unanswered, leaving a gap in the understanding of PiLog's impact on MMDM within the organization.

3 Methodology

The research methodology adopted in this study, specifically focusing on the moderating role of PiLog External Service Provider (ESP), utilized a mono-qualitative approach. This choice was guided by the definition of qualitative research provided by [53], which describes it as a process of immersing oneself in the research to gain a deep understanding of the scenario. This approach is particularly well-suited for exploring the nuanced aspects of MMDM implementation, especially when considering the moderating influence. Additionally, the Resource-Based View (RBV) theory, which highlights the importance of an organization's internal resources and capabilities for achieving competitive advantage, further supports this exploration.

Despite potential criticisms of subjectivity in qualitative research [54], its appropriateness for this study lies in contextualizing MMDM within FLS through in-depth interviews, capturing participants' perspectives, and understanding the moderating role of PiLog.

The research questions were exploratory, centering on "What" and "How." Therefore, the exploratory approach was deemed necessary following suggestions by [55]. This study employed pragmatism; a philosophical approach selected to comprehend the implementation of MMDM in FLS under the moderating effects introduced by PiLog.

3.1 Research design

3.1.1 Units of analysis, population, and sampling

The study delved into MMDM implementation within FLS, PiLog, and PiLog's customer base, with a specific emphasis on PiLog's moderating role. We used purposive sampling to select participants whose data aligned with the study's objectives, focusing on the impact of PiLog on MMDM implementation. Non-probability purposive sampling ensured that FLS employees, PiLog Staff, and PiLog's customers met the study's criteria. A sample size of 25 respondents from FLS, 3 from PiLog, and 11 from PiLog's customer base was chosen considering the intricacies and complexities of MMDM.

3.1.2 Data collection

Data was collected through semi-structured interviews with 18 strategically selected employees from FLS and 4 of PiLog's main customers. The selection of employees was tactical, focusing on those involved in critical functions related to material master data management (MMDM), such as supply chain management, IT, and procurement, where they directly influence or manage the MMDM processes. Similarly, the customers selected were frequent or key customers who interact regularly with PiLog's services.

3.1.3 Data analysis

The data were analyzed using thematic analysis, which involved coding interview transcripts and identifying key themes related to MMDM and supply chain performance. The analysis, guided by the Resource-Based View (RBV) theory, focused on how FLS's internal resources, particularly MMDM, contribute to competitive advantage. Additionally, it explored how PiLog, as an external service provider, moderates these performance metrics, extending the RBV framework to include external factors in resource management. Patterns in interviewees' perceptions of PiLog's contributions were examined qualitatively to assess its moderating role in MMDM implementation.

3.1.4 Validity and reliability

Credibility was ensured through triangulation, aligning in-depth interviews with secondary data. Transferability was addressed as findings held general applicability to MMDM and supply chain performance, with a focus on the moderating role of PiLog. Dependability was established by rigorously conducting and aligning themes from literature with collected data. Objectivity (confirmability) was maintained through open and truthful reporting, preventing data misrepresentation [56].

The research methodology, guided by the research onion, aligned with the study's exploratory nature, emphasizing qualitative insights into MMDM implementation and its influence on supply chain performance in FLSmidth, with PiLog explicitly considered as a key moderating factor.

4 Results

4.1 Impact of Material Master Data Management (MMDM) implementation on supply chain performance in Flsmidth

The implementation of MMDM at FLSmidth, facilitated by PiLog, has demonstrated several positive impacts on supply chain performance, as supported by RBV theory**.** Enhanced visibility, better planning, reduced lead times, and increased stock availability contributed to improved inventory turnover, order fulfilment accuracy, and lead time reduction, key indicators of supply chain performance. These improvements align with RBV's assertion that strategic resources like MMDM can provide a competitive edge by optimizing internal processes and capabilities.

However, challenges emerged, particularly in convincing stakeholders of MMDM's value and accessing necessary databases and infrastructure. This deviation highlights a potential gap in the RBV application, where the expected seamless integration of internal resources (MMDM) was impeded by external factors like infrastructure and stakeholder resistance. This discrepancy

suggests that while RBV emphasizes the importance of internal resources, successful implementation also requires effective management of external constraints.

Standardization, as emphasized by PiLog, significantly contributed to improved supply chain performance. The implementation of Master Data Record Manager (MDRM), Structured Text Generation, and Technical Dictionary enhanced content quality and governance, which aligns with RBV's focus on leveraging resources for competitive advantage. Nonetheless, challenges in governance, such as integrating standardization practices within existing business structures, emerged as a notable issue. This finding underscores that while RBV provides a robust framework for understanding resource management, practical implementation may reveal additional complexities.

4.2 The moderating role of PiLog

PiLog's role as an External Service Provider (ESP) was instrumental in moderating MMDM implementation at FLSmidth. PiLog's structured frameworks and emphasis on standardization were crucial in overcoming challenges related to convincing stakeholders and accessing infrastructure. This supports RBV's perspective that external support can enhance the value derived from internal resources, aligning with the theory's assertion that strategic partnerships can optimize resource management.

PiLog's focus on governance and process management, particularly in data cleaning, played a significant moderating role. This involvement addressed some of the governance challenges faced by FLS, enhancing the effectiveness of MMDM implementation. The positive impact on visibility, planning, and inventory management reported by PiLog's customers further supports the RBV theory, demonstrating how effective external moderation can amplify the benefits of internal resources.

Unexpectedly, while PiLog's moderation improved MMDM outcomes, some issues persisted, such as stock visibility and planning inefficiencies at FLSmidth. These challenges indicate that external support alone may not fully address all internal resource management issues, highlighting a potential limitation in applying RBV solely focused on internal resources without considering the broader context.

5 Discussions

The study's findings demonstrate that Material Master Data Management (MMDM) at FLSmidth, supported by PiLog, aligns with the Resource-Based View (RBV) theory by enhancing visibility, planning, and inventory management, leading to improved supply chain performance. According to RBV, internal resources like MMDM can provide a competitive advantage if effectively managed [57]. At FLSmidth, the successful implementation of MMDM improved key performance metrics, reinforcing this theory. However, challenges related to stakeholder persuasion and infrastructure constraints reveal limitations of RBV, which assumes that internal resource management alone is sufficient for competitive advantage. This highlights the need to integrate RBV with additional frameworks to account for external influences on resource management.

The study further extends RBV by incorporating the moderating role of external service providers like PiLog. Traditionally, RBV focuses on leveraging internal resources for competitive advantage [58], but this study shows that external support can enhance the value of these resources. PiLog's structured frameworks and standardization practices addressed challenges such as stakeholder resistance, illustrating that strategic partnerships are essential for optimizing internal resource benefits. This finding offers a more nuanced understanding of RBV, emphasizing the role of external moderators in complex organizational settings.

Moreover, the study reveals that RBV alone cannot fully capture the complexities of MMDM implementation, as governance issues also play a crucial role.

Integrating Governance Theory with RBV provides a more comprehensive perspective on how internal resources and governance structures interact to influence supply chain performance. Practically, the study recommends strategic partnerships with external service providers to enhance MMDM, particularly in addressing stakeholder engagement and infrastructure challenges. It also suggests improving governance frameworks to optimize MMDM effectiveness and supply chain performance.

6 Conclusions

This study highlights the impact of Material Master Data Management (MMDM) on supply chain performance at FLSmidth, with PiLog, an External Service Provider (ESP), playing a moderating role. Utilizing the Resource-Based View (RBV) theory, the research frames MMDM as a strategic internal resource that enhances supply chain performance and competitive advantage. The study demonstrates that effective MMDM implementation improves visibility, planning, and inventory management, reinforcing FLS's competitive position. PiLog's external support further optimizes MMDM, illustrating the importance of strategic partnerships in maximizing internal resources.

However, the study also identifies limitations within the RBV framework, particularly in addressing external challenges like stakeholder persuasion, infrastructure access, and governance issues. These limitations suggest that RBV alone is insufficient for fully understanding the complexities of MMDM.For future research, integrating RBV with Governance and Institutional Theories is recommended to address both internal and external factors affecting MMDM. Governance Theory could explore how organizational structures influence resource management, while Institutional Theory could examine external pressures. Empirical studies on the long-term effects of ESPs like PiLog are also suggested to refine the theoretical

framework and improve MMDM practices across industries.

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References

[1] BULEJ, V., STOIANOVICI, G.V., POPPEOVA, V.: *Material flow improvement in automated assembly lines using lean logistics*, 22nd Annals of DAAAM & Proceedings, 23-26th November, Vienna, Austria, pp. 253-254, 2011.

[2] DREIBELBIS, A., HECHLER, E., MILMAN, I., OBERHOFER, M., VAN RUN, P., WOLFSON, D.: *Enterprise master data management: an SOA approach to managing core information*, Boston, Pearson plc as IBM Press, 2008.

[3] ISLAM, M., MONJUR, M., AKON, T.: Supply Chain Management and Logistics: How Important Interconnection is for Business Success, *Open Journal of Business and Management*, Vol. 11, pp. 2505-2524, 2023. https://doi.org/10.4236/ojbm.2023.115139

[4] WEI, C., YU, Y., XU, C., MAO, L., MENG, F.: *A Brief discussion on the standardized management of material master data in Enterprise Resource Planning system for engineering enterprises*, SHS Web of Conferences, 8th International Conference on Social Sciences and Economic Development (ICSSED 2023), Vol. 163, pp. 1-5, 2023. https://doi.org/10.1051/shsconf/202316302028

[5] MUNIR, M., JAJJA, M.S.S., CHATHA, K.A., FAROOQ, S.: Supply chain risk management and operational performance: the enabling role of supply chain integration, *International Journal of Production Economics*, Vol. 227, No. September, 107667, 2020.

[6] IMRAN, S.G.: The importance of supply chain integration in the performance nexus: A case from developing country, *South Asian Journal of Operations and Logistics*, Vol. 3, No. 2, pp. 1-21, 2024. https://doi.org/10.57044/SAJOL.2024.3.2.2426

[7] BUI, T.D., TSAI, F.M., TSENG, M.L., TAN, R.R., YU, K.D.S., LIM, M.K.: Sustainable supply chain management towards disruption and organizational ambidexterity: A data driven analysis, *Sustainable Production and Consumption*, Vol. 26, pp. 373-410, 2021. https://doi.org/10.1016/j.spc.2020.09.017

[8] BALOCH, N., RASHID, A.: Supply Chain Networks, Complexity, and Optimization in Developing Economies: A Systematic Literature Review and Meta-Analysis, *South Asian Journal of Operations and Logistics*, Vol. 1, No. 1, pp. 1-13, 2022. https://doi.org/10.57044/SAJOL.2022.1.1.2202

[9] HAJLI, N., TAJVIDI, M., GBADAMOSI, A., NADEEM, W.: Understanding market agility for new product success with big data analytics, *Industrial Marketing Management*, Vol. 86, pp. 135-143, 2020.

[10] AROWOSEGBE, O., OLUTIMEHIN, D., ODUNAIYA, O., SOYOMBO, O.: Risk Management in Global Supply Chains: Addressing Vulnerabilities in Shipping and Logistics, *International Journal of Management & Entrepreneurship Research*, Vol. 6, No. 3, pp. 910-922, 2024. https://doi.org/10.51594/ijmer.v6i3.962

[11] STEFANOVA, M.: *Integrating quality and risk management in logistics*, Intech Open, 2022. https://doi.org/10.5772/intechopen.103050

[12] LIU, H., WU, S., ZHONG, C., LIU, Y.: The Sustainable Effect of Operational Performance on Financial Benefits: Evidence from Chinese Quality Awards Winners, *Sustainability*, Vol. 12, No. 5, pp. 1-23, 2020. https://doi.org/10.3390/su12051966

[13] NG, S.T., XU, F.J., YANG, Y., LU, M.: A master data management solution to unlock the value of big infrastructure data for smart, sustainable, and resilient city planning, *Procedia Engineering*, Vol. 196, pp. 939-947, 2017.

[14] WITTEBROCK, T.: *Master data – Everyone Needs it, but No-one Wants to Maintain it*, SAP INFO international, September 15, 2003, [Online], Available: http://www.sap.info/goto/en/go/21299/ [10 Feb 2024], 2003.

[15] VERDANTIS: *The business benefits of material master data management*, White paper, 2010.

[16] CAMPBELL, J.L., RUSTAD, L.E., PORTER, J.H., TAYLOR, J.R., DERESZYNSKI, E.W., SHANLEY, J.B., BOOSE, E.R.: Quantity is nothing without quality: Automated QA/QC for streaming environmental sensor data, *BioScience*, Vol. 63, No. 7, pp. 574-585, 2013.

[17] YEBOAH, J., EWUR, G.D.: Quality customer service as a competitive advantage in the telecommunication industry in the Western Region of Ghana, *Journal of Education and Practice*, Vol. 5, No. 5, pp. 20-30, 2014.

[18] SILVOLA, R., JAASKELAINEN, O., KROPSU-VEHKAPERA, H., HAAPASALO, H.: Managing one master data – challenges and preconditions, *Industrial Management & Data Systems*, Vol. 111, No. 1, pp. 146-162, 2011.

[19] GUALO, F., RODRÍGUEZ, M., VERDUGO, J., CABALLERO, I., PIATTINI, M.: Data quality certification using ISO/IEC 25012: Industrial experiences, *Journal of Systems and Software*, Vol. 176, No. June, 110938, 2021.

[20] BECHTSIS, D., TSOLAKIS, N., IAKOVOU, E., VLACHOS, D.: Data-driven secure, resilient and sustainable supply chains: gaps, opportunities, and a new generalized data sharing and data monetization

framework, *International Journal of Production Research*, Vol. 60, No. 14, pp. 4397-4417, 2022.

[21] EMMANUEL, A., KLAUS, H.: *The Role of Artificial Intelligence (AI) and Machine Learning*, ResearchGate, [Online], Available: https://www.researchgate.net/publication/376830969_The_Role_of_Artificial_Intelligence_AI_and_Machine_Learning [10 Feb 2024], 2019.

[22] GE, Z.: *Artificial Intelligence and Machine Learning in Data Management*, The Future and Fintech, ABCDI and Beyond, Chapter 8, pp. 281-310, 2022. https://doi.org/10.1142/9789811250903_0008

[23] CENTOBELLI, P., CERCHIONE, R., DEL VECCHIO, P., OROPALLO, E., SECUNDO, G.: Blockchain technology for bridging trust, traceability and transparency in the circular supply chain, *Information & Management*, Vol. 59, No. 7, 103508, 2022.

[24] TURGAY, S., ERDOĞAN, S.: Enhancing Trust in Supply Chain Management with a Blockchain Approach, *Journal of Artificial Intelligence Practice*, Vol. 6, No. 6, pp. 56-64, 2023. https://doi.org/10.23977/jaip.2023.060609

[25] JAVAID, M., HALEEM, A., SINGH, R.P., SUMAN, R.: Enabling flexible manufacturing system (FMS) through the applications of industry 4.0 technologies, *Internet of Things and Cyber-Physical Systems*, Vol. 2, pp. 49-62, 2022. https://doi.org/10.1016/j.iotcps.2022.05.005

[26] DEMIRKAN, H., DELEN, D.: Leveraging the capabilities of service-oriented decision support systems: Putting analytics and big data in the cloud, *Decision Support Systems*, Vol. 55, No. 1, pp. 412-421, 2013.

[27] IVANOV, D., SETHI, S., DOLGUI, A., SOKOLOV, B.: A survey on control theory applications to operational systems, supply chain management, and Industry 4.0, *Annual Review of Control*, Vol. 46, pp. 134-147, 2018. https://doi.org/10.1016/j.arcontrol.2018.10.014

[28] ERYUREK, E., GILAD, U., LAKSHMANAN, V., KIBUNGUCHY-GRANT, A., ASHDOWN, J.: *Data Governance: The Definitive Guide*, O'Reilly Media, Inc., 2021.

[29] FRANK, L., MOHAMED, S.: *Evaluation and Performance Measurement: Discussing methods for evaluating the effectiveness of strategic plans and measuring organizational performance*, ResearchGate, [Online], Available: https://www.researchgate.net/publication/379270236_Evaluation_and_Performance_Measurement_Discussing_methods_for_evaluating_the_effectiveness_of_strategic_plans_and_measuring_organizational_performance#fullTextFileContent [05 Jun 2024], 2024.

[30] PILOG: PiLog, [Online], Available: https://piloggroup.com, [10 Feb 2024], 2018.

[31] KHAN, A., ABONYI, J.: Information sharing in supply chains - Interoperability in an era of circular economy, *Cleaner Logistics and Supply Chain*, Vol. 5, No. December, 100074, pp. 1-22, 2022. https://doi.org/10.1016/j.clscn.2022.100074

[32] MATE, N.: Transformation of supply chain management to agile supply chain management: Creating competitive advantage for the organizations, *World Journal of Advanced Research and Reviews*, Vol. 15, pp. 575-592, 2022. https://doi.org/10.30574/wjarr.2022.15.2.0872

[33] GUPTA, S., DRAVE, V.A., BAG, S., LUO, Z.: Leveraging smart supply chain and information system agility for supply chain flexibility, *Information Systems Frontiers*, Vol. 21, No. 3, pp. 547-564, 2019.

[34] JURGELANE-KALDAVA, I., BATENKO, A.: Assessment of Data Security Implementation in the Supply Chain Enterprises in Latvia, *WSB Journal of Business and Finance*, Vol. 57, pp. 21-27, 2023. https://doi.org/10.2478/wsbjbf-2023-0003

[35] PARFENOV, A., SHAMINA, L., NIU, J., YADYKIN, V.: Transformation of distribution logistics management in the digitalization of the economy, *Journal of Open Innovation: Technology, Market, and Complexity*, Vol. 7, No. 1, pp. 58-70, 2021.

[36] RAVI, D., RAMACHANDRAN, S., VIGNESH, R., FALMARI, V., BRINDHA, M.: Privacy-preserving transparent supply chain management through Hyperledger Fabric, *Blockchain: Research and Applications*, Vol. 3, No. 2, 100072, pp. 1-21, 2022. https://doi.org/10.1016/j.bcra.2022.100072

[37] GÓRALCZYK, M., KROT, P., ZIMROZ, R., OGONOWSKI, S.: Increasing energy efficiency and productivity of the comminution process in tumbling mills by indirect measurements of internal dynamics—An overview, *Energies*, Vol. 13, No. 24, pp. 1-19, 2020. https://doi.org/10.3390/en13246735

[38] WORLD BANK: *Global Economic Prospects: Slow Growth, Policy Challenges*, Washington, D.C: World Bank, 2020.

[39] SCHÄFFER, T., LEYH, C.: *Master Data Quality in the Era of Digitization-Toward Inter-Organizational Master Data Quality in Value Networks: A Problem Identification*, In: Innovations in Enterprise Information Systems Management and Engineering, Piazolo, F., Geist, V., Brehm, L., Schmidt, R., Eds., Springer International Publishing: Cham, Switzerland, pp. 99-113, 2017. https://doi.org/10.1007/978-3-319-58801-8_9

[40] MILIČEVIĆ, N., GRUBOR, A., ĐOKIĆ, N., AVLIJAŠ, G.: Retail Out-of-Stocks in the Context of Centralized and Direct Delivery, *Promet – Traffic&Transportatio*, Vol. 30, pp. 105-114, 2018.

[41] AKRAM, F., ABBAS, A.: *Holistic Approach: Integrating Master Data Management and Data*

Quality for Enhanced Business Performance, ResearchGate, [Online], Available: https://www.researchgate.net/publication/375609578_Holistic_Approach_Integrating_Master_Data_Management_and_Data_Quality_for_Enhanced_Business_Performance [10 Feb 2024], 2023.

[42] PANSARA, R.: Navigating Data Management in the Cloud-Exploring Limitations and Opportunities, *Transactions on Latest Trends in IoT*, Vol. 6, No. 6, pp. 57-66, 2023.

[43] NGOYI, Y.J.N., NGONGANG, E.: Forex Daytrading Strategy: An Application of the Gaussian Mixture Model to Marginalized Currency pairs, *Multidisciplinary Journal of Instruction*, Vol. 5., No. 3, pp. 1-44, 2023. https://doi.org/10.5281/zenodo.10051866

[44] VILMINKO-HEIKKINEN, R., PEKKOLA, S.: *Establishing an organization's master data management function: A stepwise approach*, Proceedings of the 46th Hawaii international conference on system sciences, pp. 4719-4728, Springer International Publishing, 2013.

[45] PANSARA, R.: Master Data Management Challenges, *International Journal of Computer Science and Mobile Computing*, Vol. 10, No. 1, pp. 47-49, 2021.

[46] LOSHIN, D.: *Why Master Data Management must be one of the first steps in post-merger integration*, Blogs SAP, [Online], Available: https://blogs.sap.com/2015/05/19/why-master-data-management-must-be-one-of-the-first-steps-in-post-merger-integration/ [10 Feb 2024], 2009.

[47] DREIBELBIS, A., HECHLER, E., MILMAN, I., OBERHOFER, M., VAN RUN, P., WOLFSON, D.: *Enterprise master data management: an SOA approach to managing core information*, Boston, Pearson plc as IBM Press, 2008.

[48] VILMINKO-HEIKKINEN, R., PEKKOLA, S.: *Establishing an organization's master data management function: A stepwise approach*, Proceedings of the 46th Hawaii international conference on system sciences, pp. 4719-4728, Springer International Publishing, 2013.

[49] THOO, E., FRIEDMAN, T., FEINBERG, D., BEYER, M.: *Hype cycle for data management*, [Online], Available: https:/www.gartner.com/ [10 Feb 2024], 2010.

[50] BERSON, A., DUBOV, L.: *Master Data Management and Customer Data Integration for a Global Enterprise*, Mcgraw-Hill, 2007.

[51] JONES, D.: *Beginners guide to master data management (MDM)*, Data Quality Pro Blog, [Online], Available: https://www.dataqualitypro.com/beginners-guide-to-mdm-master-data-management/ [10 Feb 2024], 2011.

[52] JONKER, R.A., KOOISTRA, F.T., CEPARIU, D., VAN ETTEN, J., SWARTJES, S.: *Effective master data management (Electronic version)*, Compact_ IT Advisory, [Online], Available: https://www.compact.nl/articles/effective-master-data-management/ [10 Feb 2024], 2011.

[53] TRACY, S.J.: *Qualitative research methods: Collecting evidence, crafting analysis, communicating impact*, West Sussex: John Wiley & Sons, 2013.

[54] BRYMAN, A., BELL, E.: *Business research methods*, Oxford: Oxford University Press, 2011.

[55] SAUNDERS, M., LEWIS, P., THORNHILL, A.: *Research methods for business students*, Essex: Pearson, 2016.

[56] MERRIAM, S.B., TISDELL, E.J.: *Qualitative research: a guide to design and implementation*, 4th ed., San Francisco, CA, Jossey-Bass, 2015.

[57] DE CORBIÈRE, F., ROWE, F., SAUNDERS, C.S.: Digitalizing Interorganizational Relationships: Sequential and Intertwined Decisions for Data Synchronization, *International Journal of Information Management*, Vol. 48, pp. 203-217, 2019. https://doi.org/10.1016/j.ijinfomgt.2019.04.005

[58] JONES, D.: *Beginners guide to master data management (MDM)*, Data Quality Pro Blog, [Online], Available: https://www.dataqualitypro.com/beginners-guide-to-mdm-master-data-management/ [10 Feb 2024], 2011.

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Enhancing reliability in garment manufacturing through FMEA and FTA

Asep Nana Rukmana
Department of Industrial Engineering, Faculty of Engineering, Universitas Islam Bandung, Jl. Taman Sari No.24, Bandung 40116, Indonesia, an.rukmana@unisba.ac.id (corresponding author)
Ahmad Arif Nurrahman
Department of Industrial Engineering, Faculty of Engineering, Universitas Islam Bandung, Jl. Taman Sari No.24, Bandung 40116, Indonesia, arif.nurrahman@unisba.ac.id
Selamat Selamat
Department of Industrial Engineering, Faculty of Engineering, Universitas Islam Bandung, Jl. Taman Sari No.24, Bandung 40116, Indonesia, 2122selamat@gmail.com
Syaefan Abdillah
Department of Industrial Engineering, Faculty of Engineering, Universitas Islam Bandung, Jl. Taman Sari No.24, Bandung 40116, Indonesia, syaefanabdillah99@gmail.com

Keywords: Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), clothing production, manufacturing processes, product defects.
Abstract: This study employs Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) to comprehensively investigate product defects in Biyan Konveksi's manufacturing processes, one of the growing SMEs producing clothing pieces. Analyzing critical failure modes, including tear failures, stitching irregularities, sizing discrepancies, and ribbon imperfections, the research employs FTA to trace root causes, revealing the interconnected nature of these failures. The initial defect percentage, attributed to human, machine, material, and environmental factors, stood above 3%, with culottes experiencing the highest defect percentage at 3.95%. After the company implemented the enhancement measures, the defect percentage dropped significantly, reaching a range of 1 to 1.25%. Subsequently, targeted enhancement strategies are proposed, encompassing the implementation of additional worker rest breaks to alleviate fatigue, comprehensive training for new staff, and stringent machine maintenance protocols. These interventions aim to curtail tear failures, refine stitching precision, rectify sizing errors, and enhance ribbon placement. Anticipated to yield a substantial reduction in overall defect percentages, the suggested improvements position Biyan Konveksi for sustained excellence, emphasizing proactive measures to enhance worker performance and optimize manufacturing processes. The study underscores the significance of a systematic approach, combining FMEA and FTA, in diagnosing and rectifying complex failure scenarios within manufacturing environments, offering practical implications for companies aiming to fortify their competitive edge in the market.

1 Introduction

The consumptive landscape of ready-made clothing in Indonesia is undergoing a positive developmental trend, showcasing the pivotal role played by the textile and fashion industry in the nation's economic growth, poverty alleviation, and job creation. In 2019, this sector demonstrated an outstanding performance, registering a growth rate of 15.35% [1], solidifying its position as one of Indonesia's top 10 commodities. Moreover, it has emerged as a fundamental element in the 2015-2035 National Industrial Development Master Plan (RIPIN), strategically aligned with the objectives outlined in the Indonesia 4.0 roadmap [2]. The ready-made clothing industry significantly contributes to the Gross Domestic Product (GDP), amounting to Rp139.33 trillion in 2022 at constant prices [3], this reflects a noteworthy 9.34% increase compared to the preceding year's figure of Rp127.43 trillion. The impetus behind this growth can be attributed to the burgeoning middle class in Indonesia, propelling a surge in demand for affordable and locally produced clothing, particularly in the women's apparel segment, anticipated to reach a market volume of US$10.25 million by 2023 [3].

The growth of the ready-made clothing industry in Indonesia propels the development of Small and Medium Enterprises (SMEs) in this sector. A notable example is Biyan Konveksi, located in Cirebon, West Java, producing various women's products such as culottes, pleated skirts, and baggy pants using raw materials like thread, fabric, and ribbed rubber obtained from suppliers. However, heightened consumer demand and intense regional competition have led to an increase in final products that deviate from the intended specifications. Manufacturing defects exist when the product comes off the production line in a condition different from what the manufacture intended [4]. The average defect rate exceeded 3% from May 2021 to April 2022, marking an increase from less than 2% in the preceding year.

Defects ranging from color disparities, material cutting errors, tears, uneven stitching, poorly applied ribbed rubber, weak stitching, to stains necessitate rework, adding to the production time for workers. Failures can lead to

unmet production targets and discrepancies in the quality grade of products, thereby reducing profits for Biyan Konveksi. Although some defective products can be rectified through rework, the existence of defects resulting from rework imposes additional costs on the company [5]. These failures can lead to unmet production targets, differences in the quality grade of products, reducing profits for the company, and undermining consumer trust.

In response to the challenges faced by Biyan Konveksi, the company must implement stringent quality control measures to minimize defective products, uphold existing quality standards, and enhance the overall quality of its products. This study employs the Fault Tree Analysis (FTA) and Failure Mode and Effect Analysis (FMEA) methods, with the objective of identifying factors causing defects in clothing products at Biyan Konveksi and further provides improvement suggestions based on priority, aiming to mitigate the occurrence of defective products.

2 Literature review

Efficient optimization of the reliability analysis process requires the application of suitable quality control tools, as exemplified by Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) [6]. Both Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) emerge as widely accepted methodologies for conducting failure analyses, providing a means to scrutinize critical parameters in the analyzed processes.

Recognized as a reliability management technique, Failure Mode and Effects Analysis (FMEA) finds common usage across diverse industries to ensure the security and reliability of systems, services, and projects [7]. FMEA, operating as a bottom-up method, demands a considerable time investment, particularly in systems with intricate components and parts. Conversely, Fault Tree Analysis (FTA), a top-down method, dissects the top event into sub-events, creating a fault tree. This tree aids in identifying the least cut-set and least path set of the fault tree, crucial for reliability control. The FTA used in this study is to find out factors causing failures in the FMEA manufacturing process, namely at the phase of determining the cause of failure [8].

2.1 Failure Mode and Effects Analysis (FMEA)

The industry faces challenges such as increasing quality demands from customers, the necessary cost optimization of products and processes, higher complexity, and product liability imposed by legislation. Therefore, the FMEA method is employed to proactively address the technical aspects of risk reduction. Unlike other reliability management tools, FMEA serves as a proactive method to prevent system failures, rather than an after-the-fact analysis method [9,10]. FMEA, originating in the United States Defense Department in 1949, was applied by the national aeronautics and space administration (NASA) for the Apollo plan to enhance system reliability in the 1960s [11]. A complete FMEA typically consists of four stages:

a. Identifying all known or potential failure modes of a system.
b. Confirming the causes and effects of each failure.
c. Ranking the recognized failure modes by their risk priority numbers (RPNs).
d. Taking remedial actions for higher-risk failures.

The smallest RPN value is better than the largest because the largest value indicates the severity of the risk of failure. Although FMEA is a useful and popular tool for safety and reliability analysis, it suffers from various shortcomings when used in practice [12].

2.2 Fault Tree Analysis (FTA)

The second method for failure analysis is Fault Tree Analysis (FTA), a top-down method used to identify relationships between events, such as subsystem failures and their causes. The logic gates commonly used in the FTA manufacturing process include AND gates used when all input events occur and OR gates used when one of the input events occurs [13]. The commonly used logic gates in FTA are the (1) OR-gate, (2) AND-gate, and (3) inhibit or conditional gate. The commonly used event types in FTA include the (1) top or intermediate event, (2) basic event, (3) diamond or undeveloped event, and (4) conditional event [14].

Although Fault Tree Analysis (FTA) is a highly effective and widely-utilized method for dependability analysis across various systems, it has several limitations, such as an inability to model sequence- or time-dependent dynamic behavior and to conduct quantitative analysis with uncertain failure data [15]. Despite its advantages over Failure Mode and Effects Analysis (FMEA), particularly when analyzing complex systems, FTA's structured approach is most beneficial for new systems with limited field-based failure data. This structured and deductive reasoning process reduces reliance on the analyst's practical experience, adding rigor to the analysis compared to FMEA. However, combining FMEA and FTA methodologies can enhance the overall efficiency of failure analysis [16].

3 Methods

FTA provides a comprehensive breakdown of faults leading to the undesired top event, while FMEA furnishes the exact fashion in which these faults exist and their direct effects on the top event, making the combination suitable for safety and reliability analyses [17]. The integration of FMEA and FTA presents a promising approach to enhance reliability control, especially in the post-detail design phase [18]. By combining these methodologies, a more comprehensive and structured approach can be achieved, leveraging the strengths of both FMEA and FTA. This integrated approach enhances the ability to manage reliability effectively, providing a robust framework for ensuring product reliability throughout its lifecycle.

The study employs Fault Tree Analysis (FTA) with the aim of determining the root causes of failures in Biyan Konveksi's production by modeling them into a problem tree. Subsequently, the causes are identified using FMEA, aiming to determine variable values (failure impact level, failure cause level, and assessment capability of product or process control). The Risk Priority Number (RPN) is calculated using the values derived from the variables of severity, failure detection, and frequency, this computation highlights the relationship between these variables to identify risks that necessitate corrective action [19]. Further analysis is conducted using 5W+1H (What, Where, When, Why, Who, How) to provide recommendations to improve Biyan Konveksi's production.

4 Results and discussion

Data processing was conducted to analyze product defect-related data, employing tools and methods relevant to the identified issues. The utilization of Fault Tree Analysis (FTA) in conjunction with Failure Mode and Effect Analysis (FMEA) is pivotal in this research. FTA is employed to identify failure causes and discern prevalent defect types, aiding in pinpointing the root causes that may lead to product failure. The outcomes of the failure mode identification based on FTA are subsequently processed using the FMEA method to analyze each production process sequence contributing to errors. This facilitates the understanding of failure sources and the results of the FMEA identification are proposed as design improvements to address the current issues at Biyan Konveksi.

4.1 Identifying types of defects

The initial step involves the identification of failure modes. Potential failure modes are outlined by detailing each production process stage, followed by data processing using a Pareto diagram. The Pareto diagram is instrumental in prioritizing defect data, emphasizing the most critical issues for immediate rectification based on the 80/20 principle, where 80% represents problems (mismatches) caused by triggers (causes) accounting for 20%. Figure 1 displays the Pareto diagram for each type of disability.

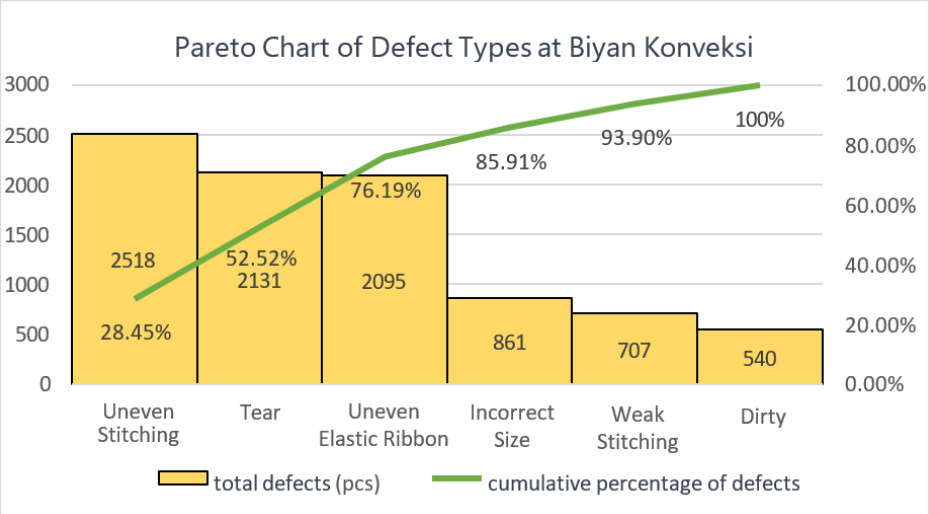

Figure 1 Pareto chart of defect types at Biyan Konveksi

Based on the Pareto diagram, dominant defects constituting the 80% principle include uneven stitching, tears, irregular ribbons, and incorrect sizing. The cumulative defect percentage depicted in the Pareto diagram highlights the most prevalent or recurring defects.

4.2 Identification of Defect Causes Using FTA

The outcomes of the Pareto diagram are further analyzed using the Fault Tree Analysis (FTA) method, constructing a fault tree diagram for an in-depth examination towards other basic events. Logic gates are employed to determine the root causes of product failures at Biyan Konveksi. The identification of factors causing failure using fault tree analysis is illustrated in Figure 2 - Figure 6.

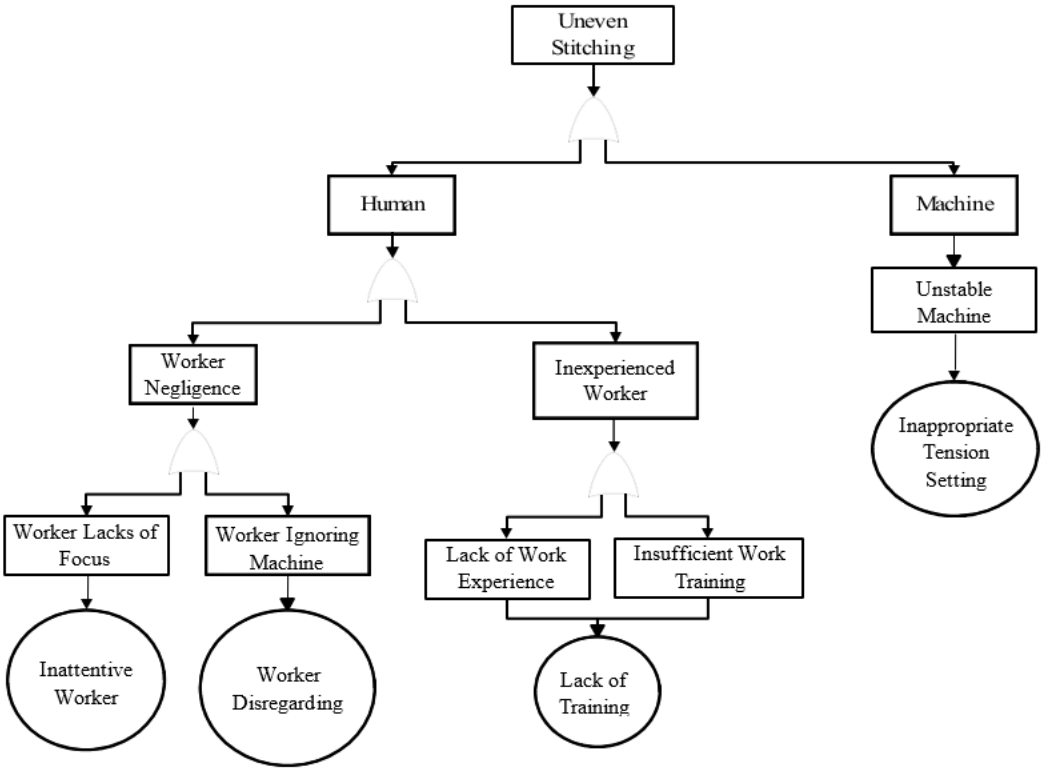

Figure 2 FTA uneven stitching

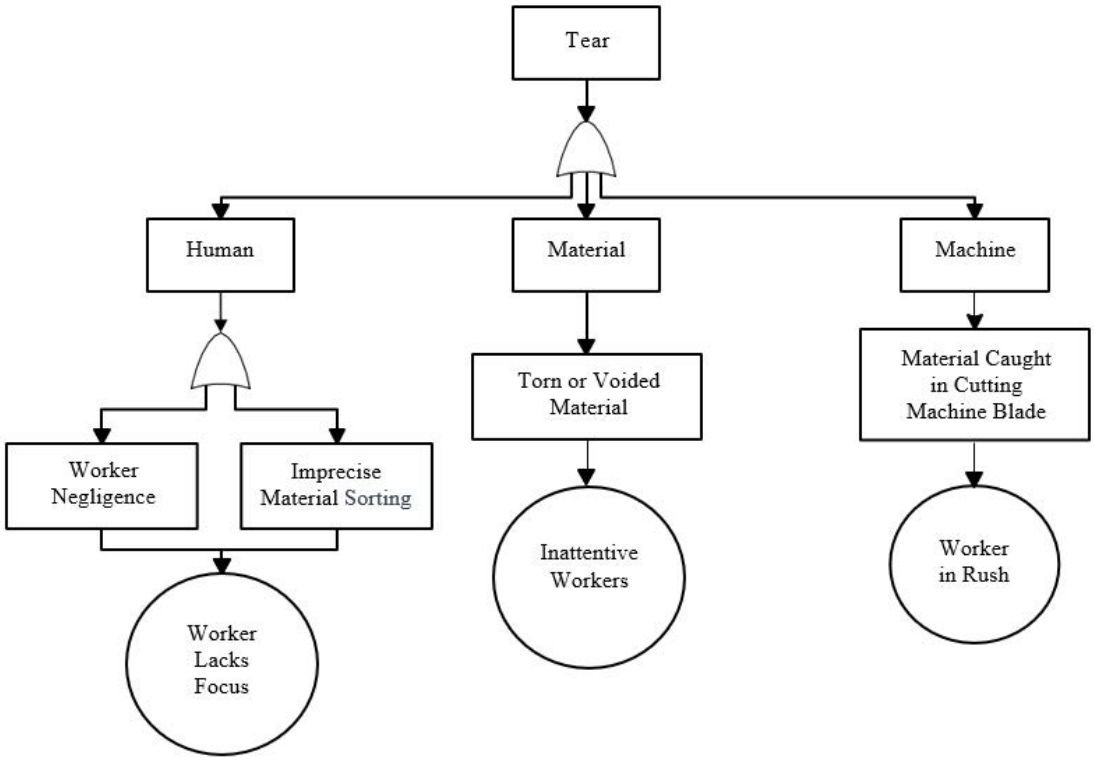

Figure 3 FTA tear

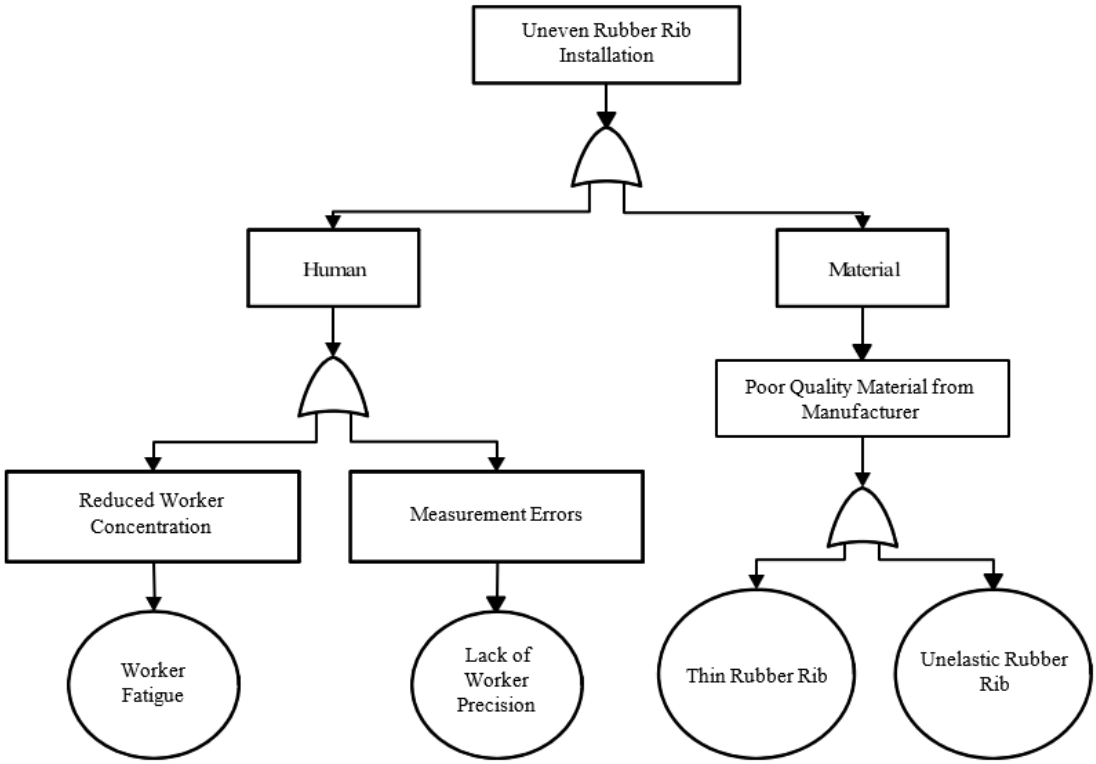

Figure 4 FTA uneven rubber rib installation

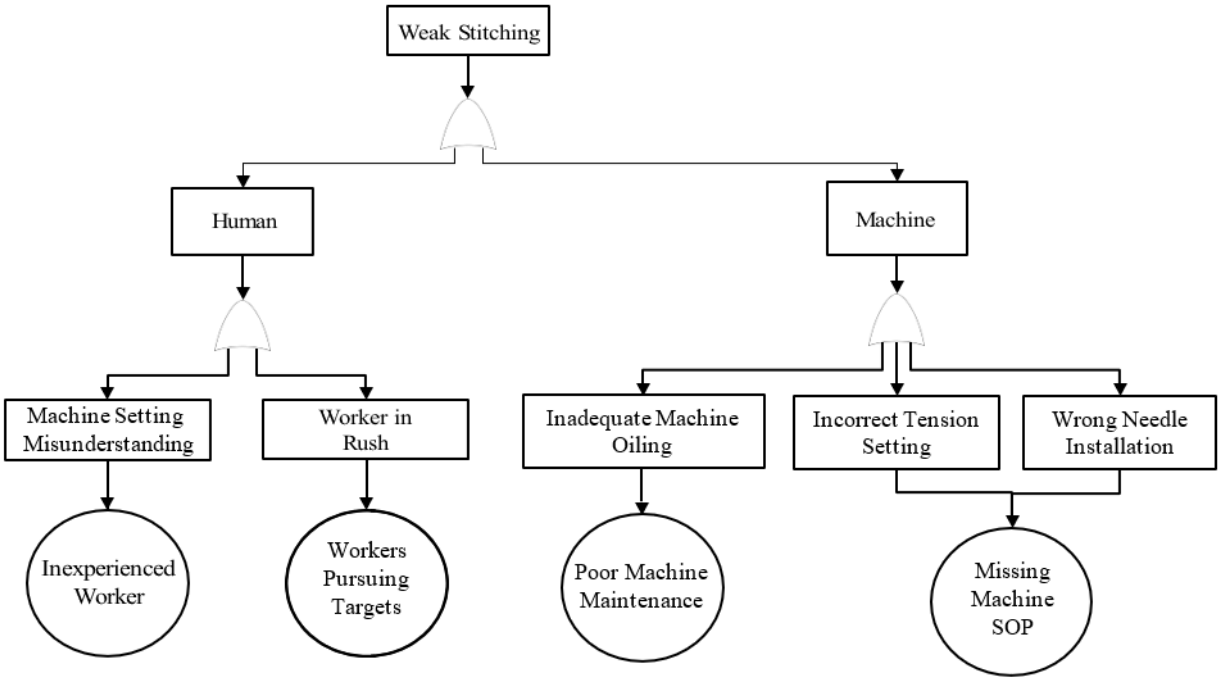

Figure 5 FTA weak stitching

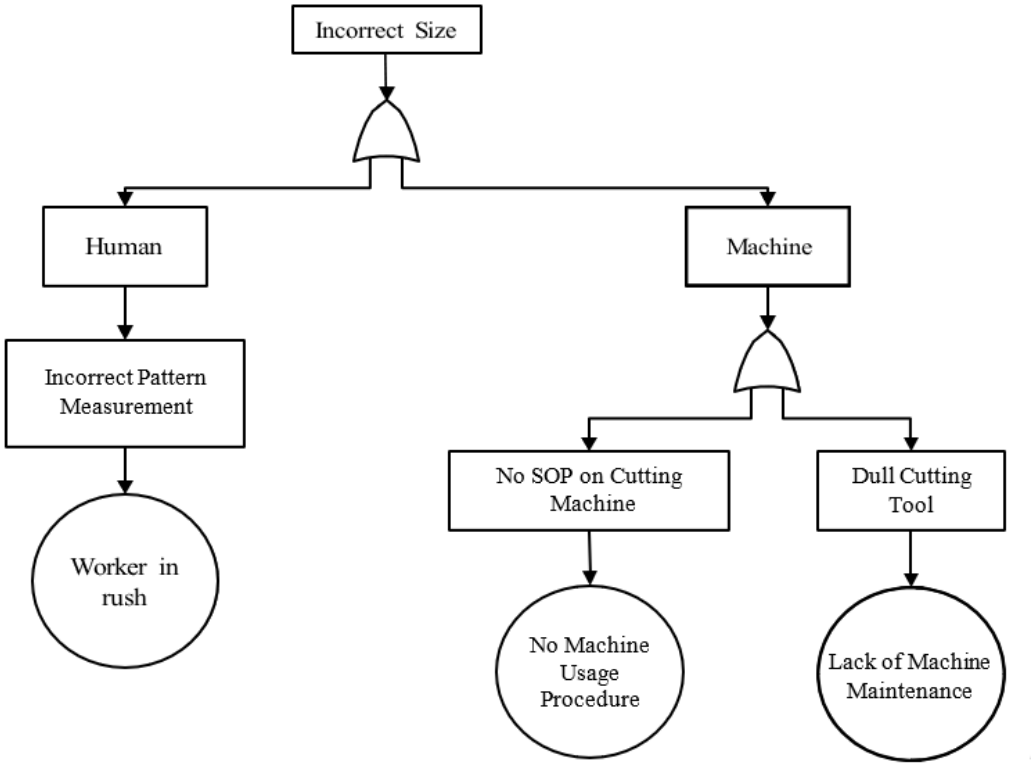

Figure 6 FTA incorrect size

4.3 Calculating RPN Values

Risk Priority Number (RPN) is a priority risk value that aids in assessing the significance of various risks. It is based on the severity of the risk's effect, the likelihood of failure causes, and the speed of detection if a failure occurs. RPN values are calculated to determine the highest failure risk level for each failure mode. The RPN value is calculated by multiplying the severity, occurrence, and detection values derived from assessing the effect of failure and potential causes for each failure mode. The results are ranked by the magnitude of these products, prioritizing issues with the highest RPN values for risk reduction. Initially, three indicators—occurrence probability (O), severity (S), and detection probability (D)—are defined. Based on the scoring criteria (see Table 1), the relationship RPN = S × O × D is established. Values are assigned to S, O and D, then converted using the entropy weight method, followed by a consistency check [20]. Table 2 presents the top RPN value as a reference for enhancement.

Tabel 1 Scoring standards of S, O, D

Severity		**Occurance**		**Detection**	
Probability	**Rating**	**Probability**	**Rating**	**Probability**	**Rating**
Extremely serious	9–10	High-risk factor, hardly be avoided	9–10	Extremely low	10
Very serious	8	High-risk factor, recurring	7–8	Very low	7-9
More serious	7	The risk factor is moderate, happens occasionally	5–6	Lower	5-6
General serious	5-6	The risk factor is low, rarely occurs	3–4	Higher	3-4
Relatively slight	4	The risk factor is extremely low, hardly occurs	1–2	Extremely high	1-2
Slight	2-3				
No effect	1				

Table 2 RPN values calculation using FMEA

Potential Failure Mode	***Potential Failure Effect***	***Severity (S)***	***Pontetial Causes***	***Occurrence (O)***	***Current Control***	***Detection (D)***	***Risk Priority Number (RPN)***	***Ranking***
Uneven stitching	Uneven stitching, rough stitching, stitching not straight	6	Worker negligence	6	Owner's supervision	4	144	5
			Worker ignores owner's instructions		Worker receives reprimand	3	108	8
			Lack of training for workers		Providing training to workers	5	180	2
			Incorrect tension setting		Adjusting tension for each type of material	2	72	12
Tear	Voided products, loss of aesthetic elements, reduced product functionality	8	Worker lacks focus	6	Providing break time during production	4	192	1
			Worker's inattention in material sorting		Worker receives reprimand	3	144	5
			Worker in rush		Owner's supervision	2	96	10
Uneven elastic ribbon	Reduced comfort or product functionality	7	Worker fatigue	6	Providing break time during production	4	168	4
			Lack of attentiveness		Worker receives reprimand	3	126	7
			Poor quality raw materials from the supplier		Separating poor quality raw materials	3	126	7
Incorrect size	Product does not meet pre-determined standards	7	Worker pursuing production targets	5	Enhancing production control through supervision	4	140	6
			Lack of machine usage procedures		Providing guidance for workers	3	105	9
			Insufficient machine maintenance		Workers checking machine conditions in the production process	5	175	3
Weak stitching	Stitching easily comes off, the product quickly becomes damaged	5	Inexperienced worker	5	Providing training to workers	3	75	11
			Worker pursuing production targets		Enhancing production control through supervision	3	75	11
			Lack of standard procedure for operating machine		Providing machine operation guidance	3	75	11

5 Results analysis

The primary focus of our analysis lies in identifying critical failure modes and assessing their severity through Risk Priority Number (RPN) values. Tear failures, with an RPN of 192, emerged as the foremost concern, leading to the loss of both aesthetic appeal and product functionality. Following closely is the uneven stitching issue, ranking second with an RPN of 180, highlighting its significant impact on product quality. Additionally, incorrect sizing and irregular ribbons, with RPN values of 175 and 168 respectively, contribute significantly to the overall product defects.

The identified failures stem from a combination of human, machine, material, and environmental factors. Tear failures result from workers' lack of focus due to insufficient rest breaks, while uneven stitching is attributed to a lack of training for new workers. Incorrect sizing is linked to inadequate machine maintenance, emphasizing

the importance of regular checks on production machines. The irregular ribbons issue is connected to worker fatigue, emphasizing the need for periodic rest breaks. Understanding these causal factors is crucial for devising effective strategies to address and mitigate these failures.

To address the identified failures and improve overall product quality, several enhancement measures are proposed. These include implementing consistent rest breaks during specific production periods to combat worker fatigue and improve focus. Providing comprehensive training for both new and existing workers, especially in the context of using production machines, can significantly enhance the precision of stitching. Moreover, introducing direct supervision from Biyan Konveksi's management during crucial production stages, such as the stitching process, can ensure meticulous attention to detail and reduce defects caused by worker oversight.

Post-implementation of the proposed improvement measures, there is a noteworthy decrease in the overall defect percentage. The initial defect percentage, attributed to human, machine, material, and environmental factors, stood above 3%, with culottes experiencing the highest defect percentage at 3.95%. After the company implemented the enhancement measures, the defect percentage dropped significantly, reaching a range of 1 to 1.25%. This substantial reduction underscores the effectiveness of the suggested enhancements in minimizing defects and improving the overall quality of Biyan Konveksi's products.

6 Conclusion

The comprehensive analysis using Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) has resulted critical insights into the primary failure modes impacting Biyan Konveksi's production processes. The identified failure factors—human, machine, material, and environmental aspects—highlight the complex challenges the company faces in maintaining product quality. FTA enabled tracing the root causes of these failures, revealing the interconnectedness of various contributing factors. Conversely, FMEA facilitated a systematic assessment of the severity, occurrence, and detection of each failure mode, thereby enabling the prioritization of improvement efforts.

Tear failures, with a Risk Priority Number (RPN) of 192, were identified as the foremost concern, significantly affecting both the aesthetic appeal and functionality of the products. Uneven stitching, with an RPN of 180, was the second most significant issue, impacting product quality. Incorrect sizing and irregular ribbons, with RPN values of 175 and 168 respectively, also contributed substantially to overall product defects. Initially, the defect percentage, attributed to human, machine, material, and environmental factors, exceeded 3%, with culottes experiencing the highest defect percentage at 3.95%. Following the implementation of the suggested enhancements, the defect percentage significantly decreased, reaching a range of 1 to 1.25%.

The proposed enhancements, derived from these analyses, provide a strategic roadmap for Biyan Konveksi to elevate its production processes and enhance product quality. Addressing issues such as inadequate rest breaks, insufficient training for new workers, and lax machine maintenance can significantly reduce the occurrence of tear failures, uneven stitching, incorrect sizing, and irregular ribbons. These improvements are aimed at optimizing worker performance, refining manufacturing processes, and ultimately lowering the overall defect percentage. The proactive implementation of these suggestions positions Biyan Konveksi on a path toward sustained improvement.

It is recommended to further investigate the long-term impacts of these enhancements on production efficiency and product quality. Additionally, exploring the integration of advanced quality control technologies and continuous training programs for workers could provide deeper insights and further improvements. Continued monitoring and adaptation of the implemented measures will be crucial for maintaining the trajectory of sustained improvement and ensuring the highest standards of product quality at Biyan Konveksi.

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References

[1] ARANIA, F., PUTRI, I.M., SAIFUDDIN, M.: The Impact of Covid-19 on Textile and Fashion Industries: The Economic Perspective, *Journal of Marketing Innovation*, Vol. 2, No. 1, pp. 1-14, 2022. https://doi.org/10.35313/jmi.v2i1.18

[2] KEMENTRIAN PERINDUSTRIAN REPUBLIK INDONESIA, Rencana Induk Pembangunan Industri Nasional Republik Indonesia, [Online], Available: www.kemenperin.go.id/ripin [18 Oct 2023], 2023. (Original in Indonesian)

[3] DIREKTORAT NERACA PRODUKSI, Produk Domestik Bruto Indonesia Triwulanan, Badan Pusat Statistik, [Online], Available: https://www.bps.go.id/id/publication/2023/10/13/9f14d43dc0c01b6d1883fb7c/produk-domestik-bruto-indonesia-triwulanan-2019-2023.html [10 Feb 2024], 2023. (Original in Indonesian)

[4] STAMATIS, D.H.: *Failure Mode and Effect Analysis: FMEA from Theory to Execution*, 2nd ed., Milwaukee, Wisconsin, Quality Press, 2003.

[5] KADIM, A.: *Penerapan Manajemen Produksi dan Operasi di Industri Manufaktur*, 1st ed., Jakarta, Mitra Wacana Media, 2019. (Original in Indonesian)

[6] CRISTEA, G., CONSTANTINESCU, D.M.:

A comparative critical study between FMEA and FTA risk analysis methods, IOP Conference Series: Materials Science and Engineering, AR2017 International Congress of Automotive and Transport Engineering - Mobility Engineering and Environment 8-10 November 2017, Pitesti, Romania, Vol. 252, No. 1, pp. 1-5, 2017. https://doi.org/10.1088/1757-899X/252/1/012046

[7] HUANG, J., YOU, J.-X., LIU, H.-C., SONG, M.-S.: Failure mode and effect analysis improvement: A systematic literature review and future research agenda, *Reliability Engineering & System Safety*, Vol. 199, No. July, 106885, 2020. https://doi.org/10.1016/j.ress.2020.106885

[8] RENOSORI, P., OEMAR, H., FAUZIAH, S.R.: Combination of FTA and FMEA methods to improve efficiency in the manufacturing company, *Acta logistica*, Vol. 10, No. 3, pp. 487-495, 2023. https://doi.org/10.22306/AL.V10I3.422

[9] LIU, H.-C., HU, Y.-P., WANG, J.-J., SUN, M.: Failure Mode and Effects Analysis Using Two-Dimensional Uncertain Linguistic Variables and Alternative Queuing Method, *IEEE Transactions on Reliability*, Vol. 68, No. 2, pp. 554-565, 2019. https://doi.org/10.1109/TR.2018.2866029

[10] LO, H.-W., LIOU, J.J.H., HUANG, C.-N., CHUANG, Y.-C.: A novel failure mode and effect analysis model for machine tool risk analysis, *Reliability Engineering & System Safety*, Vol. 183, No. March, pp. 173-183, 2019. https://doi.org/10.1016/j.ress.2018.11.018

[11] PILLAY, A., WANG, J.: Modified failure mode and effects analysis using approximate reasoning, *Reliability Engineering & System Safety*, Vol. 79, No. 1, pp. 69-85, 2003. https://doi.org/10.1016/S0951-8320(02)00179-5

[12] LO, H.-W., LIOU, J.J.H.: A novel multiple-criteria decision-making-based FMEA model for risk assessment, *Applied Soft Computing*, Vol. 73, No. December, pp. 684-696, 2018. https://doi.org/10.1016/j.asoc.2018.09.020

[13] VESELY, W.E., GOLDBERG, F.F., ROBERTS, N.H., HAASL, D.F.: *Fault Tree Handbook*, Washington D.C., U.S. Nuclear Regulatory Comission, 1981.

[14] STAMATELATOS, M., VESELY, W., DUGAN, J., FRAGOLA, J., MINARICK, J., RAILSBACK, J.: *Fault Tree Handbook with Aerospace Applications*, Washington D.C., 2002.

[15] KABIR, S.: An overview of fault tree analysis and its application in model based dependability analysis, *Expert Systems with Applications*, Vol. 77, No. July, pp. 114-135, 2017. https://doi.org/10.1016/j.eswa.2017.01.058

[16] PEETERS, J.F.W., BASTEN, R.J.I., TINGA, T.: Improving failure analysis efficiency by combining FTA and FMEA in a recursive manner, *Reliability Engineering & System Safety*, Vol. 172, No. April, pp. 36-44, 2018. https://doi.org/10.1016/j.ress.2017.11.024

[17] SHAFIEE, M., ENJEMA, E., KOLIOS, A.: An Integrated FTA-FMEA Model for Risk Analysis of Engineering Systems: A Case Study of Subsea Blowout Preventers, *Applied Sciences*, Vol. 9, No. 6, 1192, pp. 1-15, 2019. https://doi.org/10.3390/app9061192

[18] YU, S., LIU, J., YANG, Q., PAN, M.: *A comparison of FMEA, AFMEA and FTA*, In: The Proceedings of 2011 9th International Conference on Reliability, Maintainability and Safety, Jun. 2011, pp. 954-960, https://doi.org/10.1109/ICRMS.2011.5979423

[19] PRIHANANTO, D., SAHRONI, T.R.: Effectiveness Analysis of Hydraulic Torque Wrench Machine Using Failure Mode and Effect Analysis (FMEA) and Logic Tree Analysis Study Case on Heavy Equipment Manufacturing, *Journal of Applied Engineering and Technological Science*, Vol. 5, No. 1, pp. 474-494, 2023. https://doi.org/10.37385/jaets.v5i1.1920

[20] SILVA, M.M., DE GUSMÃO, A.P.H., POLETO, T., SILVA, L.C.E., COSTA, A.P.C.S.: A multidimensional approach to information security risk management using FMEA and fuzzy theory, *International Journal of Information Management*, Vol. 34, No. 6, pp. 733-740, 2014. https://doi.org/10.1016/j.ijinfomgt.2014.07.005

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Deep learning hybrid models for effective supply chain risk management: mitigating uncertainty while enhancing demand prediction
Nisrine Rezki, Mohamed Mansouri

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Deep learning hybrid models for effective supply chain risk management: mitigating uncertainty while enhancing demand prediction

Nisrine Rezki
Hassan First University of Settat, National School of Applied Sciences, Systems Analysis and Modeling and Decision Support Laboratory, BP 218, 26100, Berrechid, Morocco, n.rezki@uhp.ac.ma (corresponding author)
Mohamed Mansouri
Hassan First University of Settat, National School of Applied Sciences, Systems Analysis and Modeling and Decision Support Laboratory, BP 218, 26100, Berrechid, Morocco, mohamansouri@gmail.com

Keywords: supply chain, demand prediction, deep learning, hybrid model, supply chain risk management.
Abstract: In today's rapidly evolving business landscape, effective supply chain management (SCM) is crucial for achieving success. Accurately predicting product demand is a significant challenge for companies, impacting customer satisfaction, inventory optimization, cost reduction, and operational efficiency. This study focuses on demand forecasting within intelligent supply chains (SCs) and supply chain risk management (SCRM), aiming to enhance overall SC efficiency and mitigate risks, highlighting the use of deep learning hybrid and singles models to address SCRM challenges, specifically in mitigating uncertainty and improving demand prediction accuracy. Our research paper investigates predictive modeling techniques for demand forecasting within the automotive sector. Specifically, we assess the effectiveness of Seasonal Autoregressive Integrated Moving Average (SARIMA), Long Short-Term Memory (LSTM), Artificial Neural Network (ANN), Recurrent Neural Network (RNN), and a hybrid RNN-ANN model with Gradient Boosting (GB). Through meticulous analysis and evaluation, we demonstrate the superior predictive accuracy of the hybrid model compared to individual models. The results indicate consistent outperformance of the hybrid model, as evidenced by lower Mean Absolute Error (MAE) and Mean Squared Error (MSE) values across electric and thermal product categories. This research aims to provide valuable insights and practical tools for businesses to refine their demand prediction processes. By addressing demand uncertainty, organizations can streamline their SCs, minimize costs, and establish a responsive and adaptable framework for sustainable growth.

1 Introduction

In today's fiercely competitive manufacturing landscape, companies are increasingly turning to demand-driven SCs to navigate the complexities of fluctuating customer demands. This shift underscores a fundamental change in market dynamics, where customers wield unprecedented influence by specifying their desired products and delivery schedules to suppliers.

Effective demand forecasting is paramount in this environment, as it enables companies to optimize resource utilization across production, inventory management, and transportation. Accurate predictions facilitate the alignment of production quantities with anticipated demand, resulting in cost savings and the maintenance of optimal inventory levels while minimizing excess stock. This optimization not only fosters efficient SCM but also ensures the timely fulfillment of customer demands.However, inaccurate predictions can trigger the bullwhip effect [1] a phenomenon in SCM where minor changes in consumer demand lead to magnified fluctuations as they propagate upstream. This distortion of information among wholesalers, manufacturers, and suppliers can result in substantial variability within the SC, leading to excess inventory, wastage, operational inefficiency, and diminished profits.

Moreover, as traditional SC undergoes development, technology is becoming increasingly ingrained. Many SCs have already incorporated advanced technological components like digitalization, networking, and automation. This is especially noticeable in the automotive SC, where the adoption of new technology, particularly deep learning (DL), is a direct consequence of integrating cutting-edge scientific advancements and technological innovations to modernize traditional practices. The integration of artificial intelligence (AI) technologies, including machine learning (ML) and DL, has played a significant role in the intelligent evolution of the conventional SC.

Researchers have produced a plethora of work in the field of forecasting, proposing numerous methods and techniques mainly with ML and DL methodologies, which have showcased their effectiveness in handling vast amounts of data with numerous dimensions, revealing latent patterns crucial for decision-making and prediction [2]. These methodologies have displayed remarkable performance across various domains, such as demand forecasting and price prediction, often surpassing traditional statistical approaches [3-4]. Notably, DL models like Convolutional Neural Networks (CNNs), ANN and RNNs stand out for their capacity to automatically extract meaningful features from data decreases the need for manual feature engineering.

The application of DL extends to various SC forecasting tasks, covering domains like production

forecasting, pricing forecasting, and demand forecasting.For instance, [5] explored the multi-step ahead prediction of coal prices by employing a hybrid DL model. [6] investigated optimal pricing challenges faced by members of the automotive SC, emphasizing the pivotal role of prediction as the foundation for pricing decisions. [7] utilized statistical and econometric theories and methodologies to predict future demand for new energy vehicles within the automotive SC domain. These studies demonstrate the superiority of these models over traditional statistical methods, which, being fundamentally linear, struggle to effectively handle uncertainty and demand fluctuations. While single models have proven effective in various fields, there is limited adoption of hybrid models in demand forecasting, indicating a potential area for further exploration. Furthermore, there is a prevailing tendency to rely on single models rather than adopt combined hybrid models.

This study is grounded in the context of intelligent SCs, acknowledging the crucial role of demand forecasting in SCM, the incorporation of demand forecasting into the SCRM context offers several noteworthy contributions:

Risk anticipation: The precision of demand forecasting aids in anticipating potential risks associated with fluctuations in demand. By comprehending demand patterns, SC managers can proactively identify and prepare for potential disruptions, enhancing risk anticipation.

Inventory management: Accurate demand forecasting supports the optimization of inventory levels, leading to reduced holding costs, and mitigates the risks of stockouts or excess inventory.

Supply chain resilience: Recognizing uncertainties in demand empowers SC managers to design systems that are more resilient and adaptable to various scenarios.

Supplier collaboration: Demand forecasting fosters improved collaboration with suppliers. Understanding future demand patterns enables suppliers to align their production schedules and capacities with anticipated requirements, thereby reducing the risk of disruptions in the SC.

Resource allocation: Accurate demand forecasting guides decisions related to resource allocation, encompassing labor, transportation, and production capacities. Aligning resources with forecasted demand aids in the effective management of operational risks.

Data-driven decision-making: The utilization of AI and DL for demand forecasting facilitates more precise predictions, supporting data-driven decision-making in the realm of SCRM.

Scenario planning: Demand forecasting enables the creation of diverse demand scenarios. SC managers can leverage scenario planning to assess the potential impact of various demand-related risks, allowing for the development of robust contingency plans.

In essence, this research acknowledges the integral role of demand forecasting in SCRM. By incorporating these perspectives, the study seeks to demonstrate a comprehensive understanding of how effectively managing demand uncertainties contributes to the overall resilience and risk mitigation of intelligent SCs through DL techniques. It proposes an innovative approach that combines single and hybrid models, including SARIMA, LSTM, ANN, RNN, and GB, with the goal of improving the accuracy of customer demand prediction.

The rest of this document is structured as follows: the subsequent section comprises an in-depth examination of existing literature, the third section presents the research methods and the procedural details employed as the foundation for this paper, the fourth section scrutinizes and deliberates on the experimental findings, analysis and discussions,the fifth and final section encapsulates the conclusions drawn in this paper, along with future prospects for the field.

2 Literature review

Demand forecasting involves predicting future market demand, and the accuracy of this forecast directly affects a company's production plan, inventory management [8] and customer satisfaction [9]. It can be classified into two primary types: qualitative forecasting and quantitative forecasting. Qualitative forecasting depends on subjective judgments and expert opinions, using methods like group discussions and the Delphi method for assessing and predicting product output. On the other hand, quantitative forecasting employs data to establish mathematical models for prediction.Presently, statistical methods such as time series models and grey forecasting models, along with advanced algorithms like ANNs and support vector machines, are commonly used in demand forecasting.

In recent times, due to the swift progress of AI, there have been numerous proposals for advanced demand prediction methods employing DL models to enhance the efficiency of SCM. AI holds the potential to enhance various aspects of SCM, ranging from order forecasting to delivery management. The utilization of DL techniques facilitates the rapid analysis of extensive datasets and the construction of effective prediction models. Given these advantages, diverse industries, including but not limited to fashion [10,11] retail [12-21], tourism [22], electricity [23-26], among others [27,28], have endeavored to enhance their SCM through the incorporation of AI techniques.

The subjective nature of qualitative forecasting often results in being influenced by the personal biases of the researcher, leading researchers to frequently opt for quantitative forecasting methods. For instance, certain scholars utilized the autoregressive integrated moving average (ARIMA) model to predict the recall volume of cars for companies engaged in auto importing [29]. In cases where time series exhibit significant fluctuations and the environment is less stable, traditional statistical forecasting methods may yield suboptimal results. Consequently, an increasing number of researchers have introduced DL

methods to enhance predictive accuracy. Some researchers have recommended using the ARIMA model or multi-layer perceptron (MLP) for forecasting flood flows [30,31]. For instance, [32] utilized an ANN model to forecast car sales in the Turkish region. In another context, [33] they presented a short-term prediction system utilizing bidirectional long short-term memory (Bi-LSTM) for smart power grids. Additionally, [34] utilized a RNN to forecast the quantity of damaged car parts. In the pursuit of improved forecasting precision, demand forecast models are increasingly transitioning from single-model prediction to combination-model prediction. Combination models primarily involve the integration of traditional forecasting methods [35] involves combining traditional methods or econometric forecasting with DL forecasting methods [36] and combination models founded on multiple DL single models [37]. Scholars have significantly improved the accuracy of combined forecasting models by preserving and integrating the strengths of individual models.Some scholars predict the demand for spare automotive parts using an enhanced LSTM model, and the accuracy of predictions can be increased by refining the prediction algorithm within DL [38]. Other studies employed ANNs and MLP integrated models for air pollution prediction [39,40]. When forecasting the traffic flow of port vessels, [41] applied the SARIMA-BP model, highlighting that the joint utilization of both models yields greater optimality compared to relying solely on the SARIMA model, especially in handling more volatile data. Certain researchers choose to integrate DL methods to improve the accuracy of forecasting models. For instance, [42] Predicted China's industrial carbon peak using the BP-LSTM model, illustrating that forecasting with two deep learning models is significantly more accurate than relying on a single deep learning model. In essence, employing a combined forecasting model allows for the integration of diverse model advantages, effectively addressing the challenge of unstable time series, enhancing prediction speed, and reducing errors.

Currently, there is a limited amount of research on demand prediction, highlighting the urgent need for greater attention and exploration in this area. Accurate forecasting of product demand is essential for guiding decision-making in subsequent production, transportation, storage, and sales operations within the intelligent SC. The accuracy of demand forecasting is a pivotal factor supporting automotive companies in expanding their market shares and boosting profits. Limitations exist within the automotive SC, although they have been less thoroughly investigated. However, there is a pressing need for more research in this specific type of SC, given its complexity and extensive nature.

Hence, this research introduces a combination of single and hybrid models, utilizing customer demand data for a products purchased by an OEM. The model aims to forecast future demand for these specific products, considering the volatility inherent in customer demand data.

3 Methodology

In our study, we are tasked with the complex challenge of predicting customer demand, a critical aspect of operations for our company in the automotive sector. To address this challenge comprehensively, we carefully selected a range of individual and combined models and organized the process following the methodology outlined in Figure 5.

3.1 Exploratory data analysis and preprocessing

Our study leverages a comprehensive dataset spanning from 2019 to 2023, comprising 60 columns rich with information encompassing customer profiles, project details, product specifications, operational metrics such as hours, pricing data, and vehicle attributes including age, brand, and model. To ensure data quality and consistency, we embarked on a rigorous data preprocessing and analysing phase. This involves integrating exploratory data analysis (EDA) into our process for gaining a deeper understanding of the underlying data characteristics. Through EDA, we conducted an initial exploration of the dataset, identifying trends, patterns, and seasonality that informed subsequent preprocessing and feature engineering steps. Figure 1, illustrate key insights gleaned from our EDA process, providing visual representations of the data distribution and relationships.

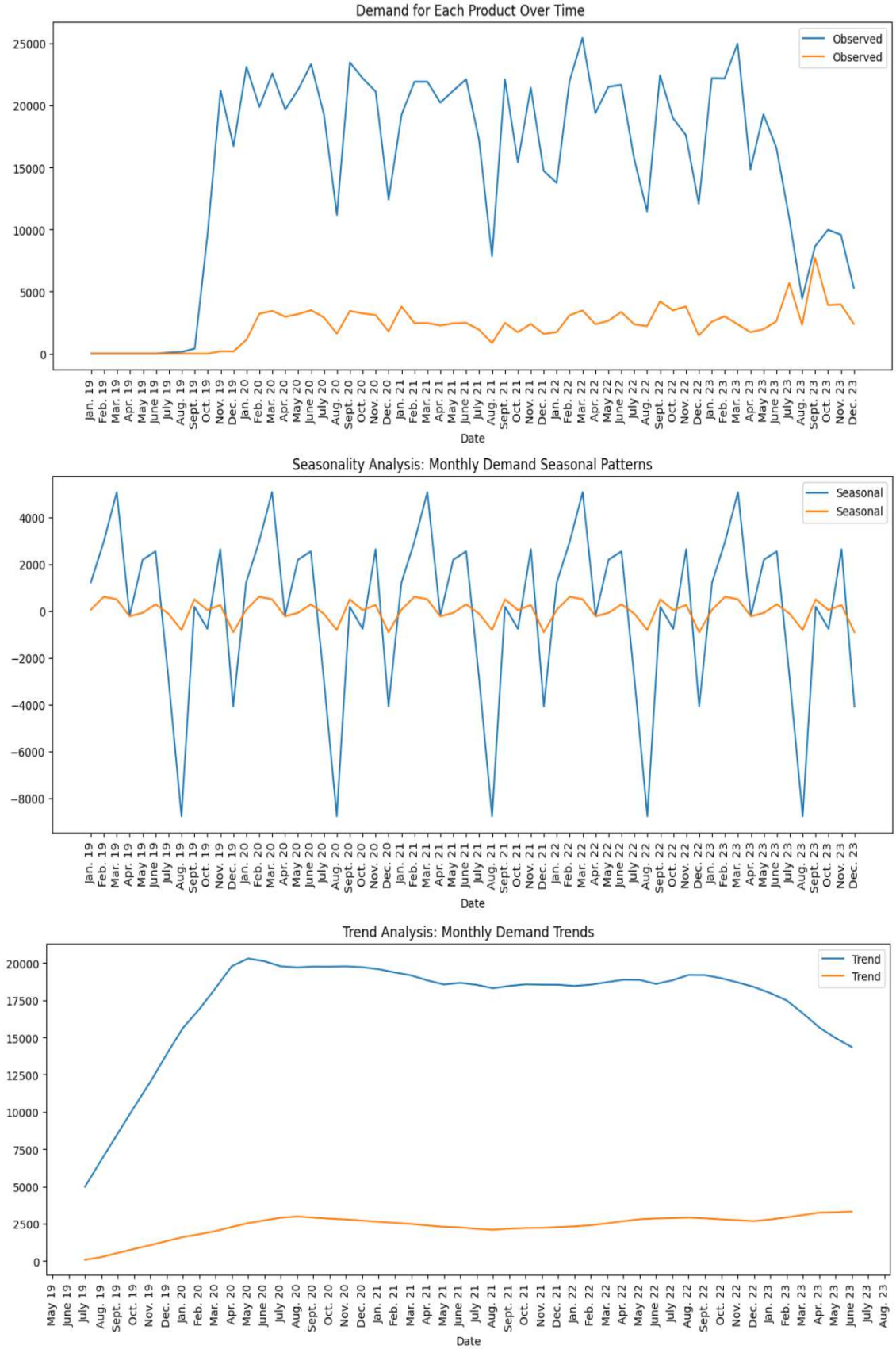

Figure 1 Data distribution, trend, seasonality

Some insightful observations from the trend were identified, such as the initial increase indicating a period of growth in demand, subsequent stabilization suggesting relatively constant demand, a slight smooth decrease indicating a gradual decline in demand over time, and significant fluctuations in demand occurring at regular intervals. This variability is mainly related to customer preferences, potentially influenced by seasonal factors such as holidays, sales trends, or other external influences. In seasonal decomposition, negative values represent deviations from the average seasonal pattern observed in the data, indicating periods where the actual demand is lower than expected based on typical seasonal behavior. These deviations present opportunities for improvement. By identifying periods of lower demand, businesses can explore strategies to stimulate demand during off-peak seasons.By analyzing the trend and seasonality components of the dataset, we are equipped to understand the underlying patterns in the demand data and make informed decisions to optimize operations.

3.2 Feature engineering

In the feature engineering step, we focus on extracting relevant features from the data to enhance the predictive power of our models. This involves the creation of both temporal and non-temporal features.For temporal features, we leverage the time-related aspects of the data, to capture trends, seasonality, and periodic patterns. Common temporal features include month, and year. These features provide valuable insights into the temporal dynamics of the data and can help improve the accuracy of our predictions. In addition to temporal features, we also engineer non-temporal features that capture other aspects of the data unrelated to time. These features include customer profiles, project details, product specifications. By encoding and transforming these features appropriately, we aim to capture meaningful information that can further enhance the predictive performance of our models.

3.3 Models architecture design

We commence our modeling approach by adopting SARIMA model, a classical time series forecasting model renowned for its ability to capture seasonal terms to capture periodic patterns in demand data, autoregressive terms for serial correlation, differencing to remove trends, and moving average terms for residual errors. By leveraging these components, SARIMA stands poised to offer insights into the nuanced temporal variations of customer demand, discerning seasonality, trends, and fluctuations in time-series data. Additionally, SARIMA's capability to combine ARIMA components with seasonal components enables the model to capture both non-seasonal and seasonal patterns effectively as in equation (1).

$$Y_t = \Phi_p Y_{t-p} + \theta_q \varepsilon_{t-q} + \phi_P Y_{t-P} + \Theta_Q \varepsilon_{t-Q} + \mu + \varepsilon_t \quad (1)$$

Where : Y_t represents the observed value at time t. Φ_p and Θ_q are autoregressive and moving average parametres for non-seasonal components ,respectively. Y_{t-P} and ε_{t-Q} are lagged values of the time series and residuals from previous observations,respectively. P and Q represent the seasonal periods. μ is the mean of the time series. ε_t Is white noise.

Building upon the foundation laid by SARIMA, we incorporate the LSTM model,as it is structure is well-suited for capturing long-term dependencies and complex temporal relationships in sequential data as in equations (2),(3),(4),(5),(6),(7), Figure 2. Its inclusion enhances our model's capacity to capture intricate patterns in customer demand.

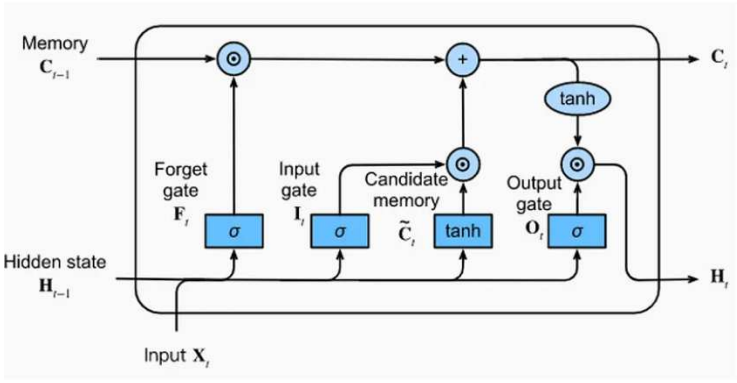

Figure 2 Cell structure of the LSTM

$$i_t = \sigma(W_{xi}x_t + W_{hi}h_{t-1} + W_{ci}c_{t-1} + b_i \quad (2)$$

$$f_t = \sigma(W_{xf}x_t + W_{hf}h_{t-1} + W_{cf}c_{t-1} + b_f \quad (3)$$

$$g_t = tanh(W_{xg}x_t + W_{hg}h_{t-1} + b_g \quad (4)$$

$$o_t = \sigma(W_{xo}x_t + W_{ho}h_{t-1} + W_{co}c_t + b_o \quad (5)$$

$$c_t = f_t * c_{t-1} + i_t * g_t \quad (6)$$

$$h_t = o_t * tanh(c_t) \quad (7)$$

Where: x_t is the input at time step t , h_{t-1} is the previous hidden state, c_{t-1} is the previous cell state (memory), i_t, f_t, g_t, and o_t are the input, forget, cell, and output gates, respectively. σ is the sigmoid activation function. W and b are the weight matrices and bias vectors for each gate.

In addition to SARIMA and LSTM, we consider the adoption of an ANN and RNN. These models offer versatility and scalability, allowing us to explore different facets of demand prediction and complement the strengths of SARIMA and LSTM.We deploy the ANN model with its capacity to learn intricate mappings between input features and output predictions as in equation (8), Figure 3, as well as RNN model is ability to analyze sequences of data by retaining memory of past inputs through loops in its architecture in equation (9), Figure 4. This ability allows RNNs to effectively recognize patterns and dependencies within sequential data, making them suitable for demand prediction.

The ANN model architecture

$$Y = f(\Sigma_{i-1}^{n} w_i x_i + b) \quad (8)$$

Where: y is the outpout of the neuron,f is the activation function, w_i are the weights of the connections from the previous layer, x_i are the inputs to the neuron,b is the bias term,n is the number of inputs to the neuron.

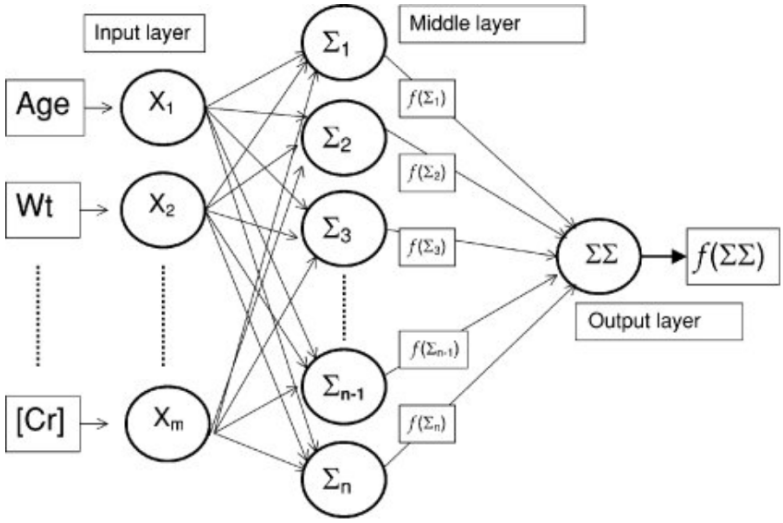

Figure 3 Cell structure of the ANN

The RNN model architecture

$$h_t = f(w_{hh}h_{t-1} + w_{xh}x_t + b_h) \quad y_t = f(w_{yh}h_t + b_y) \quad (9)$$

Where: h_t is the hidden state at time step t,f is the activation function, w_{hh} is the weight matrix for the input connections, h_{t-1} is the hidden state at the previous time step, x_t is the input at time step t, b_h is the bias term for the hidden layer. w_{yh} is the weight matrix for the output layer, h_t *and* b_y are the bias vectors for the hidden state and output layer respectively.

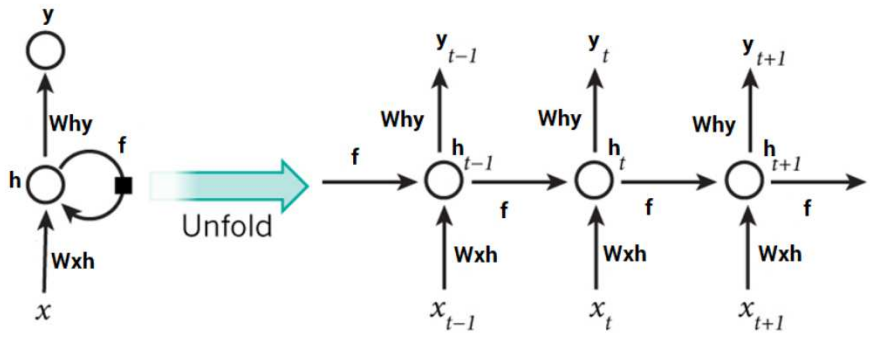

Figure 4 Cell structure of the RNN

3.4 Gradient boosting and final output prediction

After selecting the ANN and RNN models based on their performance metrics, we developed a pioneering hybrid model that integrates predictions from both models as inputs to a gradient boosting algorithm, as depicted in Figure 5. This innovative approach aims to capitalize on the diverse strengths of each model to enhance the overall predictive performance.

GB, a powerful ensemble learning technique, combines multiple weak learners (such as the ANN and RNN models) to create a robust predictive model. During the training phase, the GB model iteratively improves its predictions by minimizing errors from individual weak learners. By focusing on poorly predicted data points from previous iterations, the model gradually refines its predictions.

Once trained on the combined predictions from the ANN and RNN models, the GB model generates final output predictions. These predictions leverage insights from both models to accurately forecast future demand patterns.

By incorporating the strengths of both the ANN and RNN models through GB, the final output predictions are expected to be more robust and accurate, providing valuable insights for decision-making and resource allocation in demand forecasting scenarios.

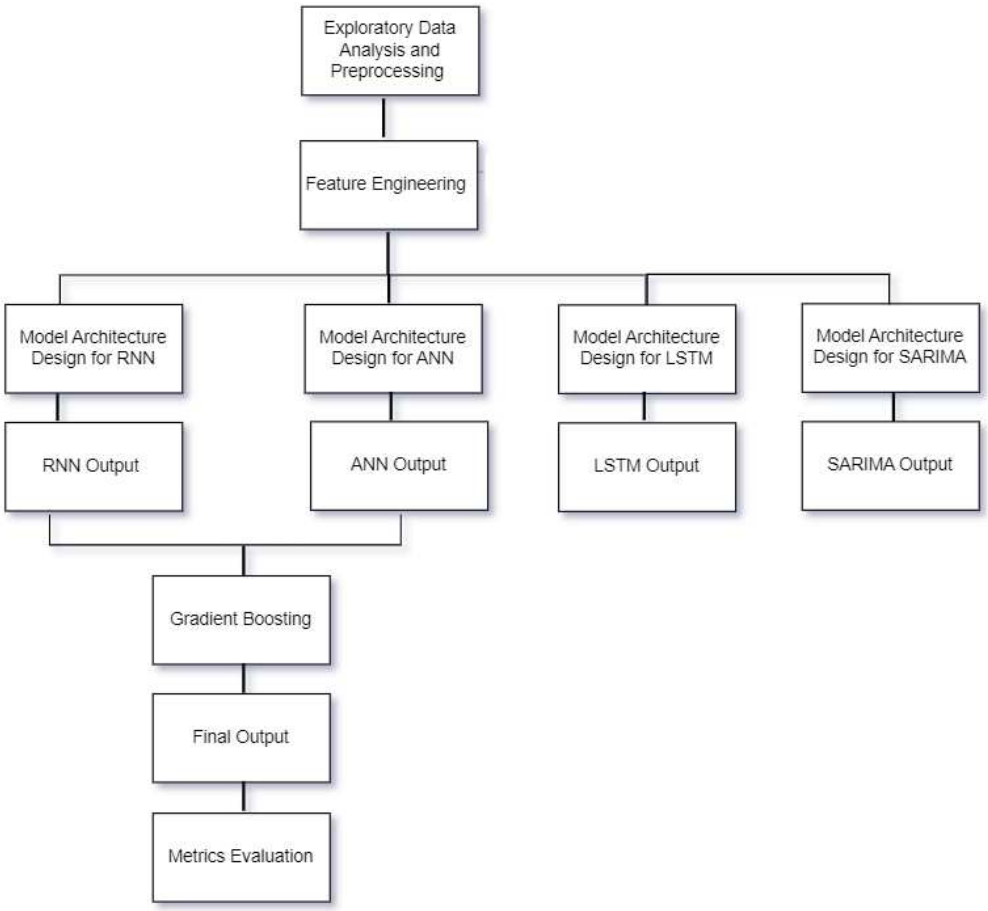

Figure 5 Demand forecasting with single and hybrid models

4 Results analysis and discussion

4.1 Models output

The models were compiled to visualize their performance. Through visual inspection of these plots, we can observe the performance of each model in capturing the underlying patterns and trends in the demand data.These plots in, Figure 6 and Figure 7, provide a graphical representation of the predicted values compared to the actual values, allowing for a qualitative assessment of each model's predictive capabilities.When comparing the LSTM and SARIMA models, we observe distinct patterns in their predictive capabilities.

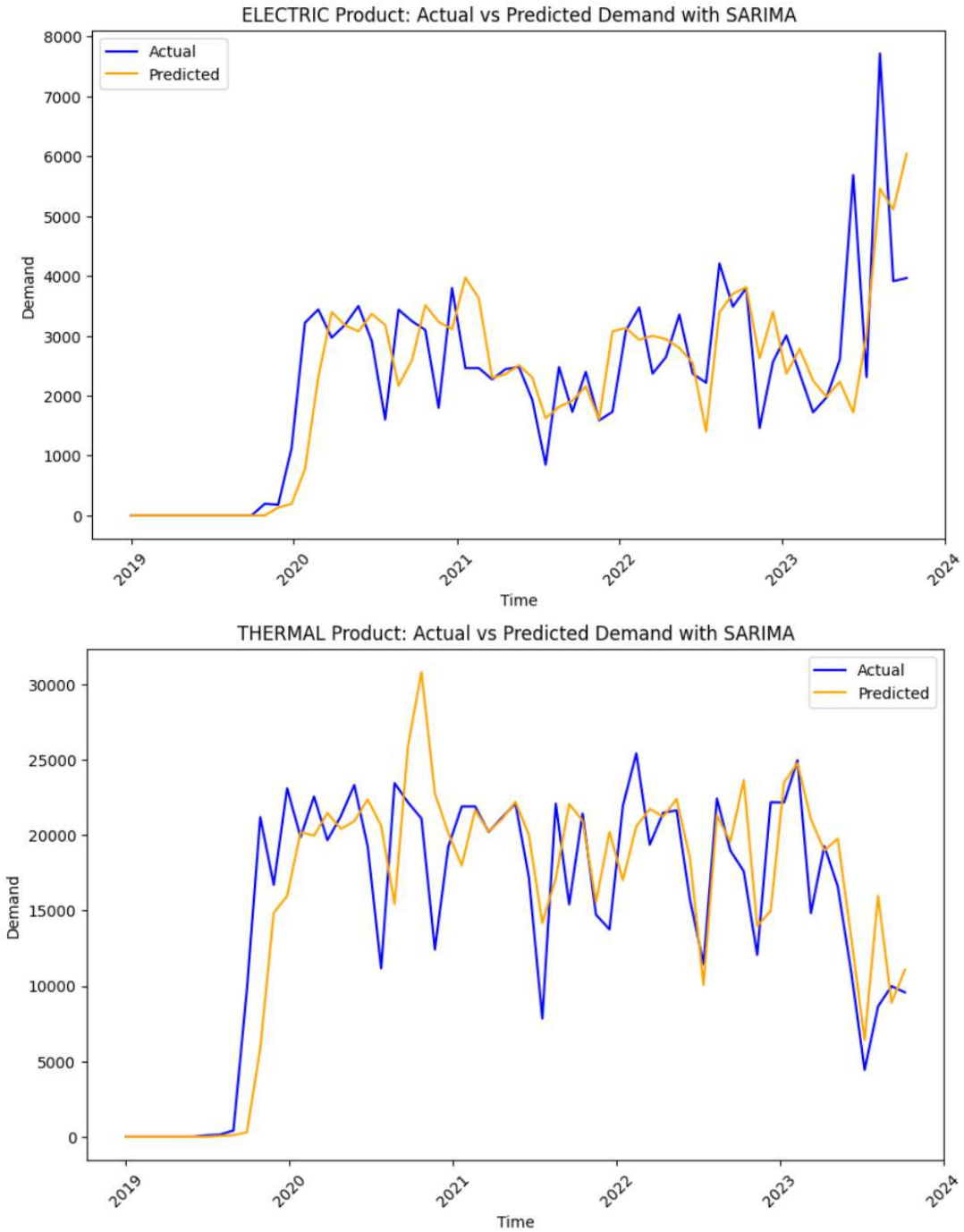

Figure 6 Product demand prediction using the SARIMA model (Actual vs. Predicted)

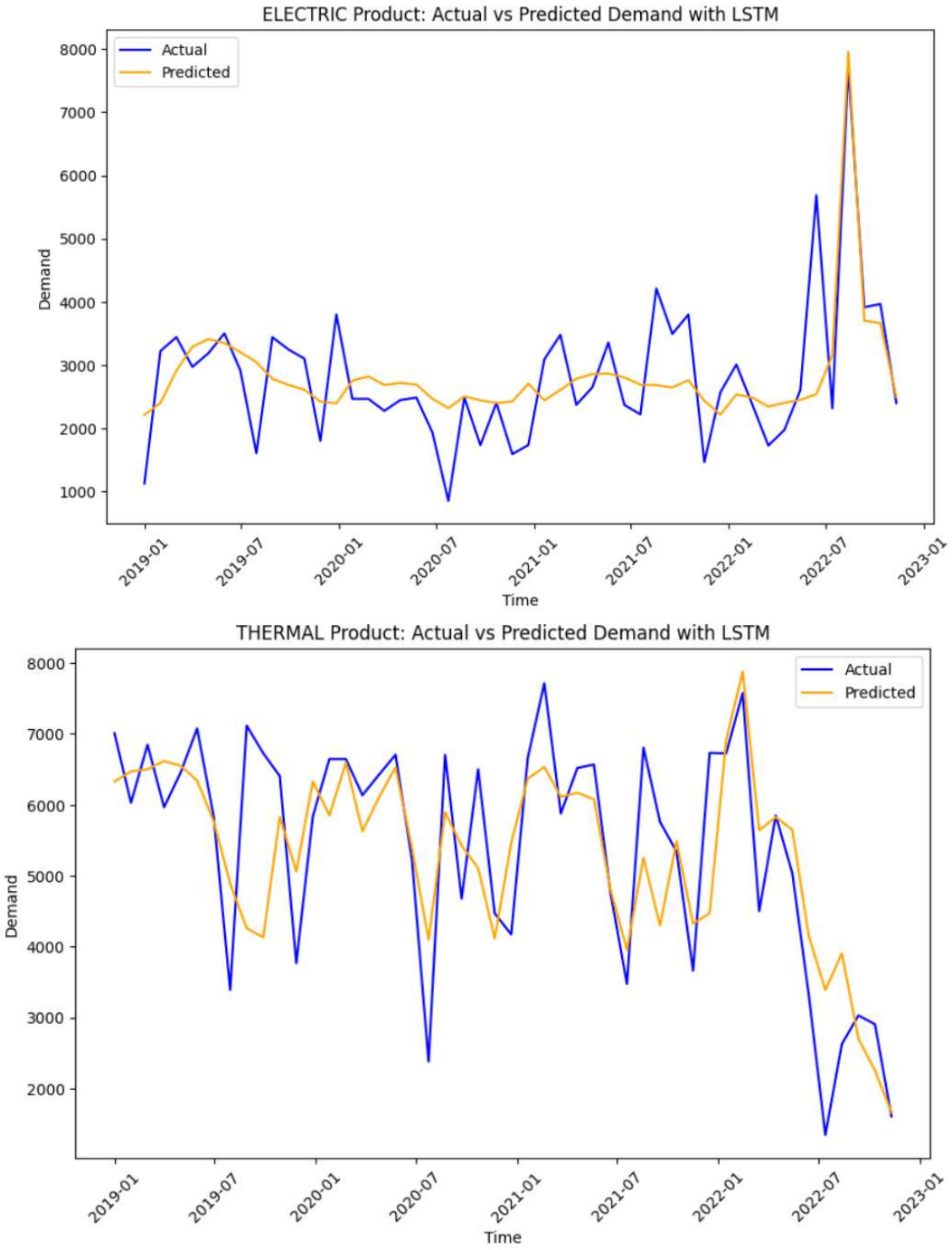

Figure 7 Product demand prediction using the LSTM model (Actual vs. Predicted)

The LSTM model uses the following hyperparameters: a look-back period of 12 time steps, 50 LSTM units with 'relu' activation, an input shape of (12, 1), a dense layer with 1 unit, the 'adam' optimizer, 'mse' as the loss function, 900 epochs for training, a batch size of 32, and a verbosity level of 0.For the SARIMA model the hyperparametres used are: order (p, d, q) for both thermal and electric products: (1, 1, 1) and seasonal order (P, D, Q, s) for both thermal and electric products: (1, 1, 1, 12).

The LSTM plot demonstrates stronger performance compared to SARIMA, aligning more closely with the actual demand values. Despite its complexity, LSTM effectively captures long-term dependencies in sequential data, contributing to its ability to predict customer demand in the automotive sector. However, while LSTM excels in capturing complex temporal relationships, there may still be room for improvement in certain aspects of its predictive accuracy.

In contrast, the SARIMA plot shows relatively weaker predictive performance compared to LSTM. While SARIMA is capable of modeling seasonality and temporal dependencies, it may struggle to fully capture the complexities of the demand data in this context. Its performance may be affected by the challenges posed by the automotive demand dynamics, resulting in less accurate predictions compared to LSTM.

As the performance of both LSTM and SARIMA still falls short of desired accuracy levels, we address this by exploring an ANN model.

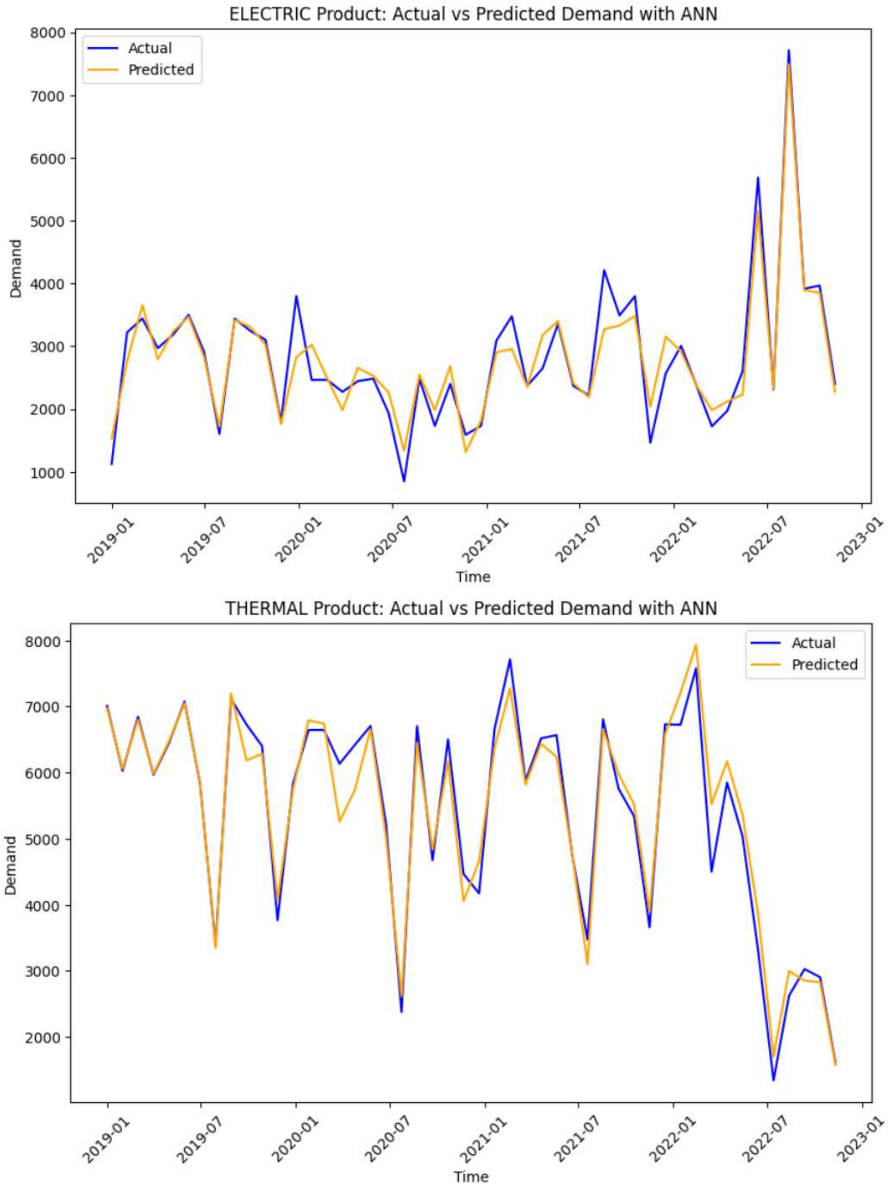

Figure 8 Product demand prediction using the ANN model (Actual vs. Predicted)

The ANN model, in Figure 8, demonstrates superior accuracy compared to both LSTM and SARIMA for both products. Its ability to effectively capture the complex patterns in the demand data suggests that ANN's architecture and learning mechanisms are well-suited for modeling the intricacies of automotive demand dynamics.

The ANN model uses the following hyperparameters: a look-back period of 12 time steps, 50 units in the first dense layer with 'relu' activation, 1 unit in the output layer, the 'adam' optimizer, 'mse' as the loss function, 800 epochs for training, a batch size of 32, and a verbosity level of 0.

In light of the superior performance demonstrated by the ANN model and the inherent ability of RNN architectures to capture sequential dependencies effectively, we employ the RNN model to further enhance predictive accuracy and address the challenges.

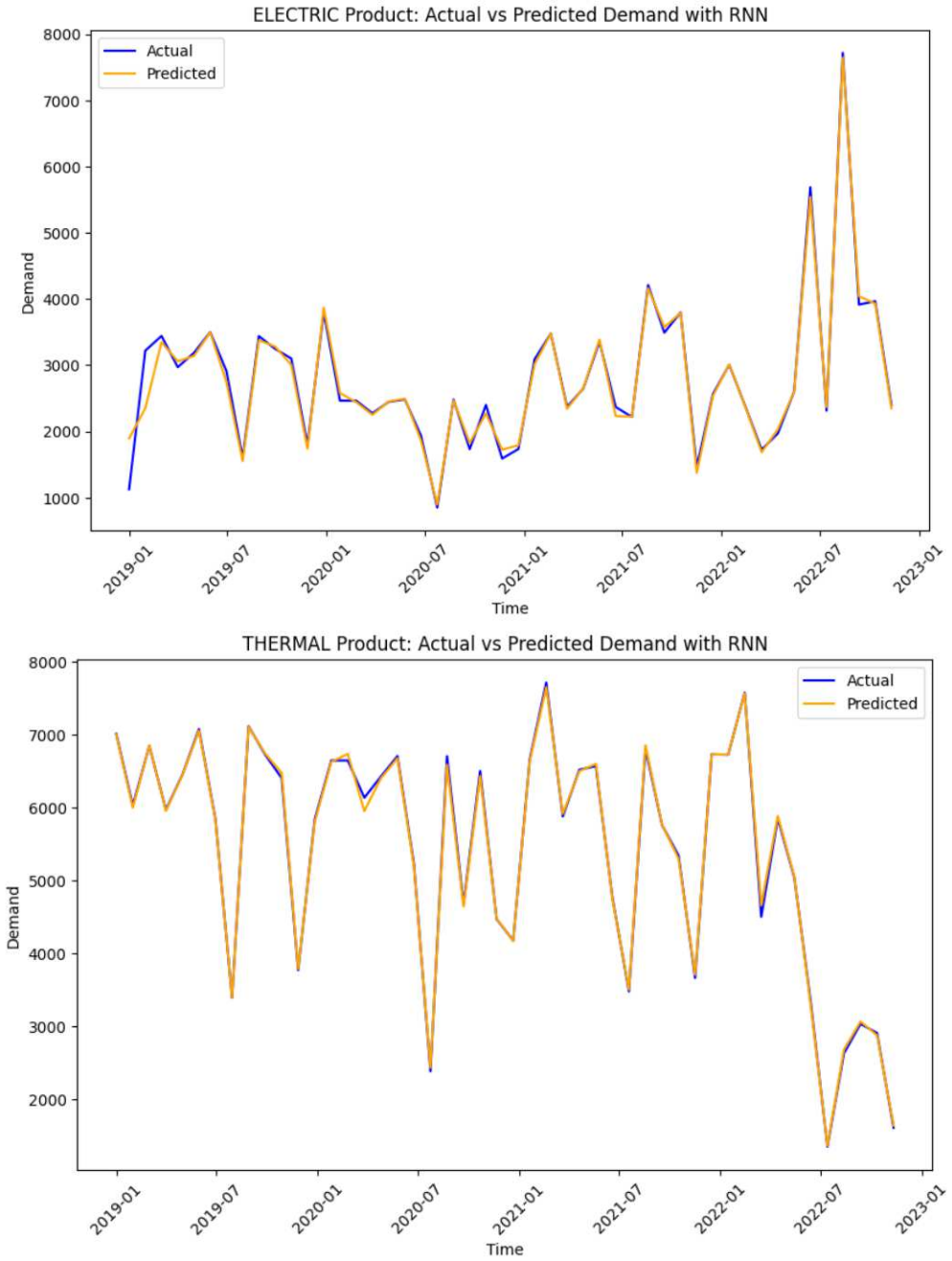

Figure 9 Product demand prediction using the RNN model (Actual vs. Predicted)

The RNN model hyperparameters are as follows: a look-back period of 12 time steps, 50 SimpleRNN units, an input shape of (12, 1), a single unit in the dense layer, 'adam' optimizer, 'mse' loss function, 900 epochs for training, a batch size of 32, and a verbosity level of 0.

The RNN model demonstrates, in Figure 9, the highest level of accuracy, with predicted values closely aligning with actual ones. This suggests that the RNN model effectively captures the underlying patterns and temporal dependencies in the data, making it the most reliable predictor among the single models evaluated.

To further boost the model's performance, we employ a hybrid approach that leverages the strengths of multiple models. Specifically, we combine outputs from both the ANN and RNN models and use them as input for the GB model.

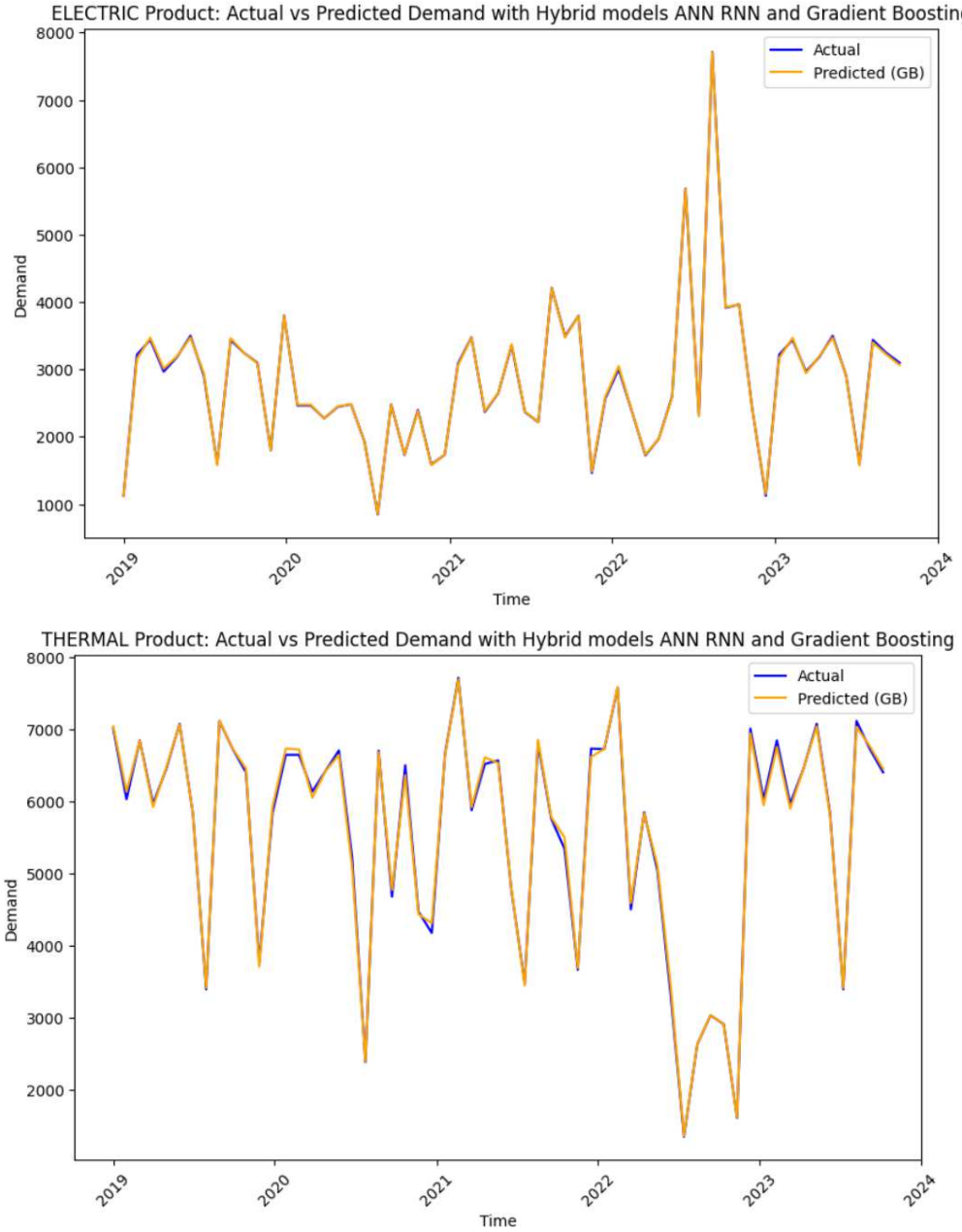

Figure 10 Product demand prediction using the hybrid model ANN-RNN and Gradient Boosting model (Actual vs. Predicted)

The GB model employs default hyperparameters provided by scikit-learn's GradientBoostingRegressor (Figure 10). These include using decision trees as base estimators, 100 estimators, a learning rate of 0.1, a max depth of 3 for each tree, a minimum number of samples required to split an internal node set to 2, a minimum number of samples required to be at a leaf node set to 1, and subsampling of the training dataset set to 1.0.

The GB emerges as the most effective model among the ensemble, outperforming the ANN, RNN, LSTM and SARIMA models. The hybrid architecture combines the complementary capabilities of ANN and RNN, effectively capturing complex patterns and sequential dependencies. Additionally, it leverages the ensemble learning technique of GB to enhance predictive accuracy.

By integrating diverse modeling approaches, we optimized the model's performance, aiming to achieve superior accuracy in forecasting automotive demand dynamics. This makes the hybrid model the optimal choice for customer demand forecasting in our case.

4.2 Metrics evaluation

We conducted a comprehensive evaluation of the performance of our demand forecasting models using two common metrics, MAE (10) and MSE (11).

$$MAE = \frac{1}{n} \sum_{i=1}^{n} |Y_i - \hat{Y}_i| \quad (10)$$

$$MSE = \frac{1}{n} \sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2 \quad (11)$$

Where: Y_i represents the actual value, $\hat{Y}_i$ represents the predicted value, and n represents the total number of observations.

These metrics were selected due to their effectiveness in quantifying the accuracy and reliability of predictive models, they capture different aspects of model performance. MAE focuses on the average magnitude of errors, while MSE considers both the magnitude and variance of errors.

By comparing MAE and MSE across SARIMA, LSTM, ANN, RNN, and GB models, we analyzed each model's accuracy and precision. The Table 1, below summarizes the performance metrics for both single and hybrid models.

Table 1 Performance metrics analysis for single and hybrid models for products

Metrics	Products	SARIMA	LSTM	ANN	RNN	GB (Hybrid model)
MAE	Electric	619.84	616.27	239.40	88.80	12.77
	Thermal	3014.96	776.62	248.06	96.70	37.18
MSE	Electric	924692.21	662561.52	111265.48	33114.56	332.34
	Thermal	20399280.60	1067173.73	111110.79	35855.71	2916.64

SARIMA exhibits relatively high MAE and MSE values across both electric and thermal product categories. This suggests that SARIMA's predictions deviate significantly from the actual values, indicating limited accuracy in demand forecasting.

LSTM performs better than SARIMA but still shows relatively high MAE and MSE values. While LSTM effectively captures some long-term dependencies in the data, its predictive accuracy falls short compared to the hybrid model with gradient boosting.

ANN demonstrates improved performance compared to SARIMA and LSTM, with lower MAE and MSE values. However, it still lags behind the hybrid model with GB, indicating room for improvement in accuracy.

RNN exhibits relatively low MAE and MSE values compared to SARIMA, LSTM, and ANN. It demonstrates strong performance in capturing underlying patterns and temporal dependencies, making it a reliable predictor among the individual models.

However, despite the similarity in products characteristics, there are significant differences in the MAE and MSE values between the thermal and electric products across all models. This discrepancy indicates that the predictive accuracy varies depending on the type of product, with the thermal product consistently yielding higher MAE and MSE values compared to the electric product. These findings suggest that the models may perform differently when applied to different types of products.

Overall, the hybrid model combining RNN and ANN with GB consistently achieves the lowest MAE and MSE values across both electric and thermal product categories. This indicates superior accuracy in demand prediction compared to individual models. The ensemble of RNN and ANN, combined with GB, effectively minimizes prediction errors and enhances the overall predictive performance.

5 Conclusions

In conclusion, this research paper has investigated various predictive models for demand forecasting in the automotive sector. Through comprehensive analysis and evaluation, we have demonstrated the effectiveness of a hybrid model combining RNN and ANN with GB in predicting demand, surpassing single models such as SARIMA, LSTM, ANN, and RNN.

The results indicate that while single models exhibit varying degrees of accuracy in demand prediction, the hybrid model consistently outperforms them. By leveraging the strengths of multiple models and ensemble learning techniques, the hybrid model demonstrates superior predictive accuracy, as evidenced by lower MAE and MSE values across both electric and thermal product categories.

In the context of demand forecasting, we looked into the performance difference between LSTM and ANN models. Remarkably, our test findings showed that, in terms of prediction accuracy, the ANN model performed better than the LSTM model, contradicting the widely accepted belief that LSTM performs better when it comes to time-series data processing. Despite the surprising performance difference that was found, this study emphasizes how crucial it is to comprehend how various models behave in practical settings. We can learn many things about the advantages, disadvantages, and task-specific applicability of LSTM and ANN models by methodically investigating the elements causing the performance disparity between them. Future studies and real-world applications in demand forecasting and other time-series prediction challenges will be greatly impacted by this insight. It highlights the requirement for careful

model selection, thorough experimentation, and continuous refinement to ensure optimal performance and reliability in real-world settings.

It's crucial to recognize this study's limitations, though. The use of historical data, which might not accurately reflect unexpected or unexpected shifts in demand patterns, is one drawback. Furthermore, the specifics of the automobile industry and the accessibility of data may have an impact on how effective the hybrid model is.

Future studies should investigate how external factors like customer preferences, changes in legislation, and economic situations affect the accuracy of demand forecasting. Furthermore, examining the hybrid model's scalability and computing efficiency in scenarios of real-time demand forecasting would yield important information for useful application in the automobile sector.

Moreover, the integration of advanced methodologies like anomaly detection algorithms and reinforcement learning may improve the resilience of demand forecasting models, especially in situations that are uncertain and dynamic. Furthermore, investigating the incorporation of data from non-traditional sources like social media, IoT devices, and SC networks may present new perspectives into demand forecasting and enhance its precision.

In summary, this study offers valuable insights into demand forecasting within the automotive sector. However, it identifies specific limitations and areas for improvement, underscoring the need for further research to advance the field towards more accurate and actionable forecasting methodologies.

References

[1] RAFATI, E.: The bullwhip effect in supply chains: Review of recent development, *Journal of Future Sustainability*, Vol. 2, No. 3, pp. 81-84, 2022. https://doi.org/10.5267/j.jfs.2022.9.007

[2] MOHSEN, B.M.: Impact of Artificial Intelligence on Supply Chain Management Performance, *Journal of Service Science and Management*, Vol. 16, No. 1, pp. 44-58, 2023. https://doi.org/10.4236/jssm.2023.161004

[3] FEIZABADI, J.: Machine learning demand forecasting and supply chain performance, *International Journal of Logistics Research and Applications*, Vol. 25, No. 2, pp. 119-142, 2022. https://doi.org/10.1080/13675567.2020.1803246

[4] SUN, X., YANG, P., TAO, Y., BIAN, H.: Improving ecosystem services supply provides insights for sustainable landscape planning: A case study in Beijing, China, *Science of The Total Environment*, Vol. 802, No. January, 149849, 2022. https://doi.org/10.1016/j.scitotenv.2021.149849

[5] ALAMEER, Z., FATHALLA, A., LI, H., JIANHUA, J.: Multistep-ahead forecasting of coal prices using a hybrid deep learning model, *Resources Policy*, Vol. 65, No. March, 101588, 2020. https://doi.org/10.1016/j.resourpol.2020.101588

[6] LIU, C., SHU, T., CHEN, S., WANG, K., LAI, K., GAN, L.: An improved grey neural network model for predicting transportation disruptions, *Expert Systems with Applications*, Vol. 45, No. 2, pp. 331-340, 2016. https://doi.org/10.1016/j.eswa.2015.09.052

[7] LIAN, R., PENG, J., WU, Y., TAN, H., ZHANG, H.: Rule-interposing deep reinforcement learning based energy management strategy for power-split hybrid electric vehicle, *Energy*, Vol. 197, No. April, 117297, 2020. https://doi.org/10.1016/j.energy.2020.117297

[8] SINGH, D., VERMA, A.: Inventory Management in Supply Chain, *MaterialsToday: Proceedings*, Vol. 5, No. 2, pp. 3867-3872, 2018. https://doi.org/10.1016/j.matpr.2017.11.641

[9] ABOLGHASEMI, M., BEH, E., TARR, G., GERLACH, R.: Demand forecasting in supply chain: The impact of demand volatility in the presence of promotion, *Computers & Industrial Engineering*, Vol. 142, No. April, 106380, 2020. https://doi.org/10.1016/j.cie.2020.106380

[10] LI, Y., YANG, Y., ZHU, K., ZHANG, J.: Clothing Sale Forecasting by a Composite GRU–Prophet Model With an Attention Mechanism, *IEEE Transactions Industrial Informatics*, Vol. 17, No. 12, pp. 8335-8344, 2021. https://doi.org/10.1109/TII.2021.3057922

[11] GIRI, C., CHEN, Y.: Deep learning for demand forecasting in the fashion and apparel retail industry, *Forecasting*, Vol. 4, No. 2, pp. 565-581, 2022. https://doi.org/10.3390/forecast4020031

[12] LINGXIAN, Y., JIAQING, K., SHIHUAI, W.: *Online Retail Sales Prediction with Integrated Framework of K-mean and Neural Network*, In: Proceedings of the 2019 10th International Conference on E-business, Management and Economics, Beijing China: ACM, Vol. 4, No. 2, pp. 115-118, 2019. https://doi.org/10.1145/3345035.3345048

[13] KILIMCI, Z.H.: An improved demand forecasting model using deep learning approach and proposed decision integration strategy for supply chain, *Complexity*, Vol. 2019, 9067367, pp. 1-15, 2019. https://doi.org/10.1155/2019/9067367

[14] LIAO, S., RAO, W.: *Accurate Demand Forecasting for Retails with Deep Neural Networks*, In: Proceedings of the 23rd International Conference on Extending Database Technology (EDBT), March 30-April 2, 2020, pp. 455-458, 2020. https://doi.org/10.5441/002/edbt.2020.56

[15] LI, X., DU, J., WANG, Y., CAO, Y.: *Automatic Sales Forecasting System Based on LSTM Network*, In: 2020 International Conference on Computer Science and Management Technology (ICCSMT), IEEE, pp. 393-396, 2020. https://doi.org/10.1109/ICCSMT51754.2020.00088

[16] PALKAR, A., DESHPANDE, M., KALEKAR, S., JASWAL, S.: *Demand Forecasting in Retail Industry*

for Liquor Consumption using LSTM, In: 2020 International Conference on Electronics and Sustainable Communication Systems (ICESC), Coimbatore, India, IEEE, pp. 521-525, 2020. https://doi.org/10.1109/ICESC48915.2020.9155712

[17] CHEN, K.: *An online retail prediction model based on AGA-LSTM neural network*, In: 2020 2nd International Conference on Machine Learning, Big Data and Business Intelligence (MLBDBI), IEEE, pp. 145-149, 2020. https://doi.org/10.1109/MLBDBI51377.2020.00032

[18] CHEN, J., KOJU, W., XU, S., LIU, Z.: *Sales forecasting using deep neural network and SHAP techniques*, In: 2021 IEEE 2nd International Conference on Big Data, Artificial Intelligence and Internet of Things Engineering (ICBAIE), IEEE, pp. 135-138, 2021. https://doi.org/10.1109/ICBAIE52039.2021.9389930

[19] KAUNCHI, P., JADHAV, T., DANDAWATE, Y., MARATHE, P.: *Future Sales Prediction for Indian Products Using Convolutional Neural Network-Long Short Term Memory*, In: 2nd Global Conference for Advancement in Technology (GCAT), Bangalore, India, IEEE, pp. 1-5, 2021. https://doi.org/10.1109/GCAT52182.2021.9587668

[20] ISLAM, MD T., AYON, E.H., GHOSH, B.P., CHOWDHURY, MD S., SHAHID, R., ROY PUJA, A., RAHMAN, S., BHUIYAN, M.S., NGUYEN, T.N.: Revolutionizing Retail A Hybrid Machine Learning Approach for Precision Demand Forecasting and Strategic Decision- Making in Global Commerce, *Journal of Computer Science and Technology Studies*, Vol. 6, No. 1, pp. 33-39, 2024. https://doi.org/10.32996/jcsts.2024.6.1.4

[21] REZKI, N., MANSOURI, M.: Improving supply chain risk assessment with artificial neural network predictions, *Acta logistica*, Vol. 10, No. 4, pp. 645-658, 2023. https://doi.org/10.22306/al.v10i4.444

[22] BI, J.-W., LI, H., FAN, Z.-P.: Tourism demand forecasting with time series imaging: A deep learning model, *Annals of Tourism Research*, Vol. 90, No. September, 103255, 2021. https://doi.org/10.1016/j.annals.2021.103255

[23] CHOI, E., CHO, S., KIM, D.K.: Power demand forecasting using long short-term memory (LSTM) deep-learning model for monitoring energy sustainability, *Sustainability*, Vol. 12, No. 3, 1109, pp. 1-14, 2020. https://doi.org/10.3390/su12031109

[24] RUAN, G., KIRSCHEN, D.S., ZHONG, H., XIA, Q., KANG, C.: Estimating demand flexibility using Siamese LSTM neural networks, *IEEE Transactions on Power Systems*, Vol. 37, No. 3, pp. 2360-2370, 2021. https://doi.org/10.1109/TPWRS.2021.3110723

[25] IRFAN, M., SHAF, A., ALI, T., ZAFAR, M., RAHMAN, S., MURSAL, S.N.F., ALTHOBIANI, F., ALMAS, M.A., ATTAR, H.M., ABDUSSAMIEE, N.: Multi-region electricity demand prediction with ensemble deep neural networks, *Plos One*, Vol. 18, No. 5, e0285456, 2023. https://doi.org/10.1371/journal.pone.0285456

[26] QI, Y., LI, C., DENG, H., CAI, M., QI, Y., DENG, Y.: *A Deep Neural Framework for Sales Forecasting in E-Commerce*, In: Proceedings of the 28th ACM International Conference on Information and Knowledge Management, Beijing China, ACM, pp. 299-308, 2019. https://doi.org/10.1145/3357384.3357883

[27] KHALESIAN, M., FURNO, A., LECLERCQ, L.: Improving deep-learning methods for area-based traffic demand prediction via hierarchical reconciliation, *Transportation research part C: emerging technologies*, Vol. 159, No. February, 104410, 2024. https://doi.org/10.1016/j.trc.2023.104410

[28] HU, A., STOCKMAN, S., WU, X., WOOD, R., ZHI, B., CHÉN, O.Y.: Enhancing Uncertain Demand Prediction, *Machine Learning*, Vol. 2024, pp. 1-16, 2024. https://doi.org/10.48550/arXiv.2404.18670

[29] JEONG, S., PARK, S., KIM, S.: Analysis of the recall demand pattern of imported cars and application of ARIMA demand forecasting model, *Journal of the Society of Korea Industrial and Systems Engineering*, Vol. 43, No. 4, pp. 93-106, 2020. https://doi.org/10.11627/jkise.2020.43.4.093

[30] BELOTTI, J.: Neural-based ensembles and unorganized machines to predict streamflow series from Hydroelectric plants, *Energies*, Vol. 13, No. 18, 4769, pp. 1-22, 2020. https://doi.org/10.3390/en13184769

[31] YANG, X., ZHOU, J., FANG, W., WANG, Y.: An ensemble flow forecast method based on autoregressive model and hydrological uncertainty processer, *Water*, Vol. 12, No. 11, 3138, pp. 1-15, 2020. https://doi.org/10.3390/w12113138

[32] KAYA, A., KAYA, G., ÇEBI, F.: *Forecasting automobile sales in Turkey with artificial neural networks*, In: Research anthology on artificial neural network applications, IGI Global, pp. 1478-1489, 2022. https://doi.org/10.4018/978-1-6684-2408-7.ch072

[33] MUNAWAR, S., JAVAID, N., KHAN, Z.A., CHAUDHARY, N.I., RAJA, M.A.Z., MILYANI, A.H., AHMED AZHARI, A.: Electricity Theft Detection in Smart Grids Using a Hybrid BiGRU–BiLSTM Model with Feature Engineering-Based Preprocessing, *Sensors*, Vol. 22, No. 20, 7818, pp. 1-18, 2022. https://doi.org/10.3390/s22207818

[34] LEE, J.-G., KIM, T., SUNG, K.W., HAN, S.W.: Automobile parts reliability prediction based on claim data: The comparison of predictive effects with deep learning, *Engineering Failure Analysis*, Vol. 129, No. November, 105657, 2021. https://doi.org/10.1016/j.engfailanal.2021.105657

[35] ZHANG, X., ZHENG, Y., WANG, S.: A Demand Forecasting Method Based on Stochastic Frontier Analysis and Model Average: An Application in Air Travel Demand Forecasting, *Journal of Systems Science and Complexity*, Vol. 32, pp. 615-633, 2019. https://doi.org/10.1007/s11424-018-7093-0

[36] FAN, D., SUN, H., YAO, J., ZHANG, K., YAN, X., SUN, Z.: Well production forecasting based on ARIMA-LSTM model considering manual operations, *Energy*, Vol. 220, No. April, 119708, 2021. https://doi.org/10.1016/j.energy.2020.119708

[37] YAN, R., LIAO, J., YANG, J., SUN, W., NONG, M., LI, F.: Multi-hour and multi-site air quality index forecasting in Beijing using CNN, LSTM, CNN-LSTM, and spatiotemporal clustering, *Expert Systems with Applications*, Vol. 169, No. May, 114513, 2021. https://doi.org/10.1016/j.eswa.2020.114513

[38] CHANDRIAH, K.K., NARAGANAHALLI, R.V.: RNN / LSTM with modified Adam optimizer in deep learning approach for automobile spare parts demand forecasting, *Multimedia Tools and Applications*, Vol. 80, pp. 26145-26159, 2021. https://doi.org/10.1007/s11042-021-10913-0

[39] SIWEK, K., OSOWSKI, S.: Improving the accuracy of prediction of PM10 pollution by the wavelettransformation and an ensemble of neural predictors, *Engineering Applications of Artificial Intelligence*, Vol. 25, No. 6, pp. 1246-1258, 2012. https://doi.org/10.1016/j.engappai.2011.10.013

[40] DE MATTOS NETO, P.S.G., FIRMINO, P.R.A., SIQUEIRA, H., DE SOUZA TADANO, Y., ALVES, T.A., DE OLIVEIRA, J.F.L., DA NÓBREGA MARINHO, M.H.M., MADEIRO, F.: Neural-based ensembles for particulate matter forecasting, *IEEE Access*, Vol. 9, pp. 14470-14490, 2021. https://doi.org/10.1109/ACCESS.2021.3050437

[41] WANG, D., MENG, Y., CHEN, S., XIE, C., LIU, Z.: A Hybrid Model for Vessel Traffic Flow Prediction Based on Wavelet and Prophet, *Journal of Marine Science and Engineering*, Vol. 9, No. 11, 1231, pp. 1-16, 2021. https://doi.org/10.3390/jmse9111231

[42] MA, X., LI, M., TONG, J., FENG, X.: Deep learning combinatorial models for intelligent supply chain demand forecasting, *Biomimetics*, Vol. 8, No. 3, 312, pp. 1-16, 2023. https://doi.org/10.3390/biomimetics8030312

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Reasons, benefits and challenges on the road to automated internal transportation

Kornelia Osieczko-Potoczna
Rzeszów University of Technology, Arcus 305, ul. Poznańska 2A, 35-959 Rzeszów, Al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland, EU, k.osieczko@prz.edu.pl

Keywords: elements of logistics, intralogistics solutions, automation, AGV, flow of materials.
Abstract: The article discusses the topic of available solutions related to process automation in companies. The focus is on intralogistics solutions, especially in the context of robotization of transport, using the example of automatically controlled vehicles. Industry 5.0, in addition to automation, pays attention to the human factor, stabilization and the environmental aspect, which is a challenge for many companies. Large organizations are automating their processes in an effort to increase flexibility and respond quickly to customer requirements. Wanting to match market requirements will be a particular challenge for small and medium-sized companies. The purpose of this article was to study and describe the case of a manufacturing company that decided to change the means of internal transportation - to automated. The article answers the research questions posed for what reasons companies are interested in intralogistics solutions and what challenges organizations face when implementing such solutions. The paper uses literature analysis and qualitative research in the form of a case study. The benefits to organizations of automating material handling are presented, which can be particularly beneficial information for the small and medium-sized business sector. A qualitative study conducted at a Polish automotive company shows that the implementation of AGV robots has significantly improved the efficiency of internal logistics, reducing the risk of accidents and increasing process systematization. These results confirm the growing interest in automation, which contributes to reducing costs, increasing revenues and meeting environmental requirements.

1 Introduction

The global market and e-commerce are contributing to the increasing demands of stakeholders, who expect high-quality products, delivered at the right place and time and at the lowest possible price [1]. Constantly changing consumer buying behaviour requires manufacturers to individualize production, variety, flexibility and shorter delivery times [2]. The aforementioned factors influence organizations' search for proven solutions to meet the expectations set by customers.

Logistics [3] focuses on how to use new technologies in a way that will increase the efficiency of an organization's operations. Modern solutions aim to improve the level of service so that logistics is characterized by faster response and better use of resources. Innovative solutions can support the transformation of businesses to meet Industry 4.0. or Industry 5.0.

Currently, companies are looking for solutions, investing in improvements that integrate processes and information flow [4,5]. The internal ordering and delivery system should allow for fluidity in the processes taking place, preventing waiting for material or even stopping entire lines. The speed of goods and information flows, maintenance of quality and efficiency of the logistics processes being carried out depend on the selection of appropriate equipment or software. The use of available technologies and devices in manufacturing companies is conditioned by the search for opportunities to improve internal processes. Organizations are also striving to digitize internal processes.

As the very definition of intralogistics indicates, such solutions should include and enable the organization, control, implementation and optimization of the internal flow of materials and information, as well as the handling of goods in both the business sector and public institutions. Currently, there is a strong emphasis on automation and digitization of processes that will take into account and facilitate human work and cooperation with robots [6]. For this, it is important to learn about intralogistics solutions, work on them, and point out good practices to others or suggestions for their improvement on the way to automating and digitizing the organization's operations.

Many recognize that the future of the logistics industry and its development is related to the application of innovative solutions to improve the quality of logistics services [7]. Taking into account the organization's pursuit of Industry 4.0, environmental aspects and meeting customer requirements, companies are striving to streamline internal processes. Using available equipment and systems, and implementing them correctly, enables a company to improve the flow of products and information. Industry 4.0 is a concept for the transformation of enterprises, related to the improvement of processes carried out internally using available technologies. Above all, it seeks to digitize and automate processes consequently facilitating the meeting of increasing market expectations [8]. Logistics for the Fourth Industrial Revolution focuses on how to use new technologies in a

way that will increase the flexibility, efficiency and productivity of an organization's operations.

The current fourth stage of logistics development offers the possibility of new business models, leading to standardization, reduction of material transportation and storage, thus creating added value in the processes taking place, including from an environmental perspective [9]. Today's logistics can be described as globally interconnected supply and value chains that are highly flexible and complex, thus underpinning modern supply and production concepts. Companies are looking for solutions to meet current challenges in the form of individualization, while optimizing production processes and costs [10]. The challenge is to apply available technologies and equipment in the field of Industry 4.0 [11]. Key technologies include intra-organizational logistics - called intralogistics.

Intralogistics refers to organizations whose activities involve the internal movement of materials. It is applicable to manufacturing companies or those involved in receiving goods and/or moving them between specific points. It includes subsystems such as warehousing, storage, picking and conveyor and transport systems [12]. In publications describing Industry 4.0 enterprises, intralogistics occupies a key position [13-15]. The implementation of available intralogistics solutions in the industrial world is playing an increasingly important role, due to the optimization and automation of processes and facilitating the flow of information and materials within a company [16]. Technological advances, emerging systems, and robots are designed to facilitate human work, automating it, eliminating the possibility of error and streamlining processes within the organization.

Given the advances in technology, widespread automation of production processes, increasing stakeholder demands and changing environments (pandemic, armed conflict, price increases, environmental aspects), companies face a huge challenge. It's hard to adapt to the changes taking place without knowing what solutions are available, or because they lack the necessary skills to sensibly select and apply something that can make work easier and allow further automation of processes. Manufacturing companies are also reluctant to share knowledge and experience with other entities. From a scientific and business perspective, there should be research and publication of works that can help other companies, especially small and medium-sized ones, on the road to automation and digitization of processes.

In connection with the topic addressed, two research questions were posed:

- for what reasons are companies interested in intralogistics solutions?
- what challenges do organizations face in implementing such solutions?

2 Literature review

The key areas of intralogistics are the use of appropriate infrastructure and storage systems for the implementation of internal logistics processes, management and the use of information technology. The right combination and alignment of solutions, promotes transparency of processes, information exchange and efficient execution of intended tasks. Intralogistics defines a future-oriented industry, representing all suppliers of conveyor technology, warehousing, systems, services and logistics software, enabling the organization, optimization and control of material and information flows in industry, commerce and public institutions [17]. It emphasizes the use of appropriate equipment, and thus the proper selection of suppliers of equipment, systems, software, along with accompanying services.

Currently there is talk of Industry 5.0 - focusing attention, in addition to automation, on the human aspect. The available digital solutions, modern technology is designed to facilitate work and/or cooperation with humans, placing human needs with the solutions of Industry 4.0. Additional aspects that Industry 5.0 pays attention to are the environment and resilience to crises - ensuring stability [18]. Automation of logistics processes, including intralogistics, is one of the key elements of Industry 5.0.

The concept of moving to the target level in intralogistics, is linked to the Internet of Things (IoT). Using automated and autonomous transport vehicles, control and communication between units is performed automatically through software. Being able to react in real time to changes in the surrounding environment, self-controlled entities increase the level of flexibility [19]. With the rapid development of IoT, networks based on wireless communication technologies are increasingly being used in Automated Guided Vehicle - AGVs [20].

Increased interest in intralogistics solutions can be observed. This trend is confirmed by a report published by the International Federation of Robotics which noted an increase in robot sales. According to the ISO 8373:2012 definition, a robot means "an automatically controlled, reprogrammable, multifunctional manipulator, programmable in three or more axes, that can be stationary or mobile for use in industrial automation applications." A distinction can be made between industrial and service robots. An industrial robot is "an automatically controlled, reprogrammable multifunctional manipulator programmable in three or more axes," while a service robot performs tasks for people or equipment excluding industrial automation applications.

One of the intralogistics solutions is automated robots (AGVs) or autonomous robots - (Autonomous Mobile Robots -AMR). In 2020, there was a 41% increase in sales of service robots compared to the previous year. The largest number (44,000 units) were applied to transportation and logistics, 34,000 to professional

cleaning, 18,000 in medical robotics, 15,000 in hospitality, and 7,000 in agriculture [21].

Among the market trends contributing to robot sales growth in the report are:

- localization and regionalization of supply chains (closer to the customer, avoiding problematic situations related to politics, security rules, possible impediments in supply chains),
- lower cost of ownership (growing supply of low-cost robots),
- individualization of production for a growing number of products (digitalization of production from order acceptance to delivery, robots influence the reduction of unit costs of mass production).

Advances in other technologies (technology trends) such as 5G, cloud computing, new machine vision, artificial intelligence (AI), are fostering the expansion of robot applications and improving their performance (speed and quality). Companies are implementing innovative solutions to match Industry 4.0 hoping to reduce production costs and wanting to gain a competitive edge. They are betting on automation, improving the quality of the products they offer and improving productivity [22].

Often in tandem with the use of automated or autonomous vehicles in internal transportation, reusable packaging is being introduced in companies. As IFR's research confirms, the use of reusable packaging reduces waste. Robotized production also has an impact on reducing the proportion of rejects, thereby reducing the carbon footprint.

The COVID-19 pandemic has also influenced an increase in robotization [23]. Companies have been forced to look for ways to become less dependent on the human factor. The global report "Intelligent Automation 2020" shows a significant increase in the percentage of organizations in 2020 that have begun implementing solutions based on intelligent automation. In this regard, 73% of surveyed companies took action in 2020, compared to only 48% a year earlier [24]. Disruption in the supply chain, the need for greater productivity in a secure environment as long-term effects of pandemics will require automation and digitization strategies from executives. Additionally, companies may be interested in intralogistics solutions wanting to delegate employees to more absorbing tasks [25].

According to a report by Interact Analysis, automation of warehouse operations is on the rise, and by 2027 more than a quarter (26%) will have some form of automation. This represents a significant jump from the 14% automation of warehouses a decade earlier. This is influenced by labor shortages, flexible manufacturing and the rise of e-commerce. Figure 1 shows the penetration of warehouse automation. As a result of the changes, manufacturing or warehousing companies should consider automation or enabling automated solutions in adjusting hall designs and/or layouts [26].

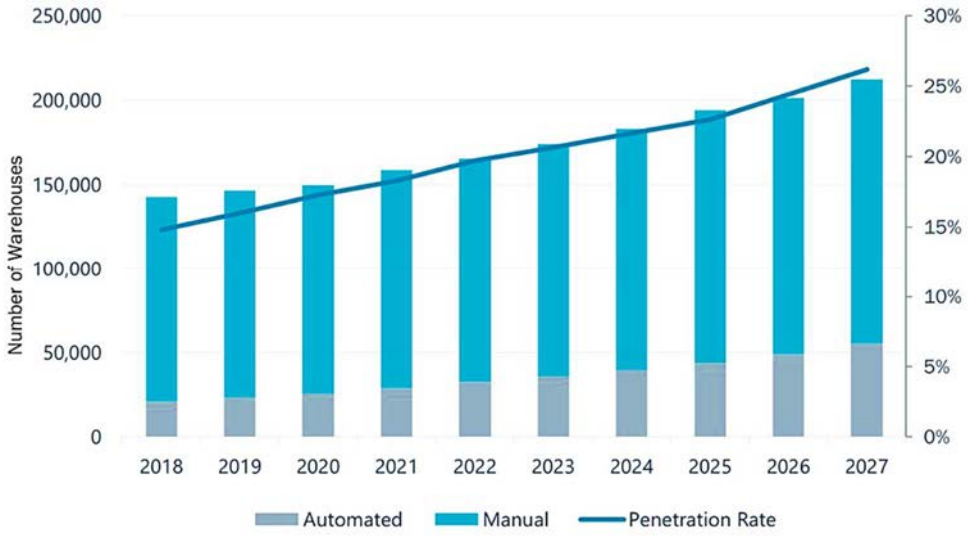

Figure 1 Warehouse automation penetration

The market for mobile robots (AGVs and AMRs) experienced strong growth in 2022. Interact Analysis forecasts the growth of automated (over 4 million) and autonomous vehicles through 2027, as shown in Figure 2 [27]. Revenue growth is projected to average 30-40% per year through 2027. Between 2022 and 2027, shipments of mobile robots will grow about 50% per year [27].

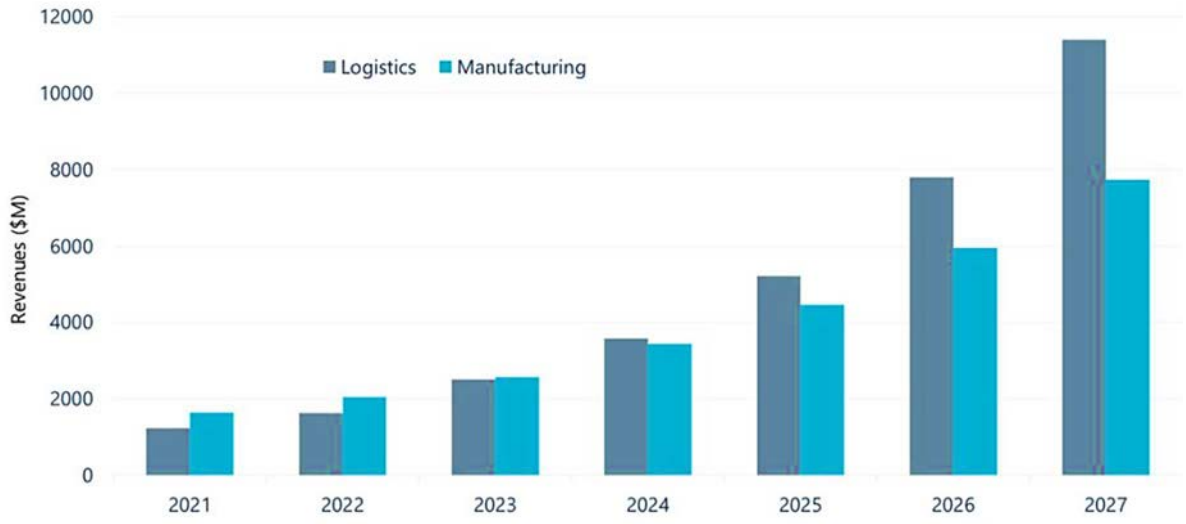

Figure 2 Mobile robot revenue forecast

Considering the cost-effectiveness of automation, interesting survey results are presented by Deloitte. Figure 3 shows the results obtained from a survey of 479 executives from various industries in 35 countries. Companies automate processes hoping to reduce costs, increase revenues, which, as the chart shows, have been increasing in recent years. The payback period is also increasing [28].

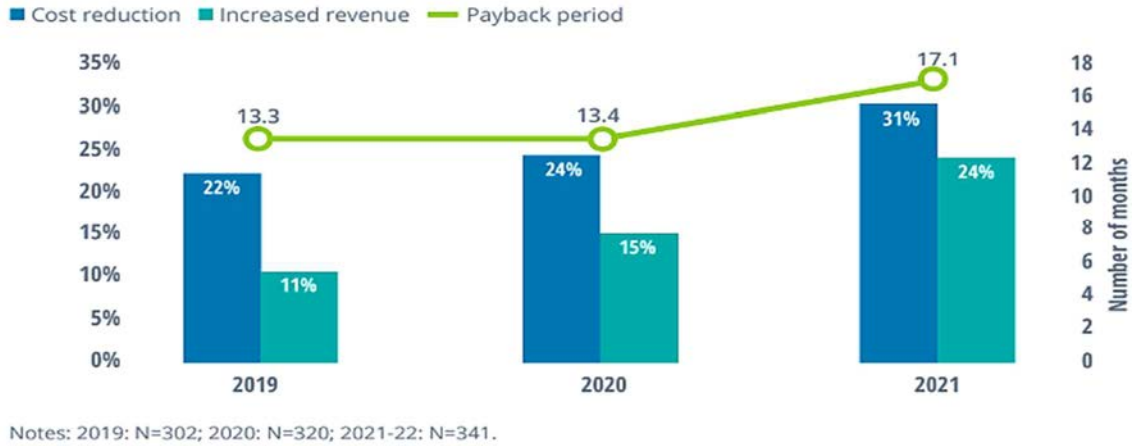

Figure 3 Enterprise automation - increased revenue, cost reduction and payback period

Taking into account the countries' policies on sustainable development, it forces the introduction of solutions that positively affect the work environment in entities. For the SME sector, there is a financial barrier related to the cost of purchasing such solutions [29,30]. Opportunities to subsidize the purchase and implementation of intralogistics solutions may prove effective in this regard. Therefore, it can be assumed that interest in the application of such solutions will grow depending on available subsidies or forms of support in the implementation of innovative solutions for small and medium-sized enterprises.

3 Methodology

Taking into account the topic addressed, which is the competitiveness of manufacturing companies, a qualitative study was chosen - a case study. Of the eight case studies conducted, one description is presented in the paper due to the same conclusions in the other companies, both small, medium and large in size. In addition, a quantitative study was conducted in Poland on a group of 35 companies that had automated internal transportation, and the conclusions were the same. The research was conducted in 2020-2021 at companies located in Poland. These were companies with both Polish and foreign capital. Due to the lack of generally available information on the type of technology and equipment used internally in companies, the results of the responding companies were relied on. It is worth noting that often this kind of information is a company secret, as it affects the preservation of the organization's competitiveness.

In order to achieve the set research questions, the method of analysis of available literature and reports on automation and digitization was carried out. The overarching goal is to explore and explain the phenomena taking place in enterprises. The search for answers to the set questions is made possible by using the inductive method applied by the qualitative study. The qualitative study was conducted in 2021 on the basis of an interview questionnaire.

4 Results and discussion

4.1 Case study

A qualitative study was conducted in a US manufacturing company located in south-eastern Poland. The company has approximately 100 employees. The means of internal transport used until now were forklift trucks, hand pallet trucks and electric trucks. The use of such a large number of vehicles also impacted on the lack of space on the production floor and increased the risk of workplace accidents involving forklifts driving on the production floor. These three main reasons led the company to find a different solution in this area.

The company, through reference visits to other organisations, tried to discern for itself the intralogistics solutions used. It also looked for examples of solutions at various industry events (e.g. intralogistics trade fairs), talking to representatives of companies offering such solutions, raising issues of potential benefits and risks.

The company, by conducting its own market research and studying the experience of other companies, identified several important aspects that led to the choice of AGV robots. It was found that this type of vehicle influences the aspect of improving work safety on the production floor, reducing the risk of accidents at work, which is important for a specific company with locations in different countries. Another aspect - the involvement of fewer people to implement internal transport. In 2016, two AGV robots were implemented in one of the branches. Before changing the means of internal transport, the company was obliged to change the layout of the hall and designate transport paths. A decision was also made to use reusable packaging in which components, products would be moved by AGV robots. An additional benefit of using such packaging is that it will not only be used internally, but also for transport from external suppliers. The robots purchased have lithium batteries, which means zero emissions for the environment.

The benefits of the implemented change were evident after the first week, and definitely influenced the systematization of internal logistics processes. The organization has a Kanban system, which works well in conjunction with the use of AGVs. One warehouseman was assigned to each of them to complete orders, deliver goods to the hall, and take empty containers to the warehouse. This organization of work made it possible to delegate the other people previously involved in handling internal transportation to other tasks.

AGVs make it possible to maintain safe working conditions, influence aesthetics, maintain good organization of the workplace, delivering the right quantities of products, at the right time, thus maintaining continuity of production. They make it possible to maintain transparency of the processes being carried out. Attached carts, on which components are transported, are more capacious compared to the previously used solutions. They make it possible to take a larger number of containers on a single trip, so that the necessary components are available on production lines, eliminating unnecessary waiting or downtime. By the same token, the efficiency of internal transport is significantly increased.

The company's biggest challenge has been to optimize transportation paths. The company is constantly optimizing internal flows, implementing appropriate solutions and reducing all costs. Simulation in a 3D environment was also considered, but such a solution, for the company, is a relatively expensive proposition, not necessarily allowing for a thorough testing of the new solution. In addition, the employees involved in the project to change the means of transportation, lack training, information or instructions for use, exchange of experience on issues related to all activities related to the preparation of the organization and information on what to look out for.

Unfortunately, not all employees saw the benefits of the improvements. On the part of the other production employees, there was negative feedback after the change in transportation means. Managers had to motivate, support the others to show the positive aspects from the use of AGVs. Often the change caused resentment and dissatisfaction among employees, but after about a month, it could be observed that employees got used to it and saw the benefits of the implemented improvements, especially in terms of improvements in order picking times at the warehouse.

The company has been richer in experience in handling this type of vehicle since 2016. Through the robotization of transportation, it is able to connect them to ERP system and monitor orders in real time. The transparency of the implemented processes has increased. The organization recognizes that this gives it an advantage over other companies in the market, and in the current situation it is more ready to automate other processes, or use autonomous robots, which is its next goal. According to the decision-makers of the company surveyed, the key is to gradually change the means of the vehicle, adapt the work, adjust the processes, and get the employees used to working with and operating robots. Once processes are stabilized, one can move on to the next challenges with emerging new technologies.

4.2 Discussion

The gradual automation of processes within the company is important. This includes transportation automation, real-time information exchange and product monitoring. Intralogistics solutions in the form of AGVs

and AMR vehicles make this possible. It is important to support the move toward automation on the scale of Industry 4.0 for small and medium-sized enterprises as well. They help achieve benefits for companies in the implementation of internal processes. They represent a positive change from the status quo. They allow real-time data exchange. This introduces some novelty on an enterprise scale. However, it is crucial to consider cyber security - network security so that unauthorized people do not have access to control such devices. The factors influencing the automation and use of intralogistics solutions by enterprises are shown in Figure 4.

Figure 4 Factors influencing the automation of enterprises - application of intralogistics solutions

Automation and real-time information sharing present great opportunities for businesses, but also risks due to the possibility of cyber-attacks. Along with the application of modern solutions, attention should be paid to any security related to access to the enterprise information system [31]. Access to the system, the exchange of information on an ongoing basis allows processes to be carried out efficiently without human intervention. However, if an unauthorized person were to take control, robots and other devices could threaten the safety of employees.

An important issue in automating processes and implementing intralogistics solutions is the human factor. The case study described shows that people are often afraid of change, of stepping out of their comfort zone. They need time to get acquainted with something new and different. In the age of digitization and automation, it is crucial to raise the competence of employees, familiarize them with available solutions and teach them how to work with new technologies. There is a reason for the emergence of the concept of Industry 5.0 - which emphasizes the focus on the human being, who is supposed to operate and cooperate with the new technology, and who is supposed to be facilitated by it. In addition, the post-pandemic experience, the turbulent environment and the changes that are currently taking place are not supposed to affect the processes taking place in companies, only their design and operation are supposed to be immune to them. Additionally, all actions taken are to consider the impact on the environment [32].

Intralogistics solutions in the form of automated or autonomous robots allow the use of environmentally friendly batteries and the way they are powered (e.g., solar energy), the use of reusable packaging, relieving the burden on human resources and delegating them to more absorbing work, automating processes and combining them with other solutions, which facilitates real-time tracking of task execution, thus allowing flexible production.

Important aspects in raising the level of automation and matching intralogistics solutions to enterprises [33] will be the exchange of experience and the popularization of research results on the characteristics of the transport solutions under study. Larger entities, working with other foreign companies, have the opportunity to follow good examples. However, despite this, the development of good practices internally is often achieved by trial and error.

Manufacturing companies are reluctant to share the experience they have developed. Each of them is concerned with being competitive. However, a general characterization of the topic could prove to be a helpful solution for companies in various industries, aiming at overall economic development. Process innovations bring beneficial changes within an organization. They create an environment for the emergence of new opportunities for

improvement, the application of available technical or technological solutions.

5 Conclusions

Increasing awareness and presenting the essence of intralogistics solutions can influence the decisions of other organizations. Automation and digitization of processes in line with Industry 4.0 or 5.0 focuses on the implementation of solutions within the organization. This is especially important in an era of increasing market demands, automation of processes in which intralogistics is a central point. The challenge of transport automation, the benefits and their impact on the organization may be particularly beneficial in the exchange of experiences of enterprises, especially from the small and medium-sized enterprise sector. Considering the statistical data, an increase in robot sales is evident. There is a lot of talk about automation, the digitization of production, the replacement of human labor with robotic work. Automation will continue, so it is worth popularizing the experiences of other enterprises to improve available technologies and solutions with a view to working with humans.

The described case study shows that companies are not always aware of the available solutions and what benefits they can introduce for themselves and the environment. Considering the organization's environment, companies are reluctant to share their experiences, given the increasing competition. The example given can be helpful in presenting a practical take on the application of a selected solution that fits into Industry 4.0 solutions. It not only has a positive impact on the organization, on the processes taking place in it, on the safety of employees' work, but also has a positive impact on the environmental aspect (solid packaging, lithium-ion batteries). An additional incentive may be European Union funds, grants for innovative solutions, which may include intralogistics solutions. The benefits presented in the case study described, can contribute to the justification of the project or grant to implement solutions that significantly improve the functioning of internal processes.

The described case study presents not only a positive impact on internal logistics, but also on other areas of the organization. The use of AGVs has forced a change from single-use packaging of transported materials to reusable packaging. As a result, the company has less waste, and the packaging used is used in the warehouse, internal and external transportation. Another positive environmental impact is the batteries used to power the automated vehicle. The company uses the Kanban system, which works perfectly with the automatic delivery of orders to individual stations. Another benefit is the overcoming of the Man-Machine barrier. Employees can learn how to work with the automated vehicle, which will affect faster adaptation to work with more automated factories in the future. Automated transportation will ease the burden of employee involvement, so companies can delegate people to more demanding tasks.

The example given has its limitations. The benefits and organizational impacts described will generally be more or less the same in manufacturing companies. However, due to the increasing importance and application of artificial intelligence and IoT integration, research should be constantly conducted on their impact on the implementation of logistics processes and the prediction of resource demand. An important issue is cybersecurity and data security research to protect enterprises from potential cyberattacks. After the COVID-19 pandemic should constantly study the adaptation of new technologies in response to changing working conditions and supply chains. Another important issue is to study the impact of automation on the employment, qualification and safety of workers.

References

[1] SHI, X., TANG, J., DONG, C.: Should a domestic firm carve out a niche in overseas markets? Value of purchasing agents, *European Journal of Operational Research*, Vol. 300, No. 1, pp. 85-94, 2022. https://doi.org/10.1016/j.ejor.2021.07.019

[2] ELMARAGHY, H., SCHUH, G., ELMARAGHY, W., PILLER, F., SCHÖNSLEBEN, P., TSENG, M., BERNARD, A.: Product variety management, *CIRP Annals*, Vol. 62, No. 2, pp. 629-652, 2013. https://doi.org/10.1016/j.cirp.2013.05.007

[3] WINKLER, H., ZINSMEISTER, L.: Trends in digitalization of intralogistics and the critical success factors of its implementation, *Brazilian Journal of Operations and Production Management*, Vol. 16, No. 3, pp. 537-549, 2019. https://doi.org/10.14488/BJOPM.2019.v16.n3.a15

[4] DOBNI, C.B.: The relationship between an innovation orientation and competitive strategy, *International Journal of Innovation Management*, Vol. 2, No. 14, pp. 331-357, 2010. https://doi.org/10.1142/S1363919610002660

[5] CHO, H.J., PUCIK, V.: Relationship between Innovativeness, Quality, Growth, Porfitability, and Market Value, *Strategic Management Journal*, Vol. 26, No. 6, pp. 555-575, 2005. https://doi.org/10.1002/smj.461

[6] URRU A., WEZEL, J.P., BONINI, M., ECHELMEYER, W.: *Dynamic Resource Allocation Considering Ergonomics in Intralogistics*, 25th IEEE International Conference on Intelligent Engineering Systems, pp. 81-88, INES 2021. https://doi.org/10.1109/INES52918.2021.9512930

[7] SCHUHMACHER, J., HUMMEL, V.: *Development of a descriptive model for intralogistics as a foundation for an autonomous control method for intralogistics systems*, 8th Conference on Learning Factories 2018 - Advanced Engineering Education & Training for Manufacturing Innovation, Procedia Manufacturing, Vol. 23, pp. 225-230, 2018.

[8] GÜNTHER, W., HOMPEL, M.: *Internet der Dinge in der Intralogistik*, Springer, pp. 9-10, 2010. (Original in German)
[9] ABHAY, G.K., HASAN, A.M.: Automnomus and IoT-driven intralogitics for Industry 4.0 warehouses: A thematic analysis of the literature, *Transportation Journal*, Vol. 63, No. 1, pp. 42-61, 2024.
[10] ABELE, E., ANDERL, R., METTERNICH, J., WANK, A., ANOKHIN, O., ARNDT, A., MEUDT, T., SAUER, M.: Effiziente Fabrik 4.0 – Einzug von Industrie 4.0 in bestehende Produkktionssyteme, *Zeitschrift für wirtschaftlichen Fabrikbetrieb*, Vol. 110, No. 3, pp. 150-153, 2015. https://doi.org/10.3139/104.111293 (Original in German)
[11] SANIUK, S., GRACZYK, M., KUŁYK, P.: *Challenges of logistics in the concept of Industry 4.0*, Carpathian Logistics Congress CLC 2018, Dec. 3rd-5th 2018, Tanger, Prage, Czech Republic, pp. 792-792, 2018.
[12] GUDEHUS, T.: *Logistik: Grundlagen-Strategien-Anwendungen*, Springer-Verlag Berlin Heidelberg, 2010. (Original in German)
[13] PEUKERT, S., TREBER, S., HAEFNER, B., LANZA, G.: Process model for the successful implementation and demonstration of SME-based industry 4.0 showcases in global production networks, *Production Management, Production Engineering*, Vol. 14, pp. 257-288, 2020.
[14] KURSCHL, W., PIMMINGER, S., SCHÖNBÖCK, J., AUGSTEIN, M., ALTMANN, J.: *Using Mixed Reality in Intralogistics – Are we ready yet?*, International Conference on Industry 4.0 and Smart Manufacturing, Procedia Computer Science, Vol. 180, pp. 132-141, 2021.
[15] ANDERL, R., PICARD, A., WANG, Y., FLEISCHER, J., DOSCH, S., KLEE, B., BAUER, J.: *Guideline Industrie 4.0: guiding principles for the implementation of Industrie 4.0 in small and medium sized businesses*, VDMA Forum Industrie, Vol. 781, pp. 1-31, 2016.
[16] FERNANDES, J., BABTISTA, A., SILVA, F.J.G., CAMPILHO, R.D.S.G, PITNO, G.F.L.: *Intralogistic and industry 4.0: designing a novel shuttle with picking system*, 29th International Conference of Flexible Automation and Intelligent Manufacturing (FAIM2019), June 24-28, 2019, Limerick, Ireland, Procedia Manufacturing, Vol. 38, 2019.
[17] WANG, G., ANDERL, R.: *Generic Procedure Model to Introduce Industrie 4.0 in Small and Medium-sized Enterprises*, Proceedings of the World Congress on Engineering and Computer Science, Vol. 2, October 19-21, San Francisco, USA, pp. 971-976, 2016.
[18] GRABOWSKA, S., SANIUK, S., GAJDZIK, B.: Industry 5.0: improving humanization and sustainability of Industry 4.0, *Scientometrics*, Vol. 127, No. 6, pp. 3117-3144, 2022. https://doi.org/10.1007/s11192-022-04370-1
[19] PRASSE, H., NETTSTRAETER, A., HOMEP, M.: *How IoT will change the design and operation of logistics systems*, International Conference on the Internet of Things (IOT), pp.55-56, 2014.
[20] SONG, Y., YE, F.R., ZHOU, L., YANG, X., HE, Z.: Applications of the Internet of Things (IoT) in Smart Logistics: A Comprehensive Survey, *IEEE Internet of Things Journal*, Vol. 8, No. 6, 4263, pp. 4250-4274, 2021. https://doi.org/10.1109/JIOT.2020.3034385
[21] IFR: *IFR International Federation of Robotics, Press Conference World Robotic 2021*, 28 Oct 2021, [Online], Available: https://ifr.org/standardisation [25.10.2023], 2021.
[22] BATORSKA, S.: Smart Industry Polska 2018. Raport o innowacyjności MŚP, *Automatyka*, Vol. 6, pp. 93-100, 2018. (Original in Polish)
[23] AHMED, T., KARMAKER, C.L., NASIR, S.B., MOKTADIR, M.A., PAUL, S.K.: Modeling the artificial intelligence-based imperatives of industry 5.0 towards resilient supply chains: A post-COVID-19 pandemic perspective, *Computers & Industrial Engineering*, Vol. 177, No. March, 109055, pp. 1-12, 2023. https://doi.org/10.1016/j.cie.2023.109055
[24] DELOITTE: *Automation with intelligence: Pursuing organization-wide reimagination*, Deloitte University EMEACVBA, Diegem, 6, 2020.
[25] HASIJA, K.G., DESAI, K., ACHARYA, S.: A*rtificial Intelligence and Robotic Automation Hit by the Pandemic: Reality or Myth*, Tyagi, P., Chilamkurti, N., Grima, S., Sood, K. and Balusamy, B. (Ed.) *The Adoption and Effect of Artificial Intelligence on Human Resources Management, Part* B (Emerald Studies in Finance, Insurance, and Risk Management), Emerald Publishing Limited, Leeds, pp. 127-147, 2023. https://doi.org/10.1108/978-1-80455-662-720230009
[26] SCRIVEN, R.: *26% of Warehouses to be Automated by 2027*, [Online], Available: https://interactanalysis.com/insight/26-of-warehouses-to-be-automated-by-2027 [11 Oct 2023], 2023.
[27] SHARMA, A.: *Mobile robot shipments grow by 53% in 2022*, [Online], Available: https://interactanalysis.com/insight/mobile-robot-shipments-grow-by-53-in-2022 [11 Jun 2023], 2023.
[28] SIKORA, S., BORAH, P.R., IYER, A.: *Automation with intelligence*, Deloitte Insight, [Online], Available: https://www2.deloitte.com/content/dam/Deloitte/de/Documents/Innovation/Automation_Intelligence.pdf [20 Nov 2023], 2023.
[29] OSOLIŃSKI, W., KOLIŃSKI, A., KILIC, Z.: *Concept of communication integration for automated production processes regarding logistics 4.0*, In: Adamczak, M. et al., Digitalization of Supply Chains,

Spatium, Radom, pp. 85-100, 2019. https://doi.org/10.17270/B.M.978-83-66017-86-3.7

[30] COOMBS, C.: Will COVID-19 be the tipping point for the Intelligent Automation of work? A review of the debate and implications for research, *International Journal of Information Management*, Vol. 55, No. December, 102182, pp. 1-4, 2020. https://doi.org/10.1016/j.ijinfomgt.2020.102182

[31] HAJDA, J., JAKUSZEWSK, R., OGONOWSKI, S.: Security Challenges in Industry 4.0, PLC Systems, *Applied Sciences*, Vol. 11, No. 21, 9785, pp. 1-26, 2021. https://doi.org/10.3390/app11219785

[32] ADITYA, A., EURESTI, D., LUNA, S., ANKOBIAH, W., LOPES, A., EDINBAROUGH, I.: State of Industry 5.0—Analysis and Identification of Current Research Trends, *Applied System Innovation*, Vol. 5, No. 1, 27, pp. 1-14, 2022. https://doi.org/10.3390/asi5010027

[33] LI, M., HUANG, G.Q.: Production-intralogistics synchronization of industry 4.0 flexible assembly lines under graduation intelligent manufacturing system, *International Journal of Production Economics*, Vol. 241, No. November, 108272, 2021.

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Optimizing ergonomic work facilities in distribution logistics to prevent manual lifting injuries
Yan Orgianus, Eri Achiraeniwati, Muhammad Ridha Rausan Fiqri, Hirawati Oemar

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Optimizing ergonomic work facilities in distribution logistics to prevent manual lifting injuries

Yan Orgianus
Industrial Engineering, Universitas Islam Bandung, Jl. Taman Sari 1, Bandung 40116, Indonesia, yorgianus@yahoo.co.id
Eri Achiraeniwati
Industrial Engineering, Universitas Islam Bandung, Jl. Taman Sari 1, Bandung 40116, Indonesia, eri_ach@yahoo.co.id
Muhammad Ridha Rausan Fiqri
Industrial Engineering, Universitas Islam Bandung, Jl. Taman Sari 1, Bandung 40116, Indonesia, fiqrimuhammadr@gmail.com
Hirawati Oemar
Industrial Engineering, Universitas Islam Bandung, Jl. Taman Sari 1, Bandung 40116, Indonesia, hirawatio@yahoo.co.id (corresponding author)

Keywords: ergonomic optimization, manual lifting, biomechanical and anthropometric.
Abstract: This study aims to improve ergonomic conditions for box-lifting operators in bottled drinking water companies. Operators handling small packaging sizes (600 ml) report significant pain, as revealed by the Nordic Body Map Questionnaire. Addressing this issue is crucial for preventing manual lifting injuries and ensuring worker safety in logistic distribution. A combination of biomechanical analysis, anthropometric data, and the Nordic Body Map Questionnaire was used to assess operator complaints and evaluate ergonomic hazards. The study utilized Catia software to simulate work facility designs, focusing on the development of an adjustable-height hydraulic pallet to optimize operator posture during lifting tasks. Key metrics included compressive and shear force calculations to evaluate injury risks. Operators reported pain in the shoulders, lower back, buttocks, and thighs over the past year. Initial evaluations showed excessive compressive forces (up to 19,778.2 N) and shear forces (over 500 N), indicating a high risk of injury. After ergonomic interventions, simulations recorded compressive forces of 3,350 N and shear forces of 185.31 N, demonstrating a significant reduction in risk and safe operational conditions. This study offers a novel, comprehensive approach to ergonomic optimization in logistics, combining operator feedback, biomechanical analysis, and technological tools like Catia for facility design. The findings provide a blueprint for improving worker safety and efficiency in manual lifting tasks. The study's outcomes benefit safety engineers, ergonomic specialists, and logistics managers, offering insights into improving worker well-being and operational efficiency. Future research could explore further technological enhancements in facility design and their impact on worker ergonomics.

1 Introduction

To maximize income, manufacturing organizations must minimize losses while meeting client requests effectively. Discrepancies between activities and equipment may result in idle time, lowering labor productivity, product quality, and cost savings. Ensuring compliance across all locations and activities is crucial to increasing manufacturing process efficiency and customer satisfaction. This emphasizes the significance of excellent ergonomics and well-designed workstations for decreasing inconsistencies, increasing productivity, and ensuring worker safety [1].

Workers' postural and manual material handling are critical components in determining the risk of musculoskeletal injury in the workplace [2]. Ergonomics is a physical feature that deals with employee working postures in the workplace. Awkward postures and repetitive movements are primarily performance factors and difficulties in the workplace [3].

PT X is a company engaged in bottled drinking water in several sizes. The company found that lifting work on the SPS 600 ml box was done by standing up when taking it from the conveyor, then the operator made a bending motion when storing the boxes onto the pallet according to the number of piles that were conducted repeatedly and continuously. As a result of these conditions, workers at the company face various problems in the industry such as fatigue, discomfort, and back pain due to non-ergonomic machine or equipment design which causes stress to the musculoskeletal system [4]. Poor work posture reduces productivity by increasing health issues, musculoskeletal ailments, and physical stress [5,6]. Ergonomic difficulties are caused by improper work posture, bending, raising, and lowering an object, twisting, pushing, and pulling [7]. Further examination of the issues at risk of further and extensive investigations. To estimate work risk using Recommended Weight Limit (RWL) and Lifting Index (LI) for work physiology are used to calculate the energy produced so that work limits can be estimated.

Several studies indicate that obese workers are a contributing factor to musculoskeletal disorders, and these findings also suggest that additional weight in obese workers has a significant impact on the musculoskeletal structures of the back, increasing the risk of musculoskeletal disorders during load-handling [8].

Logistics activities present unique ergonomic challenges that are significantly different from traditional manufacturing processes. Research indicates that incorporating ergonomic principles into logistics can enhance worker well-being and operational efficiency. For instance, the use of double-back support frameworks has shown promise in reducing the risk of musculoskeletal disorders, improving posture, and decreasing perceived exertion during manual tasks in logistics environments. Additionally, training programs aimed at enhancing logistics personnel's understanding of efficient practices have demonstrated significant improvements in knowledge and performance, which are crucial for optimizing logistics operations. Furthermore, integrating Lean Six Sigma with ergonomic principles can boost internal logistics efficiency, address warehouse management complexities, and improve productivity. Overall, a comprehensive approach that considers physical, mental, and social health, along with effective training and ergonomic design, is essential for fostering a productive logistics environment while minimizing hazard [9].

This research endeavors to fill a critical gap by spotlighting the significance of ergonomics in logistics operations, with a particular focus on distribution logistics environments. It underscores the importance of operator welfare—a pivotal element of the work environment—by addressing the health and safety concerns of individuals engaged in physical tasks. Through a comprehensive approach that incorporates the Nordic Body Map, Biomechanics, and Anthropometry methods, this study aims to enhance the comfort and safety of operators, ensuring they can perform their duties in an environment that supports their overall well-being.

The Nordic Body Map technique is a subjective valuation approach, which means that the effectiveness of its use is heavily dependent on the settings and scenarios encountered by employees at the time of the research, as well as the competence and experience of the observer in question [10]. In the domain of logistics, the use of the Nordic Body Map questionnaire is a relatively recent method. It gives researchers a deep insight into the hassles and disadvantages that operators face, allowing them to more accurately pinpoint issue areas. The use of the Nordic Body Map questionnaire provides a highly effective method for measuring the physical discomfort and pain experienced by the operator. This allows research to identify exactly the location and type of ergonomic problems that need to be fixed. Workers in the parts assembly industry have a high rate of musculoskeletal pain [11]. As a result, it is vital to enhance the workplace amenities that are utilized to maintain appropriate body posture.

The biomechanical method is the application of Newtonian mechanics to the neuromuscular and skeletal systems to calculate the amount of force occurring in each part of the worker's body as well as the internal forces acting within the body [12]. Implementing biomechanical and anthropometric methodologies in this study aids in the scientific and detailed assessment of occupational hazards. It serves as a solid foundation for building ergonomic work environments. The biomechanical and anthropometric technique enables researchers to properly quantify the occupational hazards associated with manual lifting jobs. This offers a firm foundation for ergonomic improvements by verifying that suggested modifications fit the physical features of the operator.

Catia software is used to support the design of work facilities by enabling the visualization of ergonomic solutions before implementation. This allows for adjustments and refinements to be made effectively, contributing to the research with practical recommendations to improve work conditions and operator welfare in distribution logistics.

The study makes a significant contribution to the field of ergonomic solution development in distribution logistics through its focused examination of logistical ergonomics, the adoption of sophisticated evaluation methodologies, and the presentation of evidence demonstrating the beneficial impact on worker well-being.

2 Literature review

2.1 Ergonomics

Ergonomics is a scientific subject that enhances human and overall system performance by studying the interactions between humans and other system elements. The profession applies ideas, principles, data, and methodologies [13]. Ergonomics is a systematic approach to evaluating and developing the relationship between individuals and the systems they interact with. Its primary objective is to optimize the quality of life for the particular group of individuals who engage with the system, taking into consideration their attributes, capabilities, requirements, anticipations, tasks performed, and the collection of factors (technological, environmental, organizational, and cultural) that impact them [14]. Ergonomics is a concern in all manual handling jobs, and automation is one of the primary methods for overcoming such issues. Because automation raises expenses such as installation and maintenance, it is impossible to implement. Utilizing ergonomic assessment instruments to ascertain the level of risk associated with one's work and work posture, it is subsequently necessary to devise a workable resolution to surmount such obstacles [15].

2.2 Musculoskeletal disorder

Work-related musculoskeletal disorders (WMSDs) are prevalent occupational illnesses that predominantly impact the upper and lower limbs, the lower back, and the neck [16]. Material handling activities that are conducted manually and inappropriately can cause losses to work

accidents and result in complaints of musculoskeletal disorders. Complaints of musculoskeletal disorders can be complained of with pain ranging from very mild to very painful in the skeletal muscle. Complaints regarding joint, ligament, and tendon injury are the result of extended and repetitive static load application to muscles.

2.3 Biomechanics

Biomechanical risk variables such as articular positions, efforts, repetitive work, static posture, and vibrations have been extensively studied, and it is well understood that the effects of biomechanical risk are determined by the duration of exposure, the duration of recovery, and temperatures [17]. These studies show a relationship between risk factors, particularly their combined effects, and the development of upper limb MSDs [18]. While correlations have been drawn between the intensity of biomechanical risk factors at work and the risk of MSD development, Lanfranchi and Duveau pointed out that certain low physiological demand tasks, such as working in front of a computer and assembling electronic components, resulted in significant stress and mental load [19].

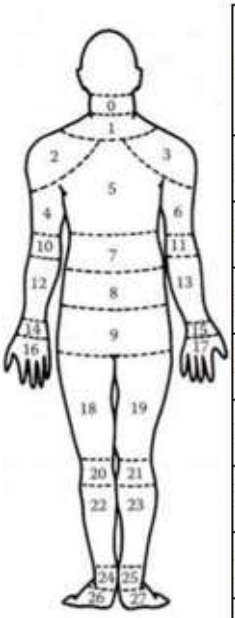
Biomechanics, particularly occupational biomechanics, studies how workers interact with their physical environment, including equipment and materials, to enhance safety and efficiency. This sub-discipline applies mechanical principles to understand human movement and the forces acting on the body, aiming to reduce the risk of musculoskeletal disorders. Research in biomechanics covers a range of applications, from sports performance to clinical contexts, where understanding mechanical forces is crucial for designing medical devices and surgical techniques [20]. Additionally, biomechanics integrates principles from engineering and biophysics to analyze the structural and functional aspects of living organisms, which is essential for designing ergonomic tools and workspaces that alleviate stress on the musculoskeletal system [21].

2.4 Manual material handling

Manual Material Handling (MMH) is the leading cause of weariness, waist pain, and spinal cord damage. Lifting activity was found to be one of the causes of a high level of injury in some manual material handling activities. In light of the risks associated with manual material handling, it is necessary to implement an intervention or enhance ergonomics to mitigate the potential for worker injuries [22].

2.5 Nordic body map questionnaire

The Nordic Body Map (NBM) is a tool used to pinpoint areas of muscle or joint discomfort experienced by workers. It categorizes body parts using numbers from 0 to 27, ranging from the neck to the feet. Six factory workers were provided with and completed the NBM questionnaire [23]. Figure 1 is the questionnaire from the Nordic Body Map [24].



Body Section	If you have ever experienced problems (pain, discomfort) in this part of your body, please rate the level of pain or discomfort you have felt. (Circle the appropriate number)										Did you see a doctor or therapist when you experienced problems (pain, discomfort) in this part of your body?
Neck	1	2	3	4	5	6	7	8	9	10	☐ Never ☐ Yes
Shoulder	1	2	3	4	5	6	7	8	9	10	☐ Never ☐ Yes
Upper Back	1	2	3	4	5	6	7	8	9	10	☐ Never ☐ Yes
Elbow	1	2	3	4	5	6	7	8	9	10	☐ Never ☐ Yes
Lower Back	1	2	3	4	5	6	7	8	9	10	☐ Never ☐ Yes
Wrist	1	2	3	4	5	6	7	8	9	10	☐ Never ☐ Yes
Knee	1	2	3	4	5	6	7	8	9	10	☐ Never ☐ Yes
Ankle	1	2	3	4	5	6	7	8	9	10	☐ Yes ☐ Yes

Figure 1 Questionnaire Nordic Body Map

2.6 Gaps from the previous research studies

This investigation aims to enhance the ergonomics of work facilities for operators in a bottled water production line by employing a comprehensive methodology. This method entails the identification of operator complaints, the assessment of work hazards using biomechanical and anthropometric methods, and the application of design

through Catia to create more ergonomic work facilities. In contrast, a previous study titled "Work Posture Analysis of Manual Material Handling Using the OWAS Method" investigated a small-scale maize chip facility. The objective of the investigation was to quantify injury risk indexes and offer precise suggestions for improving worker safety. The WinOWAS software was employed to analyze work posture and evaluate injury risks based on specific postures and loads, while the Nordic Body Map (NBM) questionnaire was employed to identify worker complaints. In contrast to the previous research, which was more focused on enhancing posture and burden in a specific factory environment, the current study provides a more comprehensive and integrated solution for enhancing workplace safety [23].

A decision matrix was employed to emphasize ergonomic procedures at a coal mining site in South Kalimantan, Indonesia, in another study. To ascertain which workgroups necessitated additional evaluation in light of ergonomic risks identified from physical distress and burden, this matrix combined incident data, responses from the Nordic questionnaire, and interviews with supervisors [25]. Musculoskeletal disorders (MSDs) were the subject of another study, which concentrated on the prevalence of MSDs in Indonesia's informal sector and across industries. The study employed quantitative data, including the Nordic Body Map (NBM) and Rapid Entire Body Assessment (REBA), to investigate the prevalence of MSD complaints and work posture among textile workers. They identified risk factors, including gender, age, work environment, and poor posture, that could contribute to MSDs. The purpose of this investigation was to ascertain the prevalence and risk factors of MSDs and to devise comprehensive preventive strategies. Compared to the previous study, which was more comprehensive and focused on the analysis of MSD risk across a variety of industries, the current study is more focused on the ergonomic issues in bottled water production facilities and integrates the most recent technology to enhance ergonomic design [26].

In a previous study on seafarers, the incidence of MSDs was also investigated by investigating the effects of age, years of service, and smoking behaviors. The Nordic Body Map questionnaire and health examination data of fishermen were the primary instruments utilized in this cross-sectional study, which also employed statistical analysis methods such as Chi-square. Musculoskeletal disorders were not significantly associated with age, according to the results. However, years of service were. Nevertheless, this research procedure was deemed to be restricted by its dependence on questionnaires rather than comprehensive medical examinations [27].

Previous research has generally focused on specific evaluations, such as identifying musculoskeletal risks based on factors like age and work environment or analyzing work posture in specific factory settings using tools such as the Nordic Body Map and REBA. While these methods were effective in certain contexts, they were limited in scope and lacked a comprehensive, integrated approach. In contrast, the present research offers a more holistic and integrated methodology. It includes hazard evaluations using biomechanical and anthropometric methods, develops ergonomic interventions tailored to the facility's design, and addresses operator complaints through the use of advanced software like Catia. This ensures more effective implementation of ergonomic solutions, significantly enhancing the well-being of workers in logistics distribution environments.

Moreover, while previous studies often focused on specific industries or individual risk factors, the current research takes a more comprehensive approach by combining multiple assessment methods and cutting-edge technology. As a result, this research provides a more robust, technology-driven solution for improving ergonomic work facilities, which not only fills the methodological gap left by earlier studies but also offers practical, evidence-based improvements. By addressing both the physical and operational aspects of ergonomics, this study surpasses previous research, providing a new standard for ergonomic interventions in distribution logistics.

3 Methodology

The research follows a systematic design, divided into key stages to address the ergonomic risks associated with manual lifting tasks in logistics operations. The stages are as follows:

1. Introduction to the Study: Initial observations were made regarding operator complaints related to fatigue, lifting frequency, and the distances involved in handling SPS 600 ml boxes. These insights guided the identification of ergonomic risks and informed the research direction.
2. Literature Review: A comprehensive review of literature related to ergonomics, biomechanics, and anthropometry was conducted. This review provided the theoretical foundation necessary for formulating the research problem and informed the design of ergonomic interventions.
3. Problem Formulation and Research Objectives: Based on the initial observations and literature, key problems were formulated, including risks associated with manual lifting tasks. The primary research objective was to design ergonomic interventions to mitigate these risks, focusing on reducing musculoskeletal strain through improved work facility design.
4. Data Collection: Data was collected from a sample of 9 operators using the Nordic Body Map questionnaire to assess their physical discomfort during box lifting tasks. Additionally, their work postures and movements were recorded during the transfer of boxes from the conveyor to the pallet. The rationale for selecting 9 operators was based on representativeness and practicality, given the constraints of the workplace environment.

5. Data Processing: The data were processed by analyzing the questionnaire responses and conducting biomechanical calculations, including forces such as compressive (Fcompression) and shear (Fshear) forces. Statistical tests were employed to validate the findings, ensuring the reliability of the data.
6. Analysis: The analysis focused on operator discomfort and the biomechanical forces exerted during lifting tasks. By correlating the Nordic Body Map results with biomechanical data, potential risks were identified, leading to recommendations for ergonomic improvements, including the potential introduction of lifting aids.
7. Design of Work Facilities: Based on the analysis, ergonomic work facilities were designed using anthropometric data and technologies such as AutoCAD and Catia. These designs aimed to minimize operator discomfort and reduce the physical demands of manual lifting tasks.
8. Conclusions and Recommendations: The research culminated in recommendations for the implementation of ergonomic interventions to improve operator well-being and safety. These recommendations were based on both biomechanical assessments and ergonomic design principles.

Illustration of SPS 600 ml Box Lifting Process: The current material lifting procedure involves lifting the 600 ml SPS box from the conveyor onto the pallet, where the operator stands and repeatedly bends while storing the box. Figure 2 illustrates lifting and storing the 600 ml SPS box from the conveyor to the pallet.

Figure 2 SPS box lifting and storage process 600 ml from conveyor to pallet

With these improvements, the research methodology is structured as a clear research flow, with data collection and questionnaire distribution included as integral parts of the methodology.

4 Results and discussion

Figure 3 presents Nordic Body Map graphics, a graph of the operator's specific concerns about the task.

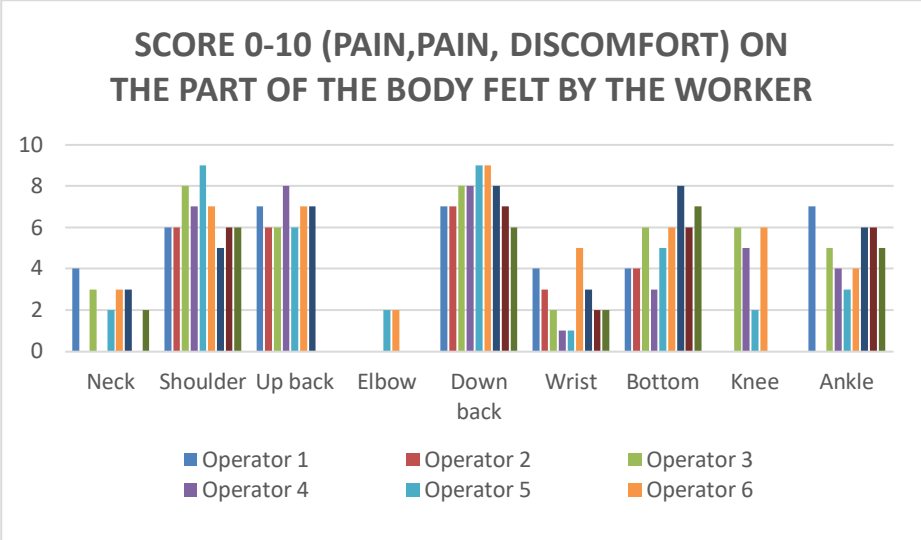


Figure 3 Nordic body map graphics

Complaints about the shoulders, lower back, buttocks, or thighs are felt by the operator when lifting loads above the conveyor and placing them on a pallet that is not at the same height as the operator. This requires the operator to perform repeated bending movements. Prolonged injury effects can occur if no immediate repair or additional work facilities are implemented. It is necessary to design ergonomic aids to facilitate operators and minimize work risks.

The occupational risk assessment uses the biomechanical method in equations (1) to equations (4) for the calculation of occupational risk assessment using the lower back model static method on the L5/S1 segment on the 600 ml SPS box moving operator. The results of the biomechanical calculation of the L5/S1 static model are the

1st stack to the 6th pile of the 1st load to the 60th load. Figure 4 shows an example of lifting a load of 3 stacks 1 operator 3.

Figure 4 Example of load lifting 3 stack 1 operator 3

Based on the existing issues, research was conducted on six workers involved in lifting the 600 ml SPS box to determine the operator's complaints. The recapitulation of the calculation of the biomechanics of the lower back static model at the L5/S1 point of lifting is shown in Table 1 shows the recapitulation of displacement biomechanics calculations, Table 2 and Table 3 show recapitulation of displacement biomechanics calculations.

Table 1 Recapitulation of lifting biomechanics calculations

Load To-	T	O	Muscle (N)	Fc (N)	Fs (N)	Information
3	1	3	7,166.67	7,934.67	2,616	Risk

Table 2 Recapitulation of displacement biomechanics calculations

Load To -	T	O	Muscle (N)	Fc (N)	Fs (N)	Information
1	1	2	12,390	12,694.2	717.6	Risk
2	1	2	11,460	11,865.6	670.8	Risk
3	1	3	18,283.3	18,547.3	760	Risk
4	1	3	19,300	19,564	760	Risk
5	1	4	17,976.7	18,557.7	581	Risk
6	1	1	9,650	10,124.5	442	Risk
7	1	1	8,933.33	9,342.83	507	Risk
8	1	1	10,100	10,444.5	552.5	Risk
9	1	4	17,473.3	17,971.3	664	Risk
10	1	4	18,410	18,908	664	Risk
11	2	2	10,340	10,925	507	Risk
12	2	2	10,500	11,077.2	522.6	Risk
13	2	3	15,400	15,960	560	Risk
14	2	3	16,616.7	17,128.7	616	Risk
15	2	3	19,600	20.192	536	Risk
16	2	1	8,716.67	9,243.17	383.5	Risk

Table 3 Recapitulation of displacement biomechanics calculations

Load To -	T	O	Muscle (N)	Fc (N)	Fs (N)	Information
17	2	1	8,550	9,031	435.5	Risk
18	2	1	10,650	11,163.5	403	Risk
19	2	6	10,050	10,563.5	403	Risk
20	2	6	12,933.3	13,472.8	364	Risk
21	3	2	11,420	12,090.8	405.6	Risk
22	3	2	14,810	15,519.8	327.6	Risk
23	3	3	11,683.3	12,363.3	424	Risk
24	3	3	11,350	12,078	336	Risk
25	3	3	11,833.3	12,521.3	416	Risk
26	3	1	7,766.67	8,403.67	110.5	Risk
27	3	1	8,516.67	9,153.67	110.5	Risk
28	3	1	9,383.33	10,000.8	214.5	Risk
29	3	6	6,383.33	7,020.33	110.5	Risk
30	3	6	5,866.67	6,497.17	169	Risk
31	4	2	12,916.4	13,535.6	282.83	Risk
32	4	2	12,965.4	13,699.2	214.03	Risk
33	4	6	8,575	9,205.63	101.92	Risk
34	4	6	5,912.67	6,549.67	0	Risk
35	4	6	6,027	6,651.26	108.29	Risk
36	4	1	9,391.67	10,022.3	89.18	Risk
37	4	1	9,212	9,842.63	31.85	Risk
38	4	1	8,575	9,205.63	31.85	Risk
39	4	6	6,141.33	6,771.96	76.44	Risk
40	4	6	6,370	7,000.63	44.59	Risk
41	5	2	12,910	13,651	257.4	Risk
42	5	2	12,700	13,456.6	171.6	Risk
43	5	6	7,300	7,943.5	32.5	Risk
44	5	6	6,683.33	7,326.83	0	Risk
45	5	5	9,683.33	10,376.3	112	Risk
46	5	1	8,000	8,643.5	19.5	Risk
47	5	1	8,150	8,800	0	Risk
48	5	6	7,066.67	7,170.67	0	Risk
49	5	6	5.483,33	6,126.83	0	Risk
50	5	6	6,550	7,193.5	0	Risk
51	6	2	10,133.2	10,706.5	496.86	Risk
52	6	2	10,290	10,855.7	512.15	Risk
53	6	6	15,092	15,640.8	548.8	Risk
54	6	6	16,284.3	16,786.1	603.68	Risk
55	6	6	19,208	19,788.2	525.28	Risk
56	6	1	8,542.33	9,058.3	375.83	Risk
57	6	1	8,379	8,850.38	426.79	Risk
58	6	1	10,437	10,940.2	394.94	Risk
59	6	6	12,142.2	12,784.8	504.308	Risk
60	6	6	16,143.9	16,819	455.50	Risk

Based on the findings, six operators with weights of 50, 55, 63, 65, and 68 kg were analyzed. The operators lift 60 loads organized into six heaps on a pallet, with 10 loads of the same weight of 15 kg in each pile. The results of the low back model calculation reveal that the compressive force (Fcompression) and shear force (Fshear) do not meet safety standards. The 60 loads exhibit varied results; if one criterion is not met, the operator's task is regarded as unsafe.

The compressive force in the 6th pile, the 55th load handled by the 6th operator, is more than the safety criterion, with the largest Fcompression being 19778.2 N, influenced by the operator's poor body posture when lifting the weight. The smallest Fshear value, 0 N, is observed in the 48th load handled by the 6th operator in the 5th pile. Despite the shear value showing 0 (not risky), the work is declared risky due to a compressive force of 7170.67 N. Recommendations for designing work facilities to reduce work risk during lifting transfers are necessary. Figure 5 shows the facilities before the design, Figure 5 shows current work facilities, while Figure 6 shows Hydraulic Pallet Work Facility Design and Size.

Figure 5 Current work facilities

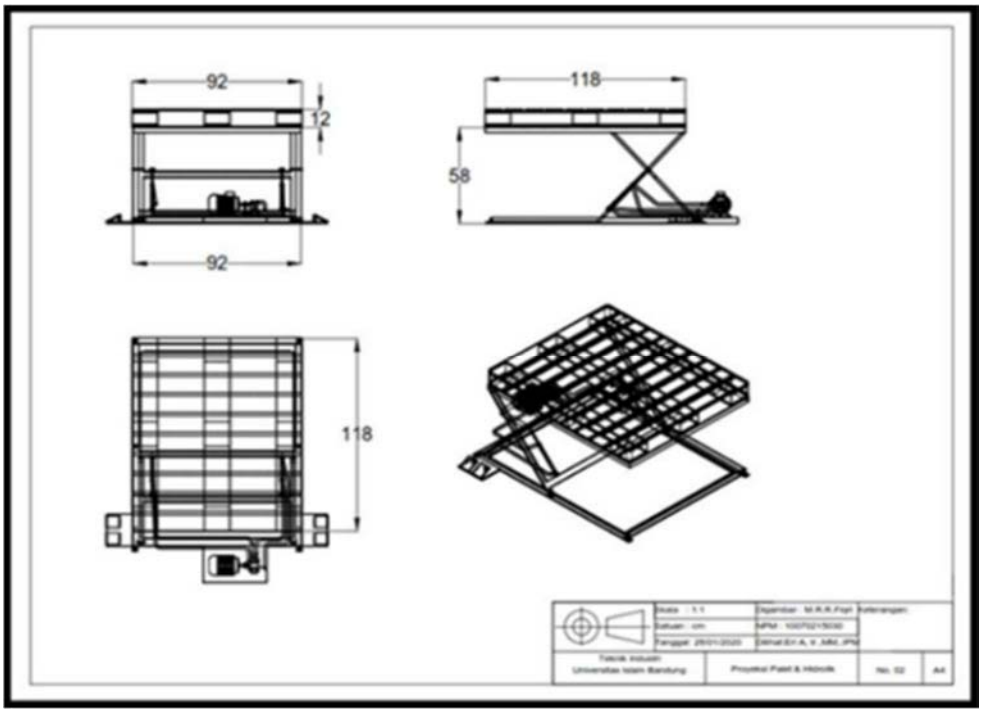


Figure 6 Hydraulic pallet work facility design and size

Determine the needed body proportions initially while developing work facilities. Table 4 displays work dimension facilities, the specified body dimensions, and their applications.

Table 4 Work dimension facilities

No.	Work facilities design	Work facility dimension	Body dimension	Reason
1	Hydraulicpallet	Hydraulic base width	3 x box (2 x boxwidth + 1 x box length)	To determine the maximum length of the hydraulic pallet hydraulic
2		Hydraulic base length	4 x box (1 x boxlength+ 3 x box width)	To determine the maximum height of the hydraulic pallet hydraulic
3		Hydraulic pallet height	Standing elbow	To determine the maximum height of the hydraulic pallet sothe operator can work as comfortable as possible

Figure 7 shows a work facility design in the form of a hydraulic pallet that has been changed to the chosen body dimensions and final facility size. Based on visualization findings in the Catia program, the operator no longer bends while performing tasks, reducing work risk by adding new work facilities since no shear force is created at locations L5/S1. Designing new work facilities using hydraulic pallets that function to raise and lower pallets prevents operators from bending when storing or lifting loads on conveyors.

The simulation of the work facility design, featuring an adjustable-height hydraulic pallet, demonstrated that operators could maintain an upright posture during lifting tasks. The compressive force (Fc) and shear force (Fs) recorded during all box-lifting activities from box 1 to 60 were significantly reduced to 3,350 N and 185.31 N, respectively, which are well within safe ergonomic limits. This represents a marked improvement from the earlier measurements, where compressive forces exceeded 19,778.2 N, indicating a high risk of injury. By allowing operators to maintain proper posture and minimize bending movements, the hydraulic pallet effectively reduces biomechanical risks, ensuring a safer working environment.

The upright standing position of the operator during storage, without continuous and repeated bending movements, minimizes work risks and allows for the implementation of new facilities.

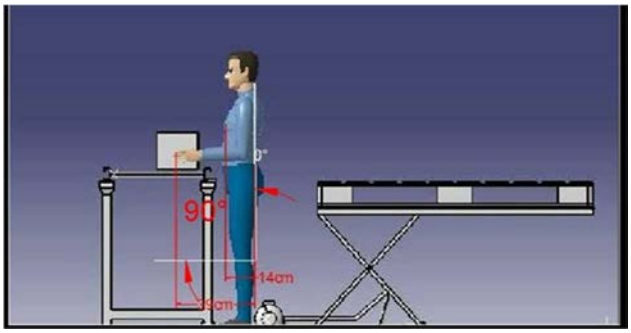


Figure 7 Work facilities design

5 Conclusions

The biomechanical analysis of lifting and transferring 600 ml SPS boxes, focusing on the lower back's static model at the L5/S1 point, has highlighted significant ergonomic concerns. Our findings indicate that the operators' postures during lifting and their positions when storing loads are unsafe. These safety issues are primarily determined by the operator's body angle and the distances between the load's center of mass and the L5/S1 point, as well as between the body's center of mass and the L5/S1 point. Proper manual lifting techniques, which include keeping the load close to the body's center, positioning the feet near the load, maintaining straight back and shoulders, and ensuring load and body position stability, are not currently being followed.

To mitigate these risks, we propose introducing a hydraulic pallet that adjusts in height, allowing operators to store or load items without bending. Simulation results from this intervention indicate a significant risk reduction, with compressive forces (Fcompression) reduced to 3,350 N—within safe criteria—and shear forces (Fshear) eliminated at the L5/S1 point. By enabling operators to maintain an erect posture during storage tasks, the redesigned work environment significantly decreases the risk associated with repetitive bending actions.

This study opens avenues for future research aimed at a deeper and broader understanding of logistical ergonomics and manual lifting. Future work could focus on the deployment and evaluation of ergonomically designed work facilities, examining their impact on operator well-being, productivity, and incidence of work-related injuries. The integration of monitoring technologies, such as motion sensors or wearable devices, in logistics settings presents a promising area for investigation, offering the potential for real-time monitoring of operator behaviors and quicker responses to emerging workplace hazards.

Further research could develop more precise ergonomic guidelines for the distribution logistics environment, providing businesses with the tools needed to create safer and more efficient workspaces. An in-depth biomechanical analysis of operators performing manual lifting tasks could enhance our understanding of the physical impacts of these tasks, including posture and joint stress. Investigating the effects of environmental factors such as temperature, lighting, and noise on operator well-being could yield a comprehensive view of the elements that influence ergonomic conditions in the workplace.

Incorporating psychological aspects of work, including stress levels and job satisfaction, could further elucidate the complex interplay between physical and mental health in occupational settings. Continued research in this field is essential for generating actionable insights into improving logistics ergonomics, leading to safer and more productive work environments that benefit both operator well-being and overall productivity.

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References

[1] SADEROVA, J., AMBRISKO, L.: Simulation of operations on the production line as a tool for making the production process more efficient, *Acta logistica*, Vol. 10, No. 4, pp. 549-556, 2023. https://doi.org/10.22306/al.v10i4.432

[2] GIANNINI, P., BASSANI, G., AVIZZANO, C.A., FILIPPESCHI, A.: Wearable sensor network for biomechanical overload assessment in manual material

handling, *Sensors*, Vol. 20, No. 14, 3877, pp. 1-29, 2020. https://doi.org/10.3390/s20143877

[3] RAMAGANESH, M., JAYASURIYAN, R., RAJPRADEESH, T., BATHRINATH, S., MANIKANDAN, R.: Ergonomics hazard analysis techniques-A technical review, *Materials Today: Proceedings*, Vol. 46, Part 17, pp. 7789-7797, 2021. https://doi.org/10.1016/j.matpr.2021.02.329

[4] DEROS, B.M., DARUIS, D.D., ISMAIL, A.R., SAWAL, N.A., GHANI, J.A.: Work-related musculoskeletal disorders among workers' performing manual material handling work in an automotive manufacturing company, *American Journal of Applied Sciences*, Vol. 7, No. 8, pp. 1087-1092, 2010. https://doi.org/10.3844/ajassp.2010.1087.1092

[5] BASAHEL, A.M.: Investigation of work-related musculoskeletal disorders (MSDs) in warehouse workers in Saudi Arabia, *Procedia Manufacturing*, Vol. 3, pp. 4643-4649, 2015. https://doi.org/10.1016/j.promfg.2015.07.551

[6] DEWANGAN, C.P., SINGH, A.K.: Ergonomic study and design of the pulpit of a wire rod mill at an integrated steel plant, *Journal of Industrial Engineering*, Vol. 2015, No. 1, pp. 1-11, 2015. https://doi.org/10.1155/2015/412921

[7] JAFFAR, N.A.T., RAHMAN, M.N.A.: *Review on risk factors related to lower back disorders at the workplace*, IOP Conference Series: Materials Science and Engineering, International Research and innovation Summit IRIS2017, IOP Publishing, Vol. 226, No. 1, p. 012035, pp. 1-9, 2017. https://doi.org/10.1088/1757-899X/226/1/012035

[8] ALIAS, A.N., KARUPPIAH, K., HOW, V., PERUMAL, V.: Prevalence of musculoskeletal disorders (MSDS) among primary school female teachers in Terengganu, Malaysia, *International Journal of Industrial Ergonomics*, Vol. 77, No. May, p. 102957, 2020. https://doi.org/10.1016/j.ergon.2020.102957

[9] BRUNNER, S., YUCHING, C.K., BENGLER, K.: Streamlining operations management by classifying methods and concepts of Lean and Ergonomics within a sociotechnical framework, *Operations Management Research*, Vol. 17, pp. 1172-1196, 2024. https://doi.org/10.1007/s12063-024-00488-y

[10] WIDODO, L., ADIANTO, YENITA, RUSLIE, C.: *Ergonomic Analysis by Using REBA, WERA, and Biomechanics Method in the Production Process of Women's Bags in Small Industry (SME)*, IOP Conference Series: Materials Science and Engineering, 3rd TICATE 2020, Vol. 1007, p. 012088, pp. 1-6, 2020. https://doi.org/10.1088/1757-899X/1007/1/012088

[11] PEREZ, J.N.S., ARELLANO, J.L.H., NEGRETE, C.: *WRMSD Survey. A Comparison Between Assembly and Manufacturing Tasks*, Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics AHFE, At Kraków, Poland, Advances in Social and Organizational Factors, AHFE (2020) International Conference, AHFE Open Access, vol 9. AHFE International, USA, Vol. 9, pp. 1-9, 2020. https://doi.org/10.54941/ahfe100318

[12] RAU, G., DISSELHORST-KLUG, C., SCHMIDT, R.: Movement biomechanics goes upwards: from the leg to the arm, *Journal of biomechanics*, Vol. 33, No. 10, pp. 1207-1216, 2000. https://doi.org/10.1016/S0021-9290(00)00062-2

[13] CECILIA, B., CAROLINE, A.: *Production Ergonomics: Designing Work Systems to Support Optimal Human Performance*, Ubiquity Press Ltd. 6 Windmill Street London W1T2JB, 2017. https://doi.org/10.5334/bbe

[14] TOSI, F.: *Ergonomics and Design. In Design for Ergonomics*, Springer Series in Design and Innovation book series, SSDI, Vol. 2, pp. 3-29, 2020. https://doi.org/10.1007/978-3-030-33562-5_1

[15] RAJENDRAN, M.., SAJEEV, A., SHANMUGAVEL, R., RAJPRADEESH, T.: Ergonomic evaluation of workers during manual material handling, *Materials Today: Proceedings*, Vol. 46, Part 17, pp. 7770-7776, 2021. https://doi.org/10.1016/j.matpr.2021.02.283

[16] HOSSAIN, M.D., AFTAB, A., AL IMAM, M.H., MAHMUD, I., CHOWDHURY, I.A., KABIR, R.I., SARKER, M.: Prevalence of work-related musculoskeletal disorders (WMSDs) and ergonomic risk assessment among readymade garment workers of Bangladesh: A cross-sectional study, *PloS one*, Vol. 13, No. 7, e0200122, pp. 1-18, 2018. https://doi.org/10.1371/journal.pone.0200122

[17] WARREN, N.: Work stress and musculoskeletal disorder etiology: The relative roles of psychosocial and physical risk factors, *Work*, Vol. 17, No. 3, pp. 221-234, 2001.

[18] MCATAMNEY, L., CORLETT, E.N.: RULA: A survey method for the investigation of work-related upper limb disorders, *Applied Ergonomics*, Vol. 24, No. 2, pp. 91-99, 1993. https://doi.org/10.1016/0003-6870(93)90080-S

[19] LANFRANCHI, J.B., DUVEAU, A.: Explicative models of musculoskeletal disorders (MSD): From biomechanical and psychosocial factors to clinical analysis of ergonomics, *European review of applied psychology*, Vol. 58, No. 4, pp. 201-213, 2008. https://doi.org/10.1016/j.erap.2008.09.004

[20] TAI, W.H., ZHANG, R., ZHAO, L.: Cutting-Edge Research in Sports Biomechanics: From Basic Science to Applied Technology, *Bioengineering*, Vol. 10, No. 6, 668, pp. 1-4, 2023. https://doi.org/10.3390/bioengineering10060668

[21] CHI, Q., LIU, P., LIANG, H.: Biomechanics Assist Measurement, Modeling, Engineering Applications, and Clinical Decision Making in Medicine, *Bioengineering*, Vol. 10, No. 1, 20, pp. 1-5, 2022. https://doi.org/10.3390/bioengineering10010020

[22] SURYOPUTRO, M.R., WILDANI, K., SARI, A.D.: *Analysis of manual material handling activity to increase work productivity (Case study: manufacturing company)*, MATEC Web of Conferences, Vol. 154, p. 01085, EDP Sciences, 2018. https://doi.org/10.1051/matecconf/201815401085
[23] WAHYUDI, M.A., DANIA, W.A., SILALAHI, R.L.: Work posture analysis of manual material handling using OWAS method, *Agriculture and Agricultural Science Procedia*, Vol. 3, pp. 195-199, 2015. https://doi.org/10.1016/j.aaspro.2015.01.038
[24] WIDANARKO, B., KUSMASARI, W., YASSIERLI, Y., IRIDIASTADI, H.: *Instrumen Survei Gangguan Otot-Rangka*, Perhimpunan Ergonomi Indonesia, 2016.
[25] NURMIANTO, E., CIPTOMULYONO, U., KROMODIHARDJO, S.: Manual handling problem identification in mining industry: An ergonomic perspective, *Procedia manufacturing*, Vol. 4, pp. 89-97, 2015. https://doi.org/10.1016/j.promfg.2015.11.018
[26] MALLAPIANG, F., AZRIFUL, NILDAWATI, SYARFAINI, MUIS, M., ADRIANSYAH: The relationship of posture working with musculoskeletal disorders (MSDs) in the weaver West Sulawesi Indonesia, *Gaceta Sanitaria*, Vol. 35, pp. S15-S18, 2021. https://doi.org/10.1016/j.gaceta.2020.12.005
[27] THAMRIN, Y., PASINRINGI, S., DARWIS, A.M., PUTRA, I.S.: Musculoskeletal disorders problems and its relation to age, working periods, and smoking habit among fishermen, *Gaceta Sanitaria*, Vol. 35, pp. S417-S420, 2021. https://doi.org/10.1016/j.gaceta.2021.10.065

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Analysis of marketing distribution efficiency of small pelagic fish on Ambon Island with path analysis

Dientje Rumerung
Pattimura University, Department of Development Economics, Jln. Ir. M. Putuhena, Campus at Poka Village, 97233, Ambon City, Indonesia, rumerungd@gmail.com (corresponding author)
Steven Siaila
Pattimura University, Department of Management, Jln. Ir. M. Putuhena, Campus at Poka Village, 97233, Ambon City, Indonesia, sivenste57@gmail.com
Izaac Tonny Matitaputty
Pattimura University, Department of Development Economics, Jln. Ir. M. Putuhena, Campus at Poka Village, 97233, Ambon City, Indonesia, tonnymatitaputty@gmail.com

Keywords: producer price, consumer price, marketing cost, marketing margin, marketing efficiency.
Abstract: This study aims to develop a path analysis of marketing distribution efficiency of small pelagic fish in the islands, particularly on Ambon Island, and investigate its most significant determinant. Producer price, consumer price, marketing cost and marketing margin are examined as determinants of marketing efficiency. An efficient marketing system provides benefits for business actors involved in the production process, so that their products can reach target consumers. A longer marketing chain results in higher marketing costs, which ultimately determines the end consumer price. The data was analysed in a descriptive-quantitative manner, conducting a supply chain analysis and a path analysis to determine the marketing margin and marketing efficiency of small pelagic fish marketing distribution in Ambon City. The results show that all distribution channels are efficient because the calculated efficiency value is <30%. First path analysis producer prices (X1) have no significant effect on marketing margin (Y), consumer prices (X2) have a positive and significant effect on marketing margins (X3); and marketing costs have a significant effect on marketing margin (Y). The second equation, all variables (X1, X2, and X3) have a significant effect on marketing distribution efficiency (Z) through marketing margin (Y). It can be concluded that marketing costs and marketing margins greatly influence the efficiency of marketing distribution. These findings imply that to gain profits, small pelagic fish fishermen (as producers) must estimate marketing costs accurately.

1 Introduction

The welfare of communities on islands is influenced not only by the potential of plentiful natural resources, but also by efficient marketing distribution. The marketing distribution refers to a marketing activity that accelerates and facilitates a product's efficient delivery to end consumers. This condition implies that if producers have efficient marketing distribution channels, they can monopolize the market. An efficient marketing system will benefit business actors involved in the production process with the aim of getting their products to the consumers as a final sales process, because the longer the marketing chain, the higher the marketing costs and, ultimately, the higher the price for the end consumers. Marketing efficiency is defined as the difference between the selling price received by the producers and the price paid by the end customers.

This is related to the producers' ability to select the appropriate marketing distribution channels, which influences the marketing pattern of goods and services to the consumers [1-4]. In other words, this distribution channels are such a structure that outlines the alternative channels chosen as well as different marketing conditions used by various companies. Indirectly, this condition implies that a variety of factors influence the distribution channels, which eventually leads to the marketing efficiency. On the other hand, fish is a highly perishable product, so inaccuracies in distribution channel placement, pricing, marketing periods, and even transportation will result in losses for fishermen as producers. Furthermore, this condition will have an impact not only on the distribution channels and marketing efficiency, but also on the macroeconomic level, making the welfare of fishermen's households more difficult to accomplish. As a result, the fishermen's households remain impoverished, and it is most likely that they will grow even poorer than before.

Maluku Islands have a larger water area (92.4% or 658,294.69 km2), than land area (7.6% or 54,184.96 km2). The domination of this marine area shows that Maluku has a significant fishing potential. This fact is supported by the control of three Fish Management Areas (Wilayah Pengelolaan Perikanan, WPP), namely WPP 714, WPP 715, and WPP 718. The control of this WPP has stretched from Seram Sea, Banda Sea, and Arafura Sea, with the significant potential for small pelagic fish and demersal fish. The following Table 1 shows the fisheries potential of WPPs in Maluku in 2023.

Table 1 Fisheries Potential of WPPs in Maluku Region in 2023

WPP	Fisheries Potential		
	Small Pelagic Fish (Tons)	Large Pelagic Fish (Tons)	Demersal Fish (Tons)
WPP 714 (Tolo Bay and Banda Sea)	222,881	370,653	292,000
WPP 715 (Tomini Bay, Maluku Sea, Halmahera Sea, Seram Sea, and Berau Bay)	443,944	74,908	80,226
WPP 718 (Aru Sea, Arafuru Sea, and Eastern Timor Sea)	669,579	655,096	701,378
Total	**1,136,404**	**1,100,657**	**1,073,604**

Source: Decree of the Minister of Maritime Affairs and Fisheries of the Republic of Indonesia Number 19 of 2022.

The total capture fisheries potential in the three WPPs is dominated by small pelagic fish (669,579 tons in WPP 718), followed by large pelagic fish (655,096 tons) and demersal fish (701,378 tons). This data demonstrates that WPP 718 has huge potential for being capitalized on and enhanced to increase the income of fishermen and the region. However, in fact, the fishermen in Maluku have yet to reap the benefits of owning such a vast marine area. The Statistics Indonesia of Maluku Province in 2023 show that the province remains the fourth poorest province in Indonesia. Ambon City is located on a small island surrounded by bays and beaches, which allows for the growth and development of the fisheries sector and will eventually contribute to the regional economy. The fisheries sub-sector contributes 15% of Ambon City's Gross Regional Domestic Product (GRDP) on average per year, with relatively consistent annual growth of roughly 4.5%. This significant contribution is supported by the majority of coastal communities/sub-districts (32 villages) that engage in active fishing activities.

The Ambon City Fisheries Department [5] reported total fisheries production of 29,010.53 tons with a value of IDR 602,855,500. However, the poverty rate in 32 coastal villages in Ambon City has been significantly higher during the last four years, ranging from 16% to 18%. Meanwhile, the poverty rate in all 50 villages/sub-districts is between 14.9% and 17%. In fact, the efforts to grow the fisheries and marine sector should be supported by optimal resource utilization and management capacities to have an impact on increasing the community welfare, particularly the fishermen who serve as both economic actors and producers.

The fluctuating development of fish productivity, which is declining, suggests that the fish resources in the waters of Ambon Island have experienced overfishing. This overfishing condition has a number of consequences for fishing activities, including the need for the fishermen to travel longer distances at higher prices. Furthermore, an effective marketing strategy can determine the profitability that the fishermen can earn on Ambon Island, including the utilization of transportation to distribute their products. The marketing activities for catching small pelagic fish provide a source of income for the fishing community on Ambon Island. [6] and [7] believed that in order to obtain profits, it takes several considerations on the determinants, such as reserves/stocks, fishing equipment, and workforce. It is because if the fishing activities are not profit-oriented, the fishermen's business sustainability will be at risk [8]. As a result, an effective marketing system must be able to meet two requirements: first, capable of collecting the results from the producers and delivering them to the consumers at low cost; and second, capable of sharing a fair compensation to all parties involved based on the end consumer price, including from the production to marketing activities [9] and [10].

Furthermore, in recent years, numerous studies have paid attention to investigate marketing distribution efficiency. These studies explained that a marketing distribution channel is considered efficient if there is a close distance between each marketing actor and the marketing location which can reduce the marketing cost incurred [11-13]; an influence of marketing institutions [14-16]; a high fish selling price [17,18] and available fish stock [19-22].

Based on the previous studies on marketing distribution efficiency, this present study proposes that fish marketing distribution efficiency in the islands has significantly more complex problem dynamics than continental areas. The marketing distribution frequently faces challenges of limited transportation access and high costs, affecting the low income and well-being of the fishing community on the islands. Furthermore, there has been little research on the fish marketing distribution efficiency in the islands. Therefore, the context of this research is intriguing, with a focus on the marketing distribution efficiency of small pelagic fish in the islands and its determinants.

The results of this study are expected to contribute to the development of studies on the fisheries resources in the islands, marketing distribution, island economy, and local fishermen's livelihood strategies. Thus, the research questions of this study are: "What is the marketing distribution channel pattern for small pelagic fish on Ambon Island?"; "How significant is the marketing margin and distribution efficiency for small pelagic fish?"; and "What factors influence the marketing efficiency of small pelagic fish on Ambon Island?".

2 Methodology

This study employed a quantitative approach – analysing the marketing margins and marketing efficiency using ratios or marketing margin percentage values as a measure of marketing efficiency; a descriptive approach – classifying the distribution channels of small pelagic fish in the islands; and a statistical analysis to examine the determinants of marketing efficiency through a path analysis. The research was conducted on Ambon Island for four months, August to December 2023 at four locations, namely in Latuhalat Country, Seri Village, Eri Village, Hutumuri Country and Hukurila Country (Figure 1).

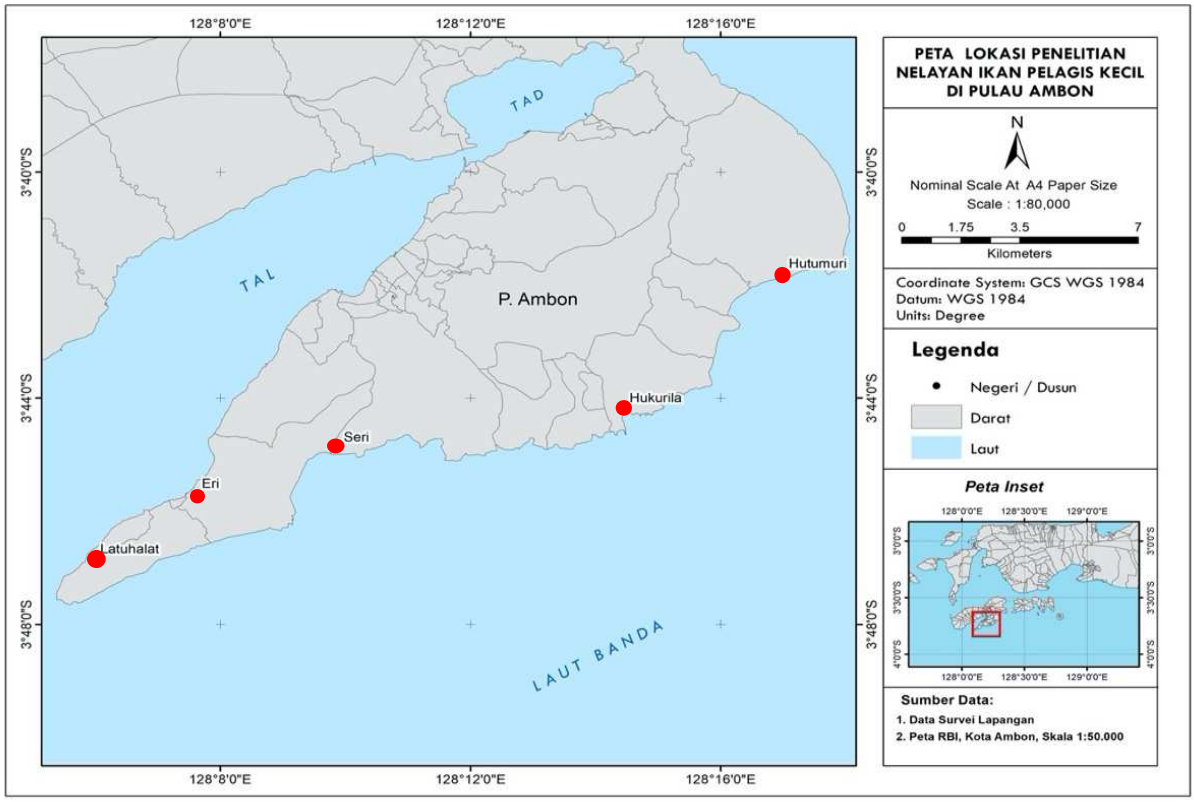

Figure 1 Research location map, 2024

Sampling was carried out non-proportionally so that a sample of 30 people was obtained at the research location. The sample consists of fishermen, collectors/auctioneers/gatherers, retailers and cold storage owners who buy fish from fishermen and then sell them to consumers during the lean season.

The parameters examined in field research are fish landing locations, interviews about distribution channels, marketing costs, costs for each distribution channel (transportation, ice, fees and labor) for fishing activities, purchase price (Rp/kg), and sales price (Rp/kg). Then, this study conducted a data analysis to calculate the marketing margin to determine the distribution of costs and profits from the marketing activities in each established marketing institution; in other words, the marketing margin analysis determined the level of competition from all marketing actors involved in the marketing process.

The marketing margin referred to the difference between the price producers received and the price consumers paid. The marketing margin was calculated by reducing the sales price at each level of the marketing institution using the Marketing Margin formula [23] as follows (1):

$$MM = Cr - Pf \quad (1)$$

Note:
MP = Marketing Margin
Pr = Consumer Price
Pf = Producer Price

Then, the marketing efficiency analysis was performed using the total marginal price at the consumer level using the following formula (2) [24]:

$$MT = \frac{Pr - Pf}{Pr} x\ 100\% \quad (2)$$

Note:
MT = Total Margin (%)
Pr = Consumer Price
Pf = Fisherman Price

Next, an estimation analysis was performed by utilizing the path analysis with the following equations (3), (4):

$$Y = \beta 0 + \beta 1\chi 1 + \beta 2\chi 2 + \beta 3\chi 3 + e1 \quad (3)$$

Note:
Y = Marketing Margin
X1 = Producer Price
X2 = Consumer Price
X3 = Marketing Cost
b0 = Constant
b1, b2, b3 = Regression Coefficient
e1 = Error

$$Z = \beta 4\chi 4 + \beta 5\chi 5 + \beta 6\chi 6 + \beta 7Y + e2 \quad (4)$$

Note:
Z = Marketing Distribution Efficiency
b4 = Path Coefficient of X1 to Z through Y
b5 = Path Coefficient of X2 to Z through Y
b6 = Path Coefficient of X3 to Z through Y
b7 = Path Coefficient of Y to Z
e2 = Error

3 Result and discussion

3.1 Profile of capture fisheries in Ambon Island

The fisheries resources in Maluku Province, particularly Ambon Island, indicated a high level of fisheries potential, both for capture and aquaculture. The potential for capture fisheries was divided into nine categories: small pelagic fish, large pelagic fish, demersal fish, coral, shrimp, lobster, crab, blue crab, and squid. The total production of capture fisheries in Maluku Province covering 11 districts/cities reached 536,112.6 tons per year in 2023, with a production value of IDR 13,820,522,191 [25]. Furthermore, geographically, Ambon City covered approximately 786 km2, with 377 km2 of land (48%) and 409.0 km2 of water (52%). The land area of Ambon City was also over half that of Ambon Island, with a 102.7-kilometer shoreline.

Meanwhile, administratively, Ambon Island was separated into two regions: Ambon City and Central Maluku Regency. Ambon City was the administrative and economic centre of Maluku Province, located in the southern Ambon Island, specifically in the coastal areas of Ambon Bay and Baguala Bay. As a result, exploiting the captured fisheries resources in the coastal areas played an essential role in the community's life by offering work opportunities, ensuring food security, and meeting nutritional demands. According to the data from the Ambon City Fisheries Department (Table 2), the total fisheries production in 2022 reached 29,010.53 tons, with 36.68% coming from Nusaniwe District – Ambon City's largest fish producing district; and Teluk Ambon Baguala District accounting for 23.12% [26].

Table 2 Development of fisheries production and value in Ambon City, 2023

Year	Production (Tons)	Production Value (Thousand Rupiah)
2018	23,506.11	1,175,306
2019	25,176.93	50,353,860
2020	25,176.93	2,824,852
2021	28,482.63	534,389,073
2022	29,010.53	602,855,500

Source: Regional statistics of Ambon City, 2023

Meanwhile, flying fish was the most popular fish in Ambon City, but tuna fish production increased by 4,638.41 tons in 2022, with a value of IDR 115,960,250. The massive increase in production and production value over the previous five years were also linked to the fishing facilities and infrastructure held by the fishermen in Ambon City. According to the [26], the fishermen employed seven different types of fishing equipment, including fishing nets, bubu nets, rakes, tug fishing rods, huhate, hoisting nets, gill nets, purse seines, and beach seines, as indicated in the following figure (Figure 2).

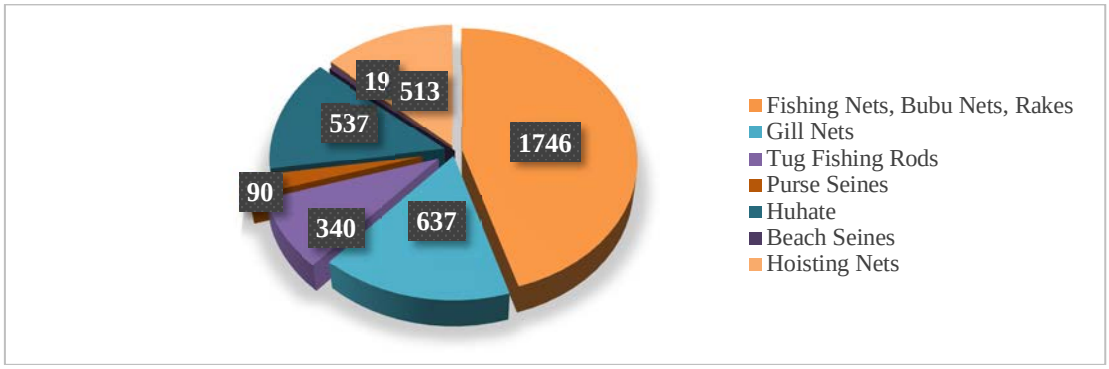

Figure 2 Type and number of fishing equipment in Ambon City in 2023
Source: Statistics Indonesia of Ambon City in 2023

Aside from that, Ambon Island had 3,820 fisheries households, according to the data by [5]. Meanwhile, there were 2,475 fishing boats of varying sizes in operation. The most common size of fishing boats was small, with 1,760 boats in total. Ownership of this size boat undoubtedly influenced the productivity of the fishermen themselves.

Further, it was explained that the fish captured by the fisherman in Negeri Latuhalat, Seri Village, Eri Village, Negeri Hutumuri, and Negeri Hukurila were distributed to Mardika market and a number of other small markets, as well as to adjacent communities. The process of captured fish distribution to the markets involved a number of economic entities collaborating. Furthermore, Ambon Island was small, having a bigger sea area than the mainland, and had several potential fisheries and marine resources. The small pelagic fish, such as trevally, mackerel, and tuna, were among the fisheries resources in Ambon Island that had economic value and the potential to be exploited. This variety of fish was typically captured with the bubu nets. The results of this study also found that there were 2,473 capture fisheries households on Ambon Island in 2020, divided into three categories: small, medium, and large.

3.2 Profile of small pelagic fish fishermen in Ambon City

On Ambon Island, the fishermen had a unique role in capturing the small pelagic fish. In addition to experience, their understanding of capturing fish was based on knowledge passed down for generations and is still practiced today. It was done by looking at natural signs, such as stars, moons, and clouds. The field observations revealed that the fishermen were the traditional ones who ran a modest business and resided along the coast. Most of them did not use modern fishing equipment, and their behaviour remained subsistence-oriented. Profile of small pelagic fish fishermen on Ambon Island could be classified according to gender, age, latest education, length of business / work experience, and mileage, as shown in the table below (Table 3).

Table 3 Profile of small pelagic fish fishermen in Ambon City

No.	Characteristic		Total	%	Average
1.	Gender	Male	30	100	
		Female	0	0	
2.	Age	< 30 Years Old	3	10	
		30 - 40 Years Old	10	37.33	40 Years Old
		41- 50 Years Old	10	37.33	
		> 50 Years Old	7	23.33	
3.	Lats Education	Elementary School	0		
		Junior High School	0		
		Senior High School	30	100	
4.	Length of Business / Work Experience	< 10 Years	0		
		10 - 20 Years	29	96.67	20 Years
		21 - 30 Years	1	3.33	
		> 30 Years	0	0	
5.	Total Training Attended	0	0	0	
6.	Fishing Time Allocation	< 5 Hours	14 Respondents	46.66	
		> 5 Hours	16 Respondents	53.33	
7.	Fishing Frequency	3 - 5 Times / Week			5 Times / Week
8.	Mileage	3 - 4 Kilometers			3.5 Kilometers

Source: Results of Field Research, 2023

According to Table 3 above, the fishermen activities could be identified based on the following characteristics:

Based on the fishermen's **gender and age**, the fishermen on Ambon Island were mostly men of a productive age, with an average age of 40 years old. Their age had a vital impact in productivity through physical strength and work experience as a fisherman. These fishermen benefitted from their productive age and their extensive expertise in pursuing this as their primary source of income. On average, the fishermen who resided in the coastal areas were of older ages, therefore fishing was not their sole source of income. The fishermen in the coastal areas tended to seek additional income outside of their work as fishermen due to their inability to maximize their income [27-29].

Further, in terms of the fishermen's **latest education**, they were typically high school graduates. This condition, of course, contrasted with the reality of the low degree of education that the fishermen in the coastal areas typically had, who only graduated from elementary school or even did not graduate from the elementary school [27,30,31]. This finding implied that, on average, the Ambon Island fishermen understood the value of education for them. This fact demonstrated that they faced no limited access to high

school education, because high schools existed in practically all research locations. However, they did face limited funding problems to continue their studies at a higher level (university).

Furthermore, according to the fishermen's **length of business / work experience**, they had been in business for an average of 15 years. This demonstrated that the business activities in which they had been involved had been ongoing for some time. People with more work experience had better work abilities than those who were new to the world of work, because they had learned from the activities and problems occurred in their workplace. The work experience had resulted in an increase in knowledge and abilities that could help self-development in the face of current developments. An individual's ability to carry out their work obligations would improve as they gained experience [32-34]. In relation to this, the fishermen's experience in fishing was usually driven by the efforts to maximize their income [35].

Then, in terms of **total training attended**, despite the fact that the typical length of business was regarded quite long, the fishermen received no training that could develop their knowledge and skills as fishermen. Although the trainings for fishermen could improve their knowledge not only of how to capture fish, but also of sustainable fisheries and captured fish quality which ultimately determined the prices and opportunities for product marketing and fishing industry in the coastal areas [36-38].

Finally, in terms of **Fishing Time Allocation and Mileage**, the fishermen allocated more than 5 hours each day to capture the fish, with a weekly frequency of 4 to 5 trips. Meanwhile, the average mileage to fishing grounds was only 3.5 kilometres. The fishing time in question covered the time they needed for preparation to after the trip [39-41]. An increase in the fishing time allocation would have an impact on boosting their income, since the longer they stayed at the sea, the farther the distance traveled and the bigger the amount of fish captured – hence increasing their income [42-45].

3.3 Marketing channels of small pelagic fish in Ambon Island

The distribution of small pelagic fish capture on Ambon Island also involved multiple actors or economic entities working together, from the fishermen to end consumers. The cooperative relationship between these actors had lasted for a long time; there was even a relationship between their parents that was still maintained by their children. For obvious reasons, the goal of this cooperative relationship was to ensure that the fishing and fish-selling activities functioned smoothly and profitably. Furthermore, this collaborative relationship was commonly referred to as a 'supply chain' or marketing channels. The marketing channels were a means of distributing products from the producers to customers in an organized manner that was mutually dependent on each other.

The empirical findings of this study reveal that the small pelagic fish supply chain on Ambon Island had four established supply networks as shown in the following Figure 3.

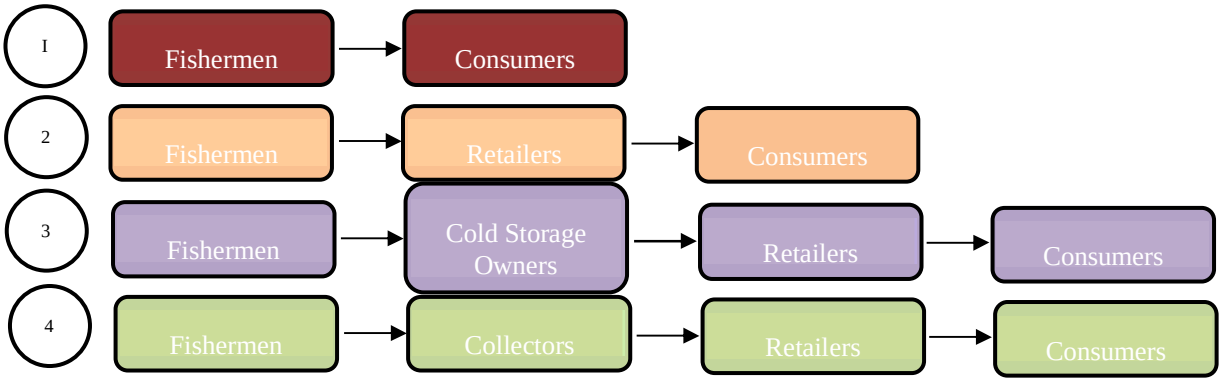

Figure 3 Small pelagic fish supply chain in Ambon Island, 2023

According to Figure 3 above, the supply chain pattern for small pelagic fish on Ambon Island could be explained as follows:

1) The first distribution chain involved the fishermen selling directly to local consumers, specifically at the time of landing.
2) The second distribution chain involved the fishermen selling directly to retailers, who then sold them to the end consumers.
3) The third distribution chain involved of two intermediaries, followed by the end consumers. The capture of small pelagic fish was transferred to cold storage before being sold to the retailers, who subsequently sold them to the end customers.
4) The fourth distribution chain started with the fishermen used the collectors' service, then the collectors sold the fish to the retailers, and the retailers would sell the fish to the end consumers.

The business actors involved had different tasks as follows (Table 4):

- The fishermen prepared the fishing facilities, determined the capture zone, captured the fish, sorted the fish, and transported the fish.
- The collectors distributed the fish, determined the fish price, and were in charge in retail sales. In this case, the fishermen as producers did not determine the selling price no paid for the marketing cost. The collectors would receive 10% of the total sales revenue.
- The retailers were in charge of the purchasing activities, determined the price, and sold the fish to the end consumers.
- The cold storage owners were in charge of the purchasing activities, and storing and selling the fish, particularly during the lean season.

Table 4 Small pelagic fish sales distribution and volume on Ambon Island

	Marketing Channel	Percentage of Sales Volume (%)	Total (Individual)
I	Fishermen – Consumers	10	3
II	Fishermen – Retailers – Consumers	15	7
III	Fishermen – Cold Storage Owners – Retailers – Consumers	15	5
IV	Fishermen – Collectors – Retailers – Consumers	60	15

Source: Results of Field Research, 2023

Based on the data presented above, the distribution of small pelagic fish capture on Ambon Island reveals that only 10% of the fish captured were sold directly to the consumers upon landing. These consumers were from the same Negeri as the fishermen, as well as from nearby villages. On the other side, the majority of sales volume was distributed to Borok/auctioneers/collectors, with 60% auctioned to the retailers and sold from the retailers to the end consumers. Meanwhile, the remaining 15% of the capture were transferred to cold storage owners, which was then sold to the end consumers through the retailers. The fish sales in this channel were often conducted during the lean season. The other 15% were then sold directly by the fishermen to the retailers, who then sold them directly to the end consumers.

These small pelagic fish collected by the fishermen were sold in pans, with the cheapest being IDR 300,000 per pan and the most expensive ranging from IDR 800,000 to IDR 1,000,000 each pan. During the peak season, there were plenty of fish, with the capture ranging from 20 to 30 pans at a time per trip. However, during a bad fishing season, the capture was limited to only 5 to 10 pans. One pan weighted approximately 30 kilograms, and the transportation would cost IDR 20,000 each pan. According to the data above, the fourth marketing channel was the most commonly preferred marketing channel by the fishermen, accounting for up to 15 individuals or 60% percent of all existing marketing channels for the small pelagic fish.

Table 5 Analysis of marketing margin and marketing channel efficiency of small pelagic fish on Ambon Island

Marketing Channel	Fisherman Price/Pan (IDR)	Consumer Price/Pan (IDR)	Marketing Margin	Efficiency
I	600,000	600,000	0	0
II	620,000	700,000	80,000	11.43
III	620,000	750,000	130,000	17.33
IV	540,000	700,000	160,000	22.86

Source: Results of Field Research, 2023

The marketing margin and efficiency calculations implied the marketing distribution channel patterns as follow (Table 5):

- The first marketing channel was a direct distribution of small pelagic fish on Ambon Island from the fishermen to the end consumers at the landing locations without the help of intermediaries, and could sell the fish for IDR 600,000 per pan. It was clear that there was no marketing cost paid as a result of costs borne by both the fishermen and end consumers that could influence the pricing; and that the marketing margin was equal to zero.
- The second marketing channel involved an assistance of retailers as the intermediaries between the fishermen and end consumers. The price from fishermen to the retailers was IDR 620,000 per pan, which was then resold by the retailers to end consumers in the market for IDR 700,000. Therefore, the marketing margin was IDR 80,000 per pan, with the fisherman receiving 88.57% of the share.
- The third marketing channel involved an assistance of cold storage owners and retailers as the intermediaries between the fishermen and end consumers. The price from fishermen to the cold storage owners was IDR 620,000 per pan, which was then resold to the end

consumers for IDR 750,000 per pan. Therefore, the marketing margin was IDR 130,000 per pan, with the fishermen receiving 82.66% of the share.

- The fourth marketing channel involved an assistance of collectors and retailers as the intermediaries between the fishermen and end consumers. The price from fishermen to the collectors was IDR 540,000 per pan, which was then resold to the end consumers for IDR 700,000 per pan. Therefore, the marketing margin was IDR 160,000 per pan, with the fishermen receiving 77.14% of the share.

This analysis shows that the consumer price was much higher than the selling price received by the fishermen in each distribution channel, resulting in a big marketing margin, causing the consumer price to rise. Similarly, a study by [46] confirmed that each institution performing different marketing functions would result in considerable pricing discrepancies between the fishermen/producers and consumers, causing the consumer price to rise. Thus, the findings of this study suggest two crucial conclusions: first, the longer the marketing distribution channel, the more ineffective it would be; and second, all distribution channels (I-IV) could be considered efficient, with each marketing distribution channel ranges from 0% to 30%.

3.4 The path analysis of marketing distribution efficiency of small pelagic fish in Ambon Island

The efficiency with which small pelagic fish were marketed and distributed on Ambon Island was dynamic. The consumer price, producer price, and marketing cost had a significant impact on the marketing efficiency. In other words, there were various determinants of small pelagic fish distribution in the market. This study conducted a path analysis based on the collected field research data, and the results can be seen in the following Table 6.

Table 6 Results of path analysis of factors affecting the marketing distribution efficiency of small pelagic fish on Ambon Island

No.	Variable	B	Sig. Prob.	Result
I	**First Equation**			
	Constant (13,622.32)			
	Producer Price (X_1)	0.031	0.071	Not Significant
	Consumer Price (X_2)	0.045	0.020	Significant
	Marketing Cost (X_3)	1.023	0.000	Significant
I	**Second Equation**			
	Constant (0.054)			
	Producer Price (X_1)	-0.0000344	0.042	Significant
	Consumer Price (X_2)	0.0000902	0.037	Significant
	Marketing Cost (X_3)	-0.001	0.046	Significant
	Marketing Margin (Y)	-0.014	0.039	Significant

The regression equations are as follow:

$$Y = 13622.323 + 0.031\chi_1 + 0.045\chi_2 + 1.023\ \chi_3 + e$$

$$Z = 0.54 - 0.0000\ 3442\ \chi_1 + 0.00009022\chi_2 - 0.001\chi_3 - 0.014\ Y + e$$

The first equation shows that the producer price (χ1) has a positive and insignificant effect on the marketing margin; the consumer price (χ2) has a positive and significant effect on the marketing margin; and the marketing cost (χ3) has a positive and significant effect on the marketing margin. These findings confirm that increasing the producer price (χ1) led to a higher marketing margin. It could be explained as the producer price, or selling price of the product, was defined by the production cost incurred while the product was in the production stage, which included operating costs, such as direct labour costs. If the production cost was high, the producer price/selling price would also be high, and this would lead to a higher consumer price/purchasing price in subsequent marketing phases, which would be even higher if the marketing cost was accumulated.

A high consumer price would have a significant impact on the marketing margin. In contrast, the producer price did not appear to have a substantial impact on the marketing margin. This suggested that the producer price was only determined by operational costs that remained within appropriate boundaries, implying that the producer price was determined reasonably and it had had no effect on the determination of consumer price or marketing margins. Further, the marketing margin was positively impacted by the consumer price (χ2) as a result of longer marketing chains, which caused the marketing cost to be greater and simultaneously would have an impact on the higher marketing margin. In addition, the high marketing cost (χ3) could boost the marketing margin [47,48].

[49] and [50] underlined in their respective research that the fishermen/producers had little bargaining power while conducting transactions. Thus, an increase in the consumer price due to an increase in the marketing cost

would not result in a major fisherman price increase. This condition could also emerge as a result of the extensive marketing chain of small pelagic fish established on Ambon Island. Ultimately, it would affect the marketing margin and efficiency the small pelagic fish on Ambon Island. The second equation above shows that both producer price (χ1) and consumer price (χ2) have a negative and insignificant impact on the marketing distribution efficiency of small pelagic fish on Ambon Island. Meanwhile, the marketing cost (χ3) and marketing margin (Y) have a negative and significant effect on the marketing distribution efficiency of small pelagic fish on Ambon Island.

It should also be noted that the marketing efficiency in each existing supply chain could be influenced by the behaviour of producers and consumers, which might play a role in lowering a product's selling price. Thus, the higher the marketing cost, the higher the marketing margin, and the more inefficient the marketing distribution would be. In conclusion, the longer the marketing chain, the higher the marketing cost, and the higher the discrepancies between the selling price and the purchasing price. These would cause the marketing margin to increase, and eventually resulted in inefficiencies in the marketing distribution [51-53].

The total effect of the analysis model can be calculated as follows:

Total Effect of Fisherman Price (χ1): - 0.0000344 + (0.001 x 0.031)	=	-0.003409
Total Effect of Consumer Price (χ2): 0.0000902 + (0.001 x - 0.045)	=	0.000857
Total Effect of Marketing Cost (χ3): - 0.001 + (0.001 x 1.023)	=	-0.000001023
Total Effect	**=**	**0.00255098**

Based on the above explanation, it could be concluded that the marketing margin mediates the fisherman price on the marketing distribution efficiency of small pelagic fish on Ambon Island, and that it has a negative and significant effect, with a total effect of -0.0003409. Furthermore, the consumer price has a positive effect on the marketing distribution efficiency of small pelagic fish on Ambon Island, with a total effect of 0.000857. Meanwhile, the marketing cost has a negative and significant effect on the marketing distribution efficiency of small pelagic fish on Ambon Island, with a total effect of -0.000001023. Thus, the marketing margin, in its role as a moderating variable, led the effect of all independent factors to decrease in the same direction, with the exception of the fisherman price and marketing cost variables, which have a negative effect on the marketing distribution efficiency of small pelagic fish on Ambon Island.

4 Conclusions

This study finds that there are four marketing distribution channels for small pelagic fish on Ambon Island: Fishermen – Consumers; Fishermen – Retailers – Consumers; Fishermen – Cold Storage Owners – Retailers – Consumers; and Fishermen – Collectors – Retailers – Consumers. Furthermore, the longer the marketing chain, the higher the marketing margin, reducing the efficiency of marketing distribution of small pelagic fish on Ambon Island. For this reason, it is best to develop marketing distribution activities for small pelagic fish on Ambon Island using short distribution chains. Meanwhile, the marketing distribution efficiency of tiny pelagic fish on Ambon Island demonstrated that all four marketing distribution channels were efficient, with a range of less than 30%. Then, the marketing cost and marketing margin have a significant effect on the efficiency of marketing distribution, implying that if the fishermen/producers wish to obtain profits, the first thing they need to consider is to accurately estimate the marketing cost.

References

[1] CALISKAN, A., ÖZKAN ÖZEN, Y.D., OZTURKOGLU, Y.: Digital transformation of traditional marketing business model in new industry era, *Journal of Enterprise Information Management*, Vol. 34, No. 4, pp. 1252-1273, 2021. https://doi.org/10.1108/JEIM-02-2020-0084

[2] REIM, W., SJÖDIN, D., PARIDA, V.: Circular business model implementation: A capability development case study from the manufacturing industry, *Business Strategy and the Environment*, Vol. 30, No. 6, pp. 2745-2757, 2021. https://doi.org/10.1002/bse.2891

[3] BENNER, M.J., WALDFOGEL, J.: Changing the channel: Digitization and the rise of 'middle tail' strategies, *Strategic Management Journal*, Vol. 44, No. 1, pp. 264287, 2023. https://doi.org/10.1002/smj.3130

[4] ŚMIGLAK-KRAJEWSKA, M., WOJCIECHOWSKA-SOLIS, J., VITI, D.: Consumers' Purchasing Intentions on the Legume Market as Evidence of Sustainable Behaviour, *Agriculture*, Vol. 10, No. 10., 424, pp. 1-20, 2020. https://doi.org/10.3390/agriculture10100424

[5] AMBON CITY GOVERNMENT, *Ambon City Regional Statistics*, Ambon, Maluku, 2023.

[6] DIENTJE, R., SIAILA, S.: Analysis of the profitability of small pelagic capture fisheries in Ambon City, Indonesia, *Aquaculture, Aquarium, Conservation & Legislation Bioflux*, Vol. 15, No. 2, pp. 608-620, 2022.

[7] KAZUMI, S.: Case Study: A Simulation Model of the Spawning Stock Biomass of Pacific Bluefin Tuna and Evaluation of Fisheries Regulations, *American Journal of Climate Change*, Vol. 5, No. 2, pp. 245-260, 2016. https://doi.org/10.4236/ajcc.2016.52021

[8] HOSHINO, E., PASCOE, S., HUTTON, T., KOMPAS, T., YAMAZAKI, S.: Estimating maximum economic yield in multispecies fisheries: a review, *Reviews in Fish Biology and Fisheries*, Vol. 28, No. 2, pp. 261-276, 2018. https://doi.org/10.1007/s11160-017-9508-8

[9] PRANATA, S.A., MUSNAINI, M.: Efisiensi Pemasaran Ikan Nila (Oreochromis Niloticus) Keramba Jaring Apung Sungai Batanghari Kabupaten Muaro Jambi, *Jurnal Manajemen Terapan dan Keuangan*, Vol. 11, No. 03, pp. 554-568, 2022. https://doi.org/10.22437/jmk.v11i03.17978 (Original in Indonesian)

[10] MANGALLE, M.I., SYAFRIL, M., SUSILO, H.: Analisis Usaha Dan Efisiensi Pemasaran Pengolahan Ikan Asin Di Kawasan Toko Lima Kecamatan Muara Badak, *Jurnal Perikananan. Unram*, Vol. 13, No. 2, pp. 575-586, Jan. 2024. https://doi.org/10.29303/jp.v13i2.526 (Original in Indonesian)

[11] RUIZ-SALMÓN, I., FERNÁNDEZ-RÍOS, A., CAMPOS, C., LASO, J., MARGALLO, M., ALDACO, R.: The fishing and seafood sector in the time of COVID-19: Considerations for local and global opportunities and responses, *Current Opinion in Environmental Science & Health*, Vol. 23, No. October, 100286, pp. 1-5, 2021. https://doi.org/10.1016/j.coesh.2021.100286

[12] IWAN FADLI, P., TRISNANI, D.H.: Analisis Pemasaran Ikan Tongkol (Euthynnus Affinis) Di Pangkalan Pendaratan Ikan Kranji, Kabupaten Lamongan, *Marina*, Vol. 8, No. 2, pp. 103-115, 2022. https://doi.org/10.15578/marina.v8i2.11043 (Original in Indonesian)

[13] RIAN, H., EKO, S.W., IIN, S.: Pola Distribusi Dan Efisiensi Pemasaran Ikan Cakalang Di PPI Dufa-Dufa Kota Ternate, *Albacore*, Vol. 7, No. 2, pp. 235-242, 2023. https://doi.org/10.29244/core.7.2.235-242 (Original in Indonesian)

[14] ITA, S., ISTIQOMAH, SUKIMAN, SODIK, D.P.: Analisis Margin Pemasaran Ikan Layang Di Kabupaten Pati, *Jurnal Ekonomi Pertanian dan Agribisnis*, Vol. 6, No. 1, pp. 238-248, 2022. https://doi.org/10.21776/ub.jepa.2022.006.01.23 (Original in Indonesian)

[15] HIKMAH, H., NENSYANA, S., ARMEN, Z., AGUS, H.P.: Market Development Strategy of Demersal Fish in Merauke Regency, *Buletin Ilmiah Marina: Sosial Ekonomi Kelautan dan Perikanan*, Vol. 7, No. 1, pp. 43-54, 2021.

[16] GREMA, H.A., KWAGA, J.K.P., BELLO, M., UMARU, O.H.: Understanding fish production and marketing systems in North-western Nigeria and identification of potential food safety risks using value chain framework, *National Library of Medicine*, Vol. 181, No. August, 105038, 2020. https://doi.org/10.1016/j.prevetmed.2020.105038

[17] SETYAWAN, H.A., WIBOWO, B.A., MUDZAKIR, A.K.: Margin Dan Tingkat Efisiensi Pemasaran Ikan Tenggiri (Scomberomorus Commerson) Di PPI Tanjungsari Kabupaten Pemalang, *Jurnal Teknologi Perikanan dan Kelautan*, Vol. 11, No. 1, pp. 53-62, 2020. https://doi.org/10.24319/jtpk.11.53-62 (Original in Indonesian)

[18] MENOZZI, D., NGUYEN, T.T., SOGARI, G., TASKOV, D., LUCAS, S., CASTRO-RIAL, J.L.S., MORA, C.: Consumers' Preferences and Willingness to Pay for Fish Products with Health and Environmental Labels: Evidence from Five European Countries, *Nutrients*, Vol. 12, No. 9, pp. 1-20, 2020. https://doi.org/10.3390/nu12092650

[19] CHRISTIAN, M., DEWI, D., GLISINA, D.R, EKO, R.I., SURYO, W., YUSTINUS, Y.: Business Performance Determinants of Salted Fish Distribution in Kapuk During the COVID-19, *Journal of Distribution Science*, Vol. 19, No. 6, pp. 29-39, 2021. https://doi.org/10.15722/jds.19.6.202106.29

[20] GÓMEZ, S., MAYNOU, F.: Alternative seafood marketing systems foster transformative processes in Mediterranean fisheries, *Marine Policy*, Vol. 127, No. May, 104432, pp. 1-11, 2021. https://doi.org/10.1016/j.marpol.2021.104432

[21] SHAMSUZZAMAN, M.M., HOQUE MOZUMDER, M.M., MITU, S.J, AHAMAD, A.F., BHYUIAN, M.S.: The economic contribution of fish and fish trade in Bangladesh, *Aquaculture and Fisheries*, Vol. 5, No. 4, pp. 174-181, 2020. https://doi.org/10.1016/j.aaf.2020.01.001

[22] COCHRANE, K.L.: Reconciling sustainability, economic efficiency and equity in marine fisheries: Has there been progress in the last 20 years?, *Fish and Fisheries*, Vol. 22, No. 2, pp. 298-323, 2021. https://doi.org/10.1111/faf.12521

[23] LENOU, L.N., MATHE, S., DOROTHY,. E.F., GEITZENAUER, M., AWAH, M.A.: Cocoa marketing chain in developing countries: How do formal-informal linkages ensure its sustainability in Cameroon?, *Geoforum*, Vol. 117, pp. 61-70, 2020. https://doi.org/10.1016/j.geoforum.2020.09.005

[24] PERMANA, A., BUDIRAHARJO, K., SETIADI, A.: Analisis Efisiensi Saluran Pemasaran Komoditas Salak Pondoh di Desa Girikerto Kecamatan Turi Kabupaten Sleman Yogyakarta, *urnal Ekonomi Pertanian dan Agribisnis (JEPA) Universitas Brawijaya*, Vol. 5, No. 4, pp. 1-15, 2021. (Original in Indonesian)

[25] STATISTIC INDONESIA OF MALUKU PROVINCE, Maluku Dalam Angka, Maluku, 2023.

[26] REGIONAL STATISTICS OF AMBON CITY, Kota Ambon Dalam Angka, Ambon, Maluku, 2023.

[27] CHEN, Q., HONGYAN, S., YU, X., HU, Q.: Livelihood Vulnerability of Marine Fishermen to

Multi-Stresses under the Vessel Buyback and Fishermen Transfer Programs in China: The Case of Zhoushan City, Zhejiang Province, *International Journal of Environmental Research and Public Health*, Vol. 17, No. 3, 765, pp. 1-17, 2020. https://doi.org/10.3390/ijerph17030765

[28] POWELL, F., LEVINE, A., ORDONEZ-GAUGER, L.: Climate adaptation in the market squid fishery: fishermen responses to past variability associated with El Niño Southern Oscillation cycles inform our understanding of adaptive capacity in the face of future climate change, *Climatic Change*, Vol. 173, No. 1, pp. 1-21, 2022. https://doi.org/10.1007/s10584-022-03394-z

[29] ZHENG, S., WANG, S., XU, W., LIU, Q.: Research on the job transfer pathway of Chinese marine fishermen and its driving factors, *Marine Policy*, Vol. 129, No. July, 104572, 2021. https://doi.org/10.1016/j.marpol.2021.104572

[30] AYISI, C.L., SIENSO, G., MENSAH, G.D., N'SOUVI, K., BAIDOO, K., ALHASSAN, E.H., OSEI, S.A.: Examining the socio-economic characteristics, fishing patterns and challenges of fishermen at James Town in Ghana, *Social Sciences & Humanities Open*, Vol. 8, No. 1, 100591, pp. 1-9, 2023. https://doi.org/10.1016/j.ssaho.2023.100591

[31] HUYNH, P.T.A., LE, G., LE, S.T.H., TRAN, T.N.: Adaptive livelihood strategies among small-scale fishing households to climate change-related stressors in Central Coast Vietnam, *International Journal of Climate Change Strategies and Management*, Vol. 13, No. 4/5, pp. 492-510, 2021. https://doi.org/10.1108/IJCCSM-04-2020-0034

[32] AZIZ, M.S.B., HASAN, N.A., MONDOL, M.M.R., ALAM, M.M., HAQUE, M.M.: Decline in fish species diversity due to climatic and anthropogenic factors in Hakaluki Haor, an ecologically critical wetland in northeast Bangladesh, *Heliyon*, Vol. 7, No. 1, e05861, pp. 1-13, 2021. https://doi.org/10.1016/j.heliyon.2020.e05861

[33] MANGUBHAI, S., LAWLESS, S.: Exploring gender inclusion in small-scale fisheries management and development in Melanesia, *Marine Policy*, Vol. 123, No. January, pp. 1-11, 104287, 2021. https://doi.org/10.1016/j.marpol.2020.104287

[34] HAHURY, H.D., PRABAWA, T.S., WILOSOP, G., SOUMOKIL, T., NDOEN, M.: Institutional Impacts on Choice of Traditional Agroforestry-Based Rural Community Livelihood Strategies in Maluku: (Utilization of 'Dusung' and Nutmeg in Booi Village, Maluku), *Jurnal Manajemen Hutan Tropika*, Vol. 26, No. 2, pp. 189-200, 2020. https://doi.org/10.7226/jtfm.26.2.189

[35] WIJERMANS, N., BOONSTRA, J., ORACH, K., HENTATI-SUNDBERG, J., SCHLÜTER, M.: Behavioural diversity in fishing—Towards a next generation of fishery models, *Fish and Fisheries*, Vol. 21, No. 5, pp. 872-890, 2020. https://doi.org/10.1111/faf.12466

[36] MATENA, M., RAFFEL, C.: Merging Models with Fisher-Weighted Averaging, *Advances in Neural Information Processing Systems*, Vol. 35, pp. 17703-17716, 2022.

[37] KAKERISSA, A.L., HAHURY, H.D., LOUHENAPESSY, F.H.: Potential of Smoked Fish Industrial Cluster in the Islands Areas, *Acta logistica*, Vol. 9, No. 4, pp. 457-466, 2022. https://doi.org/10.22306/al.v9i4.347

[38] COOKE, S.J., NGUYEN, V.M, CHAPMAN, J.M., ANDREA, J.R., LANDSMAN, S.J., YOUNG, N., HINCH, H.G., SCHOTT, S., MANDRAK, N.E., SEMENIUK, C.A.D.: Knowledge co-production: A pathway to effective fisheries management, conservation, and governance, *Fisheries*, Vol. 46, No. 2, pp. 89-97, 2021. https://doi.org/10.1002/fsh.10512

[39] BEHIVOKE, F., ETIENNE, M.P., GUITTON, J., RANDRIATSARA, R.M., RANAIVOSON, E., LEOPOLD, M.: Estimating fishing effort in small-scale fisheries using GPS tracking data and random forests, *Ecological Indicators*, Vol. 123, No. April, pp. 1-7, 107321, 2021. https://doi.org/10.1016/j.ecolind.2020.107321

[40] BRESNAN, E., AREVALO, F., BELIN, C., BRANCO, M.A.C., CEMBELLA, A.D., CLARKE, D., CORREA, J., DAVIDSON, K., RAPKOVA, M.D., LAZANO, R.F., TEJEDOR, M.F., GUÐFINNSSON, H., CARBONELL, D.J., MARTINEZ, L.M., LEMOINA, M., LEWIS, A.M., MENENDEZ, L.M., MASKREY, B.H., MCKINNEY, A., PAZOS, Y., REVILLA, M., SIANO, R., SILVA, A., SWAN, S., TURNER, A.D., SCHWEIBOLD, L., PROVOOST, P., ENEVOLDSEN, H.: Diversity and regional distribution of harmful algal events along the Atlantic margin of Europe, *Harmful Algae*, Vol. 102, No. February, 101976, 2021. https://doi.org/10.1016/j.hal.2021.101976

[41] ERMGASSEN, P.S.E.Z.: Fishers who rely on mangroves: Modelling and mapping the global intensity of mangrove-associated fisheries, *Estuarine, Coastal and Shelf Science*, Vol. 247, No. December, 106975, 2020. https://doi.org/10.1016/j.ecss.2020.106975

[42] PINSKY, M.L., FENICHEL, E., FOGARTY, M., LEVIN, S., MCCAY, B., MARTIN, K.ST., SELDEN, R.L., YOUNG, T.: Fish and fisheries in hot water: What is happening and how do we adapt?, *Population Ecology*, Vol. 63, No. 1, pp. 17-26, 2021. https://doi.org/10.1002/1438-390X.12050

[43] BAUDRON, A.R., BRUNEL, T., BLANCHET, M.A., HIDALGO, M., CHUST, G., NIKOLIOUDAKIS, N., FERNANDES, J.A., FERNANDES, P.G.: Changing fish distributions challenge the effective management of European

fisheries, *Ecography*, Vol. 43, No. 4, pp. 494-505, 2020. https://doi.org/10.1111/ecog.04864

[44] IRABOR, A.E., OBAKANURHE, O., OZOR, A.O., AARON, H.: Is small-scale fishing sustainable in Delta State, Nigeria? A glance into the problems and possible solutions, *Fisheries Research*, Vol. 274, No. June, 106981, 2024. https://doi.org/10.1016/j.fishres.2024.106981

[45] MACUSI, E.D., MACUSI, E.S., JIMENEZ, L.A., CATAM-ISAN, J.P.: Climate change vulnerability and perceived impacts on small-scale fisheries in eastern Mindanao, *Ocean & Coastal Management*, Vol. 189, No. May, 105143, 2020. https://doi.org/10.1016/j.ocecoaman.2020.105143

[46] ENAYATI, M., ARLIKATTI, S., RAMESH, M.V.: A qualitative analysis of rural fishermen: Potential for blockchain-enabled framework for livelihood sustainability, *Heliyon*, Vol. 10, pp. 1-17, 2024. https://doi.org/10.1016/j.heliyon.2024.e24358

[47] HIRVONEN, K., MINTEN, B., MOHAMMED, B., TAMRU, S.: Food prices and marketing margins during the COVID-19 pandemic: Evidence from vegetable value chains in Ethiopia, *Agricultural Economics*, Vol. 52, No. 3, pp. 407-421, 2021. https://doi.org/10.1111/agec.12626

[48] MGALE, Y.J., YUNXIAN, Y.: Marketing efficiency and determinants of marketing channel choice by rice farmers in rural Tanzania: Evidence from Mbeya region, Tanzania, *Australian Journal of Agricultural and Resource Economics*, Vol. 64, No. 4, pp. 1239-1259, 2020. https://doi.org/10.1111/1467-8489.12380

[49] ROJAS, C.A., CINNER, J., LAU, J., RUANO-CHAMORRO, C., CONTRERAS-DREY, F.J., GELCICH, S.: An experimental look at trust, bargaining, and public goods in fishing communities, *Scientific Reports*, Vol. 11, No. 1, 20798, pp. 1-13, 2021. https://doi.org/10.1038/s41598-021-00145-5

[50] KIMANI, P., WAMUKOTA, A., MANYALA, J.O., MLEWA, C.M.: Factors influencing financial performance in marine small-scale fisheries value chain in Kenya, *Marine Policy*, Vol. 122, No. December, 104218, 2020. https://doi.org/10.1016/j.marpol.2020.104218

[51] TAREKEGN, K., ASADO, A., GAFARO, T., SHITAYE, Y.: Value chain analysis of banana in Bench Maji and Sheka Zones of Southern Ethiopia, *Cogent Food & Agriculture*, Vol. 6, No. 1, 1785103, pp. 1-20, 2020. https://doi.org/10.1080/23311932.2020.1785103

[52] NASIRI, G.R., DEYMEH, H., KARIMI, B., MIANDOABCHI, E.: Incorporating sales and marketing considerations into a competitive multi-echelon distribution network design problem with pricing strategy in a stochastic environment, *Journal of Retailing and Consumer Services*, Vol. 62, No. September, 102646, 2021. https://doi.org/10.1016/j.jretconser.2021.102646

[53] ADAMS, F., WONGNAA, C.A., COLEMAN, E.: Profitability and choice of marketing outlets: evidence from Ghana's tomato production, *Journal of Agribusiness in Developing and Emerging Economies*, Vol. 11, No. 3, pp. 296-312, 2021. https://doi.org/10.1108/JADEE-06-2019-0090

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Crypto technologies in logistics
Gabriel Fedorko, Hana Neradilova, Jan Kral, Nikoleta Mikusova, Martin Duriska

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Crypto technologies in logistics

Gabriel Fedorko
Technical University of Košice, Faculty BERG, Logistics Department, Park Komenského 14, 040 01 Košice, Slovak Republic, EU, gabriel.fedorko@tuke.sk (corresponding author)
Hana Neradilova
The College of Logistics, Palackého 1381, 750 02 Přerov, Czech Republic, EU, hana.neradilova@vslg.cz
Jan Kral
Technical University of Košice, Faculty of Mechanical Engineering, Letná 9, 042 00 Košice, Slovak Republic, EU, jan.kral.2@tuke.sk
Nikoleta Mikusova
Technical University of Košice, Faculty BERG, Logistics Department, Park Komenského 14, 040 01 Košice, Slovak Republic, EU, nikoleta.mikusova@tuke.sk
Martin Duriska
Technical University of Košice, Faculty BERG, Logistics Department, Park Komenského 14, 040 01 Košice, Slovak Republic, EU, martin.duriska@tuke.sk

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Abstract: Crypto technologies present a challenge for the field of logistics, which is associated with the change of stereotypes in the management of logistics processes. It is practically another stage of development connected with a wide range of logistics processes, resulting in the creation of new paradigms that bring increased efficiency and improved process quality. The understanding of crypto technologies is generally associated primarily with cryptocurrencies. However, the presented knowledge is wrong and very misleading. Crypto technologies are not only cryptocurrencies. Crypto technologies, in connection with logistics, represent this field's future direction. This statement is also underlined by the current trend aimed at the development of digitisation. The paper presents the issue of the relationship between crypto-technologies and logistics. The effort will be to point out that crypto technologies are not only Blockchain, but Blockchain is the base on which crypto technologies are built, thus bringing benefits to the field of logistics and supporting its development.

1 Introduction

Logistics needs to ensure the maximal possible efficiency, reliability, and safety of its processes for its functioning. Several methods and technologies meet these requirements, and in the last period, it has been possible to monitor the potential for significant application of Blockchain technology and other crypto technologies.

Crypto technologies have a huge and, so far, unused potential, which can gradually minimise even the main problems in logistics, such as order delays, damage of goods, mistakes and multiple data entries [1]. In connection with the field of logistics, crypto technologies can be characterised as innovative technologies [2] with key potential for developing logistics in the future. The gradual application of crypto technologies in logistics can increase the effective implementation of logistics processes [3]. Specifically, crypto technologies can provide indisputable and immutable proof of the origin of raw materials, products, and their sale to the final customer. This can potentially increase customer confidence in the product and gain financial benefit for the producer by protecting their intellectual property rights [4].

So far, in most cases, the use of crypto technologies in connection with logistics has focused exclusively on Blockchain [5]. On the one hand, this approach is logical because blockchain technology is key to the functioning of crypto technologies. On the other hand, however, the full potential of crypto technologies available in logistics is not used this way. The application of Blockchain is visible in connection with transport logistics chains using container transport [6], within intra-company transport systems [7], reverse logistics [8] or most often in the field of supply chains [9,10].

However, crypto technologies represent a challenge for logistics in searching for other possibilities for their practical application within various logistics processes. In addition to Blockchain, it is also necessary to consider other crypto technologies based on decentralised applications (dApps), Non-fungible tokens (NFT), cryptocurrencies or WEB 3.0. The first signs of the use of other crypto technologies in the field of logistics can be monitored, for example, in the use of smart contracts [11,12] that are based on dApps. Smart contracts can be effectively used again, e.g. within supply chains [13,14]. Similarly, NFTs are starting to be used in connection with logistics in the energy field.

Based on the above examples, the implementation of crypto technologies in logistics is progressing very slowly. One reason for this is that many logistics experts do not realise the potential of crypto technologies. The paper aims

to present the issue of crypto technologies from the point of view of logistics and indicate possible areas for their potential use.

2 Crypto technologies

Crypto technologies are a term that has been appearing increasingly lately and used in various contexts. From the point of view of searching for the meaning of what this term denotes, it is necessary to mention the year 2008, which represents a kind of imaginary turning point and a change in the understanding of its meaning. Until 2008, it would have been possible to define crypto technology as a technology whose active use and functioning were based on various cryptographic tools, protocols, and methods. After 2008, however, crypto technology has been chiefly understood as Blockchain and related technologies such as cryptocurrencies, decentralised applications, smart contracts, or other technologies associated with blockchain. 2008 was a turning point regarding the perception of crypto technologies because it introduced and described the principle of the first successful cryptocurrency, Bitcoin. The author of the allowlist describing Bitcoin acted under the pseudonym Satoshi Nakamoto.

However, blockchain technology was not created in 2008. Its existence in connection with informatics was known quite a long time ago. However, in connection with cryptocurrencies, blockchain was reborn, became widely known, especially among the broad professional and scientific public, and began to develop further (Figure 1). Currently, blockchain is considered a technology of the future, which can significantly change the functioning of our society and will affect many areas.

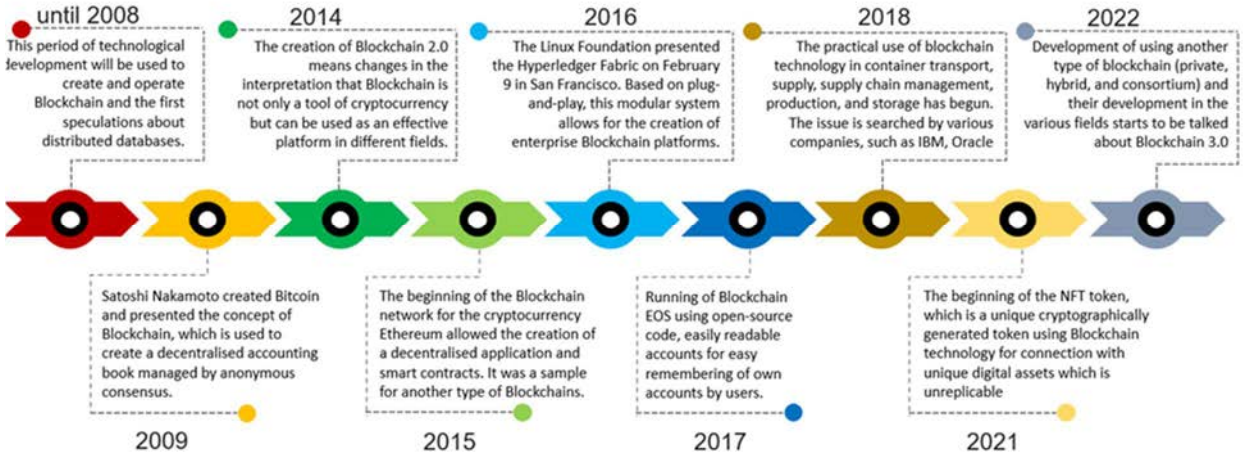

Figure 1 Overview of Blockchain Technology Development

As already mentioned, crypto technologies are not only Blockchain. These are the technologies that Blockchain uses for its operation. We currently know five technologies that can be labelled crypto-technologies (Figure. 2) and are directly connected to blockchain technology. The link means that Blockchain is a prerequisite for their operation.

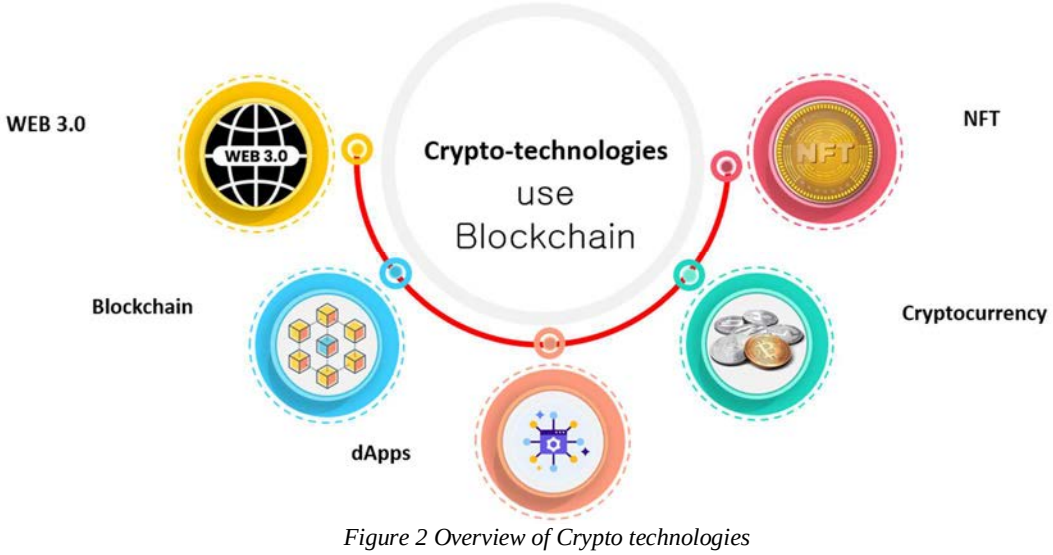

Figure 2 Overview of Crypto technologies

Crypto technologies were generally believed to be a highly speculative means of achieving a high financial commission and profit. They are often seen as technologies for a specific group of users - enthusiasts who are the only ones who understand them and know how to use them. However, these technologies are largely unknown and difficult to understand in everyday life and for ordinary people.

But this opinion is wildly inaccurate and wrong. Crypto technologies represent a tool that, in the future, can significantly impact various areas of our society. Regarding its functioning and future development, logistics must pay adequate attention to the issue of crypto-technologies and gradually implement them into its functioning.

However, crypto technologies must be looked at in a completely different way from the point of view of logistics. Their perception must be realised regarding their potential benefits for the functioning of logistics processes. For logistics, crypto technologies cannot only be synonymous with decentralised finance. On the contrary, decentralisation is not a condition for their use. Crypto technologies represent a technology with high potential for the field of logistics, which, if used correctly, will bring a competitive advantage and significantly improve the functioning of logistics processes. The first pioneering efforts using crypto technologies have already been completed in logistics. Progress in their use continues. For it to be successful and effective, it is necessary to know crypto technologies from the point of view of logistics and its processes.

2.1 Blockchain

It is possible to define Blockchain as a particular type of distributed database that was initially exclusively decentralised, but nowadays, there are also variants in a centralised form. It is a continually expanding database that stores records and protects them against modification and alteration.

Applying this technology does not directly belong to crypto technologies (Blockchain does not mean that cryptography must automatically be used). However, its use as an accounting book database for the functioning of cryptocurrencies, for example, when cryptographic methods are used to ensure the immutability of entries and confirm their authenticity, makes it a full-fledged crypto technology. The principle of Blockchain is relatively simple (Figure 3).

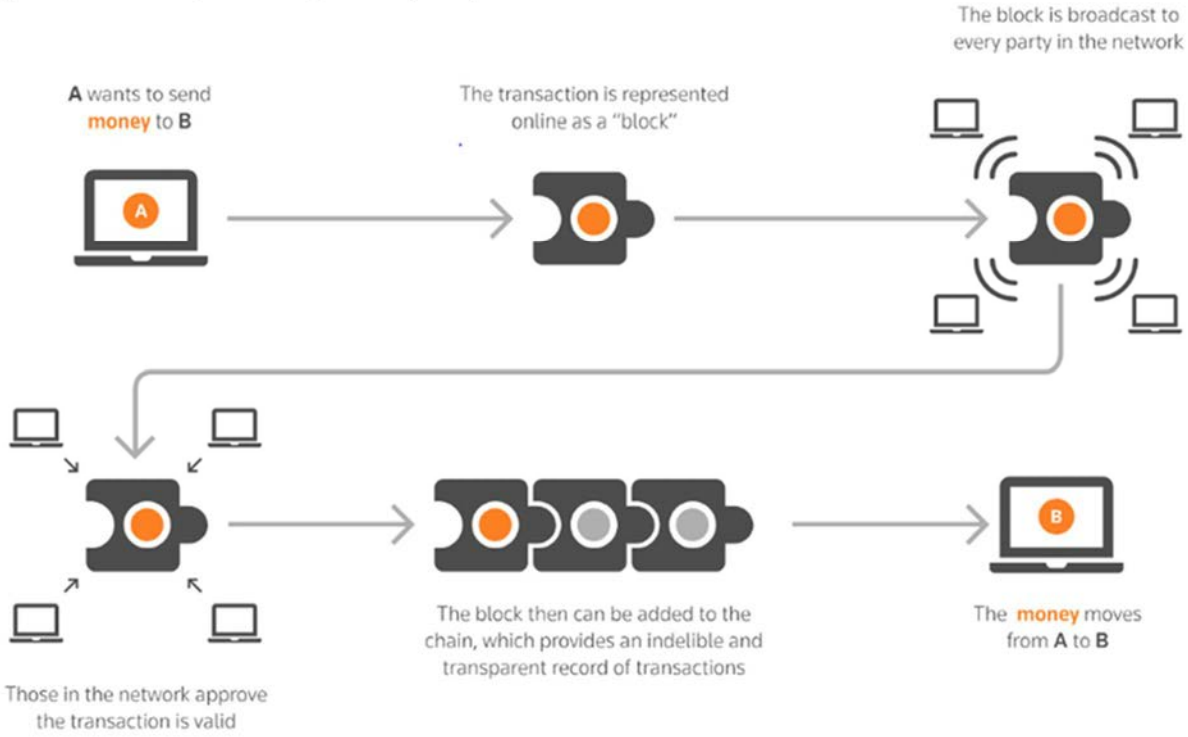

Figure 3 One of the working principles of blockchain technology [15]

As mentioned, the Blockchain used in logistics does not have to be fully decentralised. This means that its users, owners of full nodes, must be known. However, this variant of Blockchain does not decrease the possibilities of this technology in logistics; on the contrary, it enables its full use within processes where participants must know each other and communicate. Blockchain is increasing due to its generally known possibilities and advantages (Figure 4), which have application potential for logistics.

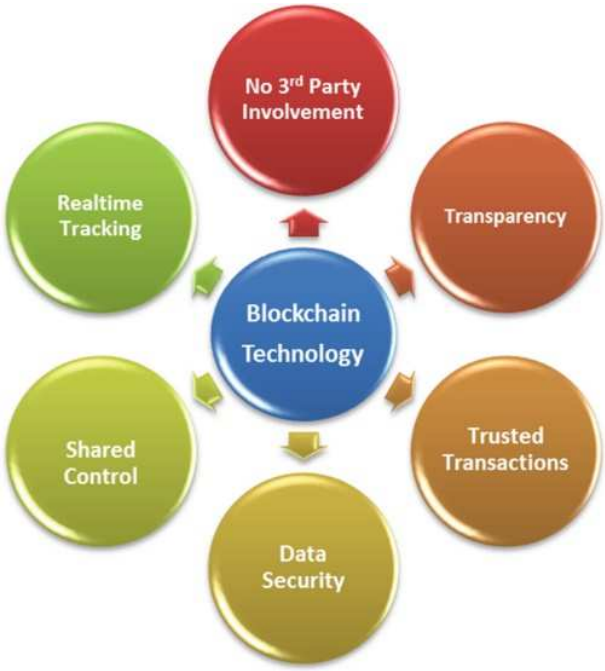

Figure 4 Blockchain advantages and potentials [16]

The benefits of blockchain technology for logistics can be classified into three basic levels. The first is the "High" level, a significant advantage. This benefit is characterised by increased efficiency, acceleration of processes, or expansion of the capacity of provided services and processes. The second level is "Middle". These are cases when the application of Blockchain will bring a change to the implementation of logistics processes; it will be reflected in their efficiency, reliability, and security. However, the benefit in that case is not so drastic, but it is important and makes sense to use. The third level is represented by "Low". This is the lowest level that will manifest itself only in certain specific situations, and the impact of Blockchain is not so significant or crucial. The use of Blockchain within this level should be considered in terms of investment, operating costs, and benefits. Based on the mentioned assessment, it is thus possible to evaluate the contribution of blockchain technology to logistics activities (Table 1).

Table 1 Importance of Blockchain for the selected logistical activities

	Traceability	Data Security	Transparency	Quality	Realtime Monitoring	Service	Trusted Transactions
Supply Chain	High	Middle	High	Middle	Low	Low	High
Warehousing	High	Low	Low	Low	High	Middle	Low
Productions	High	Low	Middle	High	High	Middle	Low
Transport	High	High	Low	Middle	High	Low	High
Manipulation	Middle	Low	Low	High	Middle	Low	Low
Planning	Low	Middle	High	Low	Low	High	Middle

2.2 Non-fungible tokens

In crypto technology, a token is a coin (which may have its name) of a digital currency that does not have its Blockchain. Generally, a token is a carrier of value, and we consider tokens interchangeable. Fungibility means that if we have one specific token with some value, we can exchange it for another identical token with the same value. Therefore, the token is often called a "digital coin." The token can be divisible into smaller units.

However, with the development of crypto-technologies and blockchain technology, a unique token was created, characterised by its incommutability and indivisibility. The name non-fungible token (NFT) was used for this token type.

NFT was primarily created and used to verify and prove the originality of digital content. Its initial application focused on digital creation, such as graphics, audio, and video. Over time, however, the application possibilities begin to be further developed and explored. NFT is finding more and more new application areas, including logistics. NFT represents a massive potential for the field of logistics (Table 2). Active use can significantly increase logistics processes' quality and reliability. In the future, NFTs could thus become essential to various products and services and participate in managing multiple logistics chains. It would be, for example, about guaranteeing the originality of products, proving the right to service and additional services, and enabling the improvement of quality and safety in the distribution of food and other commodities.

In logistics, recording most NFTs within private blockchains seems logical, where access will be regulated and controlled. On the other hand, however, for example, by verifying the originality of products, it is also possible to use decentralised public Blockchains from the point of view of availability.

The principle of operation of NFT is quite simple. It is based on a record of ownership of digital media based on the Blockchain. The entry contains a link to the relevant digital medium. However, this digital medium does not reside directly on the Blockchain. However, the application possibilities of NFT are no longer limited to graphics and multimedia. For example, it is possible to mention one of the key areas of logistics, namely supply chain (Figure 5).

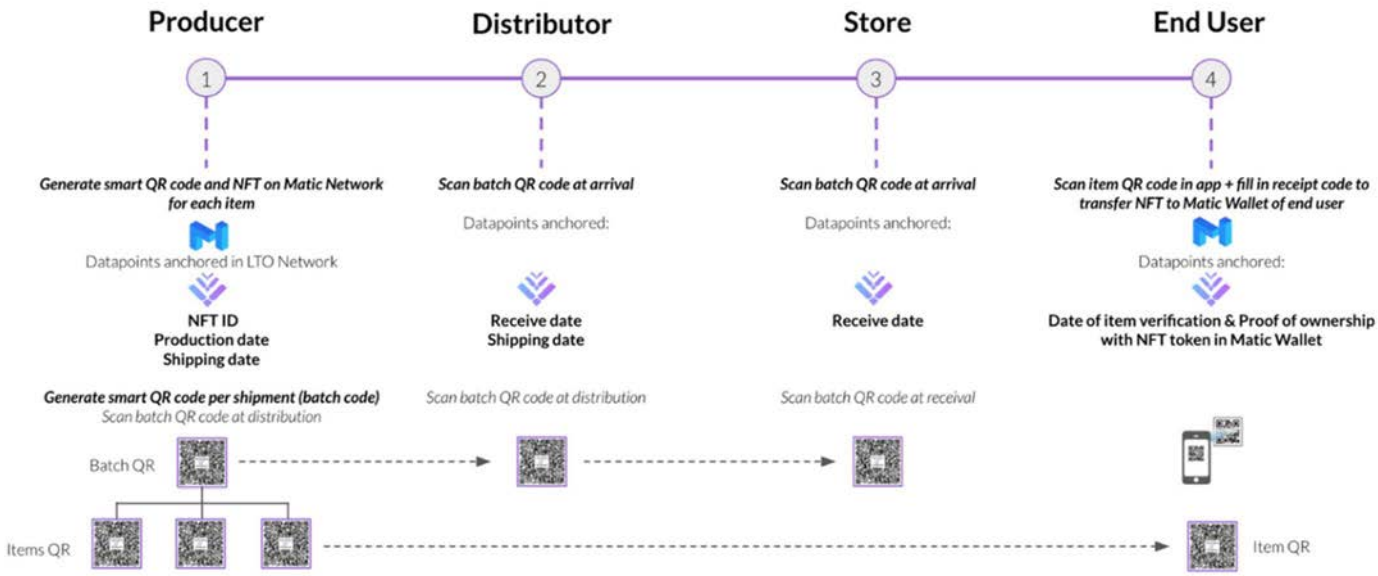

Figure 5 Tracing a supply chain with NFT and QR codes in the Matic Network functions on TO Network [17]

The application possibilities of NFT in logistics relate to criteria such as originality, quality, safety, transparency, and traceability. These are parameters that directly affect several logistics areas (Table 2).

Table 2 Possibilities of NFT use for the selected logistics activities

	Originality	*Quality*	*Security*	*Transparency*	*Traceability*
Supply Chain	*yes*	*yes*	*yes*	*yes*	*yes*
Warehousing	--	-	*yes*	*yes*	*yes*
Productions	*yes*	*yes*	-	*yes*	-
Transport	-	*yes*	*yes*	*yes*	*yes*
Manipulation	-	-	-	*yes*	*yes*
Planning	-	*yes*	*yes*	*yes*	-

2.3 Cryptocurrencies

Cryptocurrencies are a technology that rediscovered the Blockchain, significantly starting and accelerating the issue of crypto technologies. Nowadays, cryptocurrencies are mentioned more and more often, and they are not only a means of interest for technology fans who see the future of a functional and independent financial sector.

Logistics, from the point of view of its further development, cannot overlook the issue of cryptocurrencies and must be prepared for their acceptance as part of financial flows and payments. A specific deficiency causing problems with accepting cryptocurrencies, not only in logistics, can currently be their high volatility and possible limitations in the speed and amount of realised payments. However, these facts cannot be a reason for their rejection.

In the future, modern logistics must actively prepare to accept cryptocurrencies as full-fledged financial means for realising payments. The main emphasis must be placed on their selection. At the same time, their key criteria must be considered (Table 3). The selection of a cryptocurrency for logistics needs must reflect parameters such as the speed of transactions (Figure 6), public acceptance and trust of the public, their expansion, quality of the used Blockchain and, of course, the rate of inflation.

Based on the mentioned criteria, it will be possible to implement selected cryptocurrencies into the logistics portfolio. However, the implementation of cryptocurrencies cannot be realised massively in terms of acceptance of a broad spectrum of cryptocurrencies; on the contrary, the selection must be narrowly limited from the beginning to one or two cryptocurrencies, which would be supplemented by one stablecoin. This way, it will be possible to use cryptocurrencies effectively, and logistics processes will not be threatened. Also critical is an approach to logistics for cryptocurrencies. It is possible to talk about an alternative that is a full-fledged supplement to existing currencies. At the same time, it is necessary to decide at what level cryptocurrencies will be used, whether all types of payments from customers will be realised through them, or whether their acceptance will only be realised in connection with specific logistic processes. However, it is necessary to approach all the mentioned questions on a highly individual basis.

Table 3 Cryptocurrencies criteria selection for logistics needs

	Bitcoin	Ether	XRP	Cardano	Solana	Tether	Shiba Inu
Transaction speed	1	2	4	3	5	3-5*	3
Acceptance by public	5	4	2	3	3	4	1
Expansion	5	5	4	3	4	5	2
Blockchain	5	5	5	4	4	3-5*	2
Inflation	1	3	3	2	3	4	4
Decentralisation	5	5	2	3	5	1	5

(1 – low level of criterion, 2 – below-average level of criterion, 3 – middle level of criterion, 4 – above-average level of criterion, 5 – high level of criterion)
* According to the type of Blockchain

Another factor that significantly supports the implementation and use of cryptocurrencies in the field of logistics is the gradual acceptance of cryptocurrencies by large payment and financial companies. These companies are gradually making cryptocurrencies more accessible as part of regular payments and financial transactions, which significantly simplifies the use of cryptocurrencies in the field of logistics.

Figure 6 Cryptocurrencies transaction speeds compared to Visa and PayPal (2018) [18]

Therefore, for the successful implementation of cryptocurrencies into logistics processes, the conditions of transaction speed and financial operations must also be met. Implementing cryptocurrencies without ensuring a sufficient transaction speed would not be efficient and could be slightly problematic in terms of logistics. However, this condition is no longer such a problem nowadays because there are crypto technological solutions that can fully ensure and reliably implement the mentioned requirement (Figure 7).

These and similar technological solutions must negotiate various barriers, for example, in legislation. They must find and build their position within the financial market, while compliance with applicable legislation is necessary. At the same time, they must be accepted by the subjects of the logistics chain, they must win their trust in terms of reliability, and at the same time, it will be necessary to implement them in the environment of logistics systems. The implementation assumes they can realise financial operations without problems in full or limited mode. However, the development in cryptocurrencies is huge, so the solution to these questions can be implemented soon. Cryptocurrencies, as a dynamic field, bring new challenges and opportunities for the field of logistics, to which it must respond. Otherwise, there would be a risk that logistics does not use the opportunity and possibilities that implementing cryptocurrencies in logistics processes can bring.

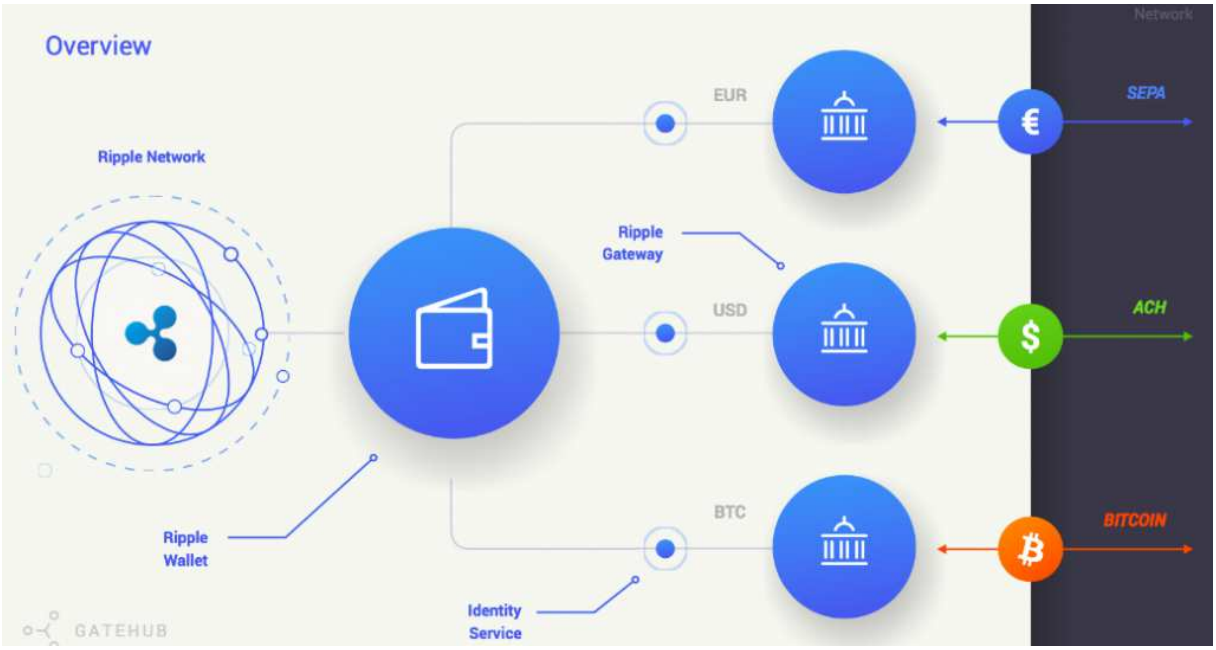

Figure 7 Example of using the XRP cryptocurrency for the realisation of financial operations [19]

2.4 Web 3.0

WEB 3.0 is a label associated with the future of the Internet. This is practically its next stage of development, which will be based primarily on the use of crypto technologies and the semantic web. It is the integration of several information technologies into one unit, the purpose of which is the verification of digital content, decentralisation, and machine processing of a wide range of information to increase the total efficiency of the Internet. WEB 3.0 will bring more efficient browsing, the possibility of targeted and relevant advertising, and customer support improvement.

In logistics, WEB 3.0 represents development in communication, information technology support, changes in classic business models, and the possibility of the coordination of logistics processes and their management. Its implementation in logistics processes will also use artificial intelligence tools.

Currently, the supply chain is one of the first fields of logistics where WEB 3.0 could be successfully implemented (Figure 8).

Figure 8 Benefits of Web3.0 in logistics and supply chain [20]

Although at first glance, it may seem that the benefits of WEB 3.0 are repeated with most of the benefits of individual crypto technologies, this is not the case (Figure 9). WEB 3.0 must be understood from the point of view of logistics as an integrating unit that combines the mentioned crypto technologies with other information technologies into one integrated unit. This increases their use and, at the same time, creates new possibilities that will be of great benefit not only to the field of logistics. Specifically, it will significantly increase logistics chain transparency and support their members' trust. WEB 3.0 will enable effective management of products and services. It will contribute substantially to updating information on the progress of logistics processes in real-time.

Figure 9 Impact of WEB 3.0 on logistics [20]

Web 3.0 has the potential for use in several areas of logistics (Table 4). It can be presented in the form of intelligent moves, which, based on the definition of various conditions, can activate multiple processes and actions, significantly accelerating and automating the entire process. On the other hand, WEB 3.0 will provide permission access within logistics, achieving control over access to information. This means the information will be accessible only to the circle of persons. Other benefits include simplified control of the Peek-A-Boo service for customers. In this way, the implementation of some operations becomes simple and convenient. At the same time, customers will have access to shared documents and a permanent communication connection, contributing to the speed-up and efficiency of logistics processes.

Table 4 Possibilities of WEB 3.0 use in logistics

	Smart Moves	Permissioned Access	Peek-A-Boo for Customers	Shared records	Staying Connected
Customer service	no	yes	yes	yes	yes
Order fulfilment	yes	yes	yes	yes	yes
Service and service parts	yes	yes	yes	yes	yes
Supply and purchase	yes	yes	yes	yes	yes
Good transportation	yes	no	no	yes	no
Reverse logistics	yes	no	no	yes	no
Storage	no	yes	no	yes	no

The development of WEB 3.0 is still in the initial phase. However, it is possible to say that its potential in the field of logistics is huge. However, it should be remembered that the development of the WEB 3.0 area will stimulate the growth of other regions, such as information technology or business information systems.

2.5 Decentralized applications

Decentralized applications (dApps), a crypto technology, began to be used only in connection with Blockchain 2.0. With its deployment, Blockchain technology began to be viewed as a broad-spectrum tool with much wider possibilities of use than just an "account book" for the needs of various cryptocurrencies. Decentralised applications represent one of the youngest crypto technologies.

Although the name decentralised applications evokes their similarity to applications used in a wide range of smart devices, this is not the case. The principle of decentralised applications is based on smart contracts. They are digital

applications (programs) that run on Blockchains, not centralised servers. All information that dApps contain is cryptographically protected. Smart contracts are made up of predefined rules (conditions), which, if met, will carry out the operation or operations the contract is supposed to realise (Figure 10).

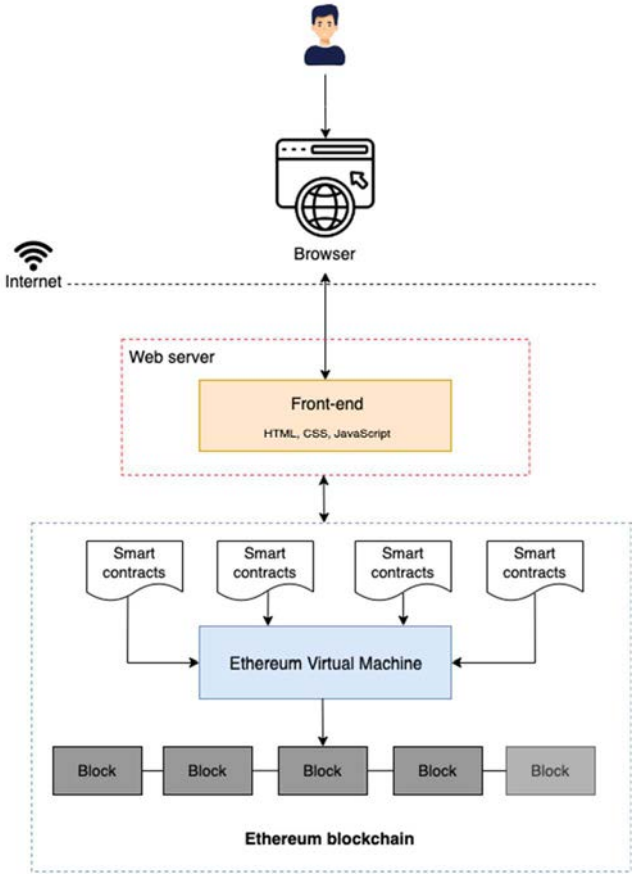

Figure 10 Architecture Of Decentralized Applications (dApps) [21]

Decentralised applications or the idea of their operation represents a chance for logistics to automate various processes, primarily management and decision-making. It is possible to use private centralised or decentralised types of Blockchain. However, the purpose for which dApps will be used depends on the purpose. It is necessary to realise that the public decentralised Blockchain in connection with dApps may have certain disadvantages. For example, the stored information will be available practically to anyone, and it would not be desirable in specific logistics processes (non-guarantee of discretion). On the contrary, some processes have no problem with this. That is why it is necessary to analyse the deployment of dApps within logistics processes and then decide what type of Blockchain will be used. Table 5 presents an example of a comparison of the kind of Blockchain for the application of dApps within selected areas of logistics.

Table 4 Comparison of Blockchain types for the application of dApps in the selected fields of logistics

	A centralised type of Blockchain			Decentralised type of Blockchain		
	High discreteness	Limited availability	Suitability	Low discreteness	Unlimited availability	Suitability
Supply chain	advantage	advantage	yes	disadvantage	advantage	no
Customer service	advantage	neutral	yes	neutral	advantage	yes/no *
Advertising	disadvantage	disadvantage	no	advantage	advantage	yes
Public relation	neutral	disadvantage	no	neutral	advantage	yes
Transport	advantage	advantage	yes	disadvantage	advantage	no
Automatisation	neutral	yes/no*	yes	neutral	advantage	yes

* need to be considered according to the specific situation

One big area where decentralised applications have potential for logistics is their product life cycle management implementation. However, the use of this technology requires further long-term research, which will aim to identify potential risks and opportunities (Figure 11).

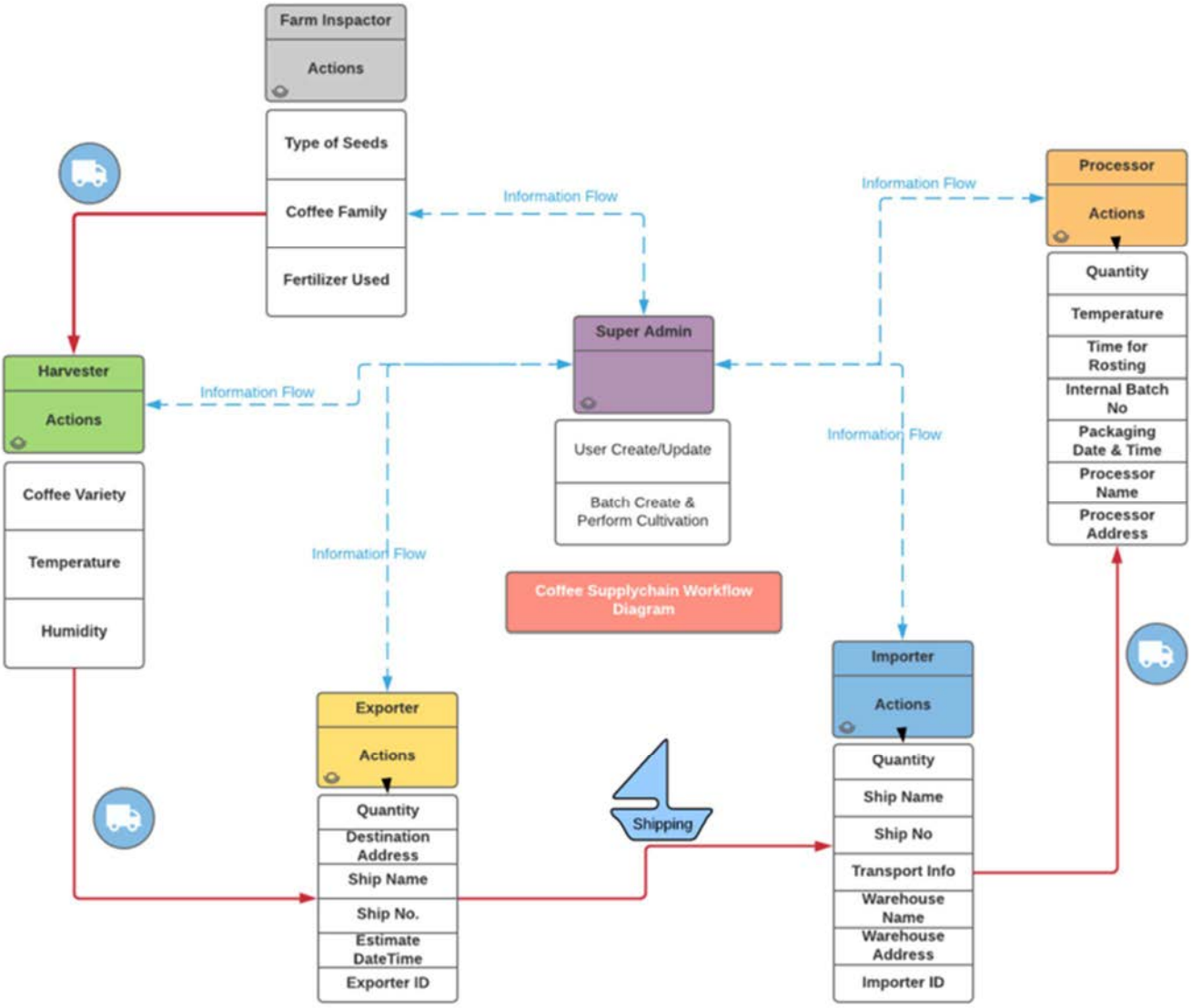

Figure 11 Ethereum-Based Supply Chain Dapp [22]

3 Conclusion

Nowadays, crypto technologies are no longer exclusively associated with cryptocurrencies. On the contrary, more and more areas are beginning to realise their potential and possibilities. One reason for such a change in perception is that their application primarily brings greater transparency and security.

Logistics is one of the dynamic fields that are characterised by an open approach to implementing new technologies to increase their activities. In connection with the growing trend of automation and extensive digital transformation aimed at managing and operating logistics processes, crypto technologies are becoming highly attractive for widespread acceptance within the mentioned activities. Crypto technologies can bring a certain level of decentralisation to logistics in connection with trust among the individual links of the logistics chain. At the same time, it is necessary to emphasise that implementing cryptocurrencies in logistics and process management is a challenge for logistics experts, especially for the current understanding of the usual standards for solving logistical issues. It can be said that based on the current knowledge of cryptocurrency ideas and ways of their implementation in logistics, application areas of logistics and logistics processes, it is possible to move towards increasing the efficiency and, finally, the quality of processes as essential cost items within logistics solutions. In conclusion, it is necessary to highlight the effort to digitise logistics processes, which is currently preferred in almost all

application areas of logistics. But as it was mentioned in the presented paper, the possibility of implementing and designing a way of realisation of a possible connection of logistics and crypto technologies is an excellent potential in the field of digitisation of logistics processes with an emphasis on managerial efficiency solutions of logistics processes with a focus on process performance and logistics cost-effectiveness.

Crypto technologies present the future of digital technology and logistics. One of the reasons that helps their promotion is the high level of efficiency and safety in their use. Crypto-technologies' development has been carried out exclusively on a general level, which was then gradually adapted to individual areas, including logistics. However, this trend will change progressively.

In the future, crypto technologies development will be more targeted and narrowly focused on specific areas where they will be deployed. Their principle will continue to be based on blockchain. However, development in the field of blockchain will progress to meet the relevant requirements for the creation of blocks in terms of speed, capacity and access to the required information. Based on the above-mentioned expected development, it is possible to expect new crypto-technologies in the future, which, e.g. in conjunction with WEB 3.0 and artificial intelligence, will significantly change and push the boundaries of logistics process possibilities.

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References

[1] TIJAN, E., AKSENTIJEVIC, S., IVANIC, K., JARDAS, M.: Blockchain Technology Implementation in Logistics, *Sustainability*, Vol. 11, No. 4, pp. 1-13, 2019. https://doi.org/10.3390/su11041185

[2] VIJAY, C., SURIYALAKSHMI, S.M., ELAYARAJA, M.: Blockchain Technology in Logistics: Opportunities and Challenges, *Pacific Business Review International*, Vol. 13, No. 7, pp. 147-151, 2021.

[3] KUMAR, A., ABHISHEK, K., GHALIB, M.R., NERURKAR, P., BHIRUD, S., ALNUMAY, W., KUMAR, S.A., CHATTERJEE, P., GHOSH, U.: Securing logistics system and supply chain using Blockchain, *Applied Stochastic Models Business and Industry*, Vol. 37, No. 3, pp. 413-428, 2021. https://doi.org/10.1002/asmb.2592

[4] ALQARNI, M.A., ALKATHEIRI, M.S., CHAUHDARY, S.H., SALEEM, S.: Use of Blockchain-Based Smart Contracts in Logistics and Supply Chains, *Electronics*, Vol. 12, No. 6, pp. 1-14, 2023. https://doi.org/10.3390/electronics12061340

[5] NGUYEN, L.T., NGUYEN, D.T., NGOC, K.N.N., DUC, D.T.V.: Blockchain adoption in logistics companies in Ho Chi Minh City, Vietnam, *Cogent Business & Management*, Vol. 10, No. 2, pp. 1-24, 2023. https://doi.org/10.1080/23311975.2023.2216436

[6] AHMAD, R.W., HASAN, H., JAYARAMAN, R., SALAH, K., OMAR, M.: Blockchain applications and architectures for port operations and logistics management, *Research in Transportation Business & Management*, Vol. 41, No. December, 100620, 2021. https://doi.org/10.1016/j.rtbm.2021.100620

[7] WANG, B., WANG, Y.L.: AHI: Smart Logistics for Autonomous Transport Using IoT and Blockchain Technology, *International Journal of Cooperative Information Systems*, Vol. 32, No. 3, 2023. https://doi.org/10.1142/S0218843021500064

[8] PANGHAL, A., MANORAM, S., MOR, R.S., VERN, P.: Adoption challenges of blockchain technology for reverse logistics in the food processing industry, *Supply Chain Forum*, Vol. 24, No. 1, pp. 7-16, 2023. https://doi.org/10.1080/16258312.2022.2090852

[9] NI, L.F., IRANNEZHAD, E.: Performance analysis of Logistic Chain: A blockchain platform for maritime logistics, *Computures in Industry*, Vol. 154, No. January, pp. 1-18, 2024. https://doi.org/10.1016/j.compind.2023.104038

[10] CHU, X., WANG, R., REN, L., LI, Y.T., ZHANG, S.: Enabling joint distribution with blockchain technology in last-mile logistics, *Computures and Industrial Engineering*, Vol. 187, No. January, 2024. https://doi.org/10.1016/j.cie.2023.109832

[11] CASADO-VARA, R., GONZÁLEZ-BRIONES, A., PRIETO, J., CORCHADO, J.M.: *Smart Contract for Monitoring and Control of Logistics Activities: Pharmaceutical Utilities Case Study*, In: Graña, M., et al. International Joint Conference SOCO'18-CISIS'18-ICEUTE'18, SOCO'18-CISIS'18-ICEUTE'18 2018. Advances in Intelligent Systems and Computing, Vol. 771, Springer, Cham, pp. 509-517, 2019. https://doi.org/10.1007/978-3-319-94120-2_49

[12] PHILIPP, R., GERLITZ, L., PRAUSE, G., LATVIA, U.: *Smart Contracts for Entrepreneurial Collaboration in Logistics Networks*, New Challenges of Economic and Business Development - 2019: Incentives for Sustainable Economic Growth, No. 11th International Scientific Conference on New Challenges of Economic and Business Development-Incentives for Sustainable Economic Growth, pp. 652-663, 2019.

[13] CHEN, J.H., ZHANG, J.T., PU, C.G., WANG, P., WEI, M., HONG, S.H.: Distributed Logistics Resources Allocation with Blockchain, Smart Contract, and Edge Computing, *Journal of Circuits Systems and Computers*, Vol. 32, No. 7, 2023. https://doi.org/10.1142/S0218126623501219

[14] GRIDA, M., MOSTAFA, N.A.: Are smart contracts too smart for Supply Chain 4.0? A blockchain framework to mitigate challenges, *Journal of Manufacturing Technology Management*, Vol. 34,

No. 4, pp. 644-665, 2023. https://doi.org/10.1108/JMTM-09-2021-0359

[15] GOKOGLAN, K., CETIN, S., BILEN, A.: Blockchain technology and its impact on audit activities, *Journal of Economice, Finance and Accounting*, Vol. 9, No. 2, pp. 72-81, 2022. https://doi.org/10.17261/Pressacademia.2022.1567

[16] ATTARAN, M., GUNASEKARAN, A.: *Blockchain Principles, Qualities, and Business Applications*, In: Applications of Blockchain Technology in Business, SpringerBriefs in Operations Management, Springer, Cham, 2019, pp. 13-20, 2019. https://doi.org/10.1007/978-3-030-27798-7_3

[17] IVANGBI: Tracing a supply chain with NFT and QR codes in the Matic Network functions on TO Network, [Online], Available: https://merehead.com/blog/wp-content/uploads/Tracing-a-supply-chain-with-NFT-and-QR-codes-in-the-Matic-Network-functions-on-TO-Network-1.png [20 Mar 2024], 2020.

[18] RAUL: Transactions Speeds: How Do Cryptocurrencies Stack Up To Visa or PayPal?, [Online], Available: https://howmuch.net/articles/crypto-transaction-speeds-compared [20 Mar 2024], 2018.

[19] ZIFA, M.: What is Ripple (XRP)?, [Online], Available: https://changelly.com/blog/what-is-ripple-xrp/ [20 Mar 2024], 2023.

[20] SOLULAB: Role of Web3 in Supply Chain and Logistics, [Online], Available: https://www.solulab.com/web3-in-supply-chain-and-logistics/ [20 Mar 2024], 2024.

[21] NGUYỄN, N.M.: Introduction to Web 3.0, [Online], Available: https://careers.saigontechnology.com/blog-detail/introduction-to-web-30 [20 Mar 2024], 2023.

[22] PARAS, K.: Ethereum Based Supply Chain Dapp, [Online], Available: https://media.licdn.com/dms/image/C5112AQGmz4HFGm989A/article-cover_image-shrink_720_1280/0/1528388602411?e=1716422400&v=beta&t=J6NZNxMPt-WXkMjV1Waj-Wl_q92AQC67JdZdB9C5Ibw [20 Mar 2024], 2018.

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The impact of logistics service quality through the perceived organizational image on performance: cold chain logistics provider in Thailand
Surasidh Boonchunone, Mariam Nami, Atchari Krommuang, Chumpol Karnpakdee, Opal Suwunnamek

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The impact of logistics service quality through the perceived organizational image on performance: cold chain logistics provider in Thailand

Surasidh Boonchunone
Ramkhamhaeng University, Thachai Building, Ramkhamhaeng Road, Hua Mak, Bang Kapi, Bangkok 20140, Thailand, surasidh.b@rumail.ru.ac.th
Mariam Nami
Ramkhamhaeng University, Thachai Building, Ramkhamhaeng Road, Hua Mak, Bang Kapi, Bangkok 20140, Thailand, mariamnami@gmail.com
Atchari Krommuang
King Mongkut's Institute of Technology Ladkrabang, No.1, Soi Chalong Krung 1, Chalong Krung Road, Ladkrabang district, Bangkok 10520, Thailand, atchari.kr@kmitl.ac.th (corresponding author)
Chumpol Karnpakdee
Ramkhamhaeng University, Sri Phichit Building, Ramkhamhaeng Road, Hua Mak, Bang Kapi, Bangkok 20140, Thailand, 6324971211@rumail.ru.ac.th
Opal Suwunnamek
King Mongkut's Institute of Technology Ladkrabang, No.1, Soi Chalong Krung 1, Chalong Krung Road, Ladkrabang district, Bangkok 10520, Thailand, opal.su@kmitl.ac.th

Keywords: cold chain logistics, logistics service quality, perceived organizational image, transportation and logistics service provider, performance.
Abstract: The impact of logistics service quality and perceived organizational image on firm performance, are explored using the structural equation modeling analysis for Thailand's cold chain logistics provider. The objectives of this study were to direct, indirect, and total impact of logistics service quality through perceived organizational image on the performance of cold chain logistics providers, assessed by customers receiving services from cold chain logistics service companies. This quantitative research method uses a questionnaire to collect data from 541 respondents. Moreover, the results obtained from logistics service quality have a significant enhancing effect on the perceived organizational image, and both have significant positive effects on performance. Additionally, the role of the perceived organizational image as a mediating variable between logistics service quality and performance is emphasized. Logistics service quality has the most direct significant effect on perceived organizational image. Additionally, corporate image perception significantly mediates the relationship between service quality and logistics efficiency. These findings have contributions, relevant support, and benefits in academic, managerial, and important implications for cold chain providers in Thailand. It empirically demonstrates that the impact of logistics service quality can be supported through the perceived organizational image. This image is built on past experiences, emotions, and perceptions about the organization's reputation and the quality of its logistics services, including management logistic flow.

1 Introduction

The logistics and supply chain services industry are experiencing remarkable growth, driven by an emphasis on both the depth and breadth of high-quality offerings [1,2]. The multifaceted impact of the logistics industry boom on national logistics costs, economic added value, and overall efficiency. The crucial role of business logistics management in various aspects of the industry is also emphasized, making it clear that success goes beyond distribution and transportation to encompass strategic planning and efficient processes [3,4].

This holistic approach goes beyond mere product movement, extending to managing the flow of data and resources from manufacturers to consumers. As Cooper, et al. [3] highlight, effective logistics management supports companies in adapting to changing customer needs and gaining a competitive edge [5]. Quality service remains paramount in delivering value to customers [1,6]. This entails factors like on-time delivery, accuracy, reliability, flexibility, and cost-effectiveness. Ensuring sustainable quality within business logistics presents both challenges and opportunities. The complex nature of supply chains with numerous variables and dynamic requirements makes it a demanding task [2,7,8]. However, mastering these challenges unlocks significant potential for growth and efficiency, impacting the company's overall smooth operations. Furthermore, strong supply chain management (SCM) capabilities have a direct positive impact on business performance [4,9]. Streamlined logistics flows and optimized inventory management contribute to increased profitability and enhanced customer satisfaction. By continually emphasizing quality, embracing technology, and adapting to evolving customer needs, the logistics and supply chain services industry can continue

its vibrant growth and serve as a vital engine for economic prosperity [4]. Cold chain business involves the transportation of temperature-sensitive goods throughout the supply chain [4]. This is to protect and maintain the integrity of transportation [10-12], for example in the areas of quality preservation, food safety, public health, economic benefits, which is a set of activities aimed at managing and the safe transport of such goods from upstream to downstream of the supply chain derived from logistics service quality (LSQ) [13]. If a company can provide excellent products and services, it shows that it has a good image and reputation that is well accepted by customers. It is considered to be a source of advantage.

The competitiveness of the company's business can be determined by evaluating delivery efficiency. Service quality customer satisfaction and behavioral intentions. This is important in monitoring and improving the quality level of the company's logistics services to be in line with the expectations, satisfaction level and behavior of customers who continue to use the service. These phenomena encompass a broad spectrum of interrelated activities, ranging from the processing of raw materials and semi-finished products to the intricate choreography of logistics services. Logistics processes, as extensively explored in works by Kuo and Chen [11], Mentzer, et al. [13], Riliandini, et al. [14], hold critical sway not only on operational efficiency but also on an organization's image and subsequent performance. Notably, research by Riliandini, et al. [14], Wallin Andreassen and Lindestad [15], Walsh and Beatty [16], and Wepener and Boshoff [17] highlights the mediating role of organizational image, bridging the gap between logistics service quality (LSQ) and firm performance.

The Cold Chain Logistics industry in Thailand is experiencing sustained expansion, fueled by the booming food and beverage sector, particularly the fresh, chilled, and frozen fruit industry, a crucial export and domestic product group. Essentially, Cold Chain Logistics manages temperature-controlled storage and transportation throughout the supply chain to maintain product quality, ensure consumer safety, and minimize losses, utilizing both freezing and chilling methods [18]. While traditionally B2B-centric, the Cold Chain Logistics landscape witnessed a remarkable shift towards B2C during the COVID-19 pandemic. The e-commerce sector, catering to consumers' growing appetite for online fresh, chilled, and frozen food purchases, thrived. Additionally, restaurants adapted by expanding online channels and home delivery services. Kasikorn Research Center predicts a significant value of 2.9-3.0 billion baht for B2C temperature-controlled shipping in 2022, representing a 15-20% year-on-year growth. Further expansion of 40-45% is anticipated, driven by both the high base effect and the temporary surge post-lockdowns. However, sustained consumer demand remains a key driver [19].

This case study evaluates the effectiveness of XYZ (Group) Holdings Company Limited in providing comprehensive, high-quality temperature-controlled logistics services. The assessment encompasses warehousing, cold storage, and freezer transportation, all powered by XYZ's modern and efficient technologies. To cater to diverse customer needs, XYZ boasts a diverse fleet of temperature-controlled vehicles. This includes (1) Flexible urban transport: 1-ton trucks with high and low roofs, ideal for maneuvering within cityscapes. (2) Large trucks: Optimized for efficiently transporting bulk quantities of temperature-sensitive goods. XYZ further distinguishes itself by its extensive logistics network, enabling them to design and execute efficient delivery plans throughout Thailand, tailored to specific customer requirements. Background: XYZ was established in 2018 through a joint venture between two industry leaders: XYZ with MK Restaurant Group Public Company Limited: Renowned for its excellence and established network in the Thai food industry. This strategic partnership leverages the strengths of both entities to provide XYZ with a robust foundation for success in the temperature-controlled logistics sector.

XYZ, a prominent leader in Japan's transportation and logistics industry, extends its reach globally with over 500 distribution centers in strategically chosen locations including the US, South Korea, China, Central Asia, and ASEAN. Through a balanced 50/50 investment model, they offer comprehensive logistics solutions encompassing warehousing, transportation, import-export services (forwarding), and product trading. This caters to both B2B and B2C segments, anticipating future customer needs. In Thailand alone, XYZ's impressive delivery network covers 682 MK Group branches, highlighting its substantial potential, market compatibility, and customer appeal as a preferred logistics provider. Consequently, we hypothesize that a strong Logistics Service Quality (LSQ) offered by providers plays a significant role in shaping customer perceptions of their organizational image and ultimately influencing firm performance.

Objective to study

To analyze the direct, indirect, and total impact of logistics service quality through perceived organizational image on the performance of cold chain logistics provider. Using an evaluation perspective from customers who use services with cold chain logistics company in Thailand.

2 Literature review

2.1 Previous studies on logistics service quality and theoretical basis

The logistics service perspective provides a unique approach to building a customer-centric foundation by tailoring traditional service quality models to incorporate specific logistics characteristics. This aligns with established frameworks for assessing logistics service quality and serves as a springboard for integrated marketing and logistics activities [13,20]. The research

highlights the complexity of pinpointing key drivers of service quality, customer retention, and consistent delivery, emphasizing their significant value for service organizations. Service quality demonstrably fosters customer retention, impacting perceptions and response behaviors, Zeithaml [21], Zeithaml, et al. [22], Zeithaml [23], as supported by multi-organizational studies.

From the existing literature on Logistics Service Quality (LSQ) measurement, key aspects emerge. First, LSQ is not simply a singular activity; it encompasses facets of facility management, transportation, and responsiveness to third-party needs. Second, delivering good logistics involves a combination of desirable service features; diverse offerings, short order cycles, dependable and cost-effective deliveries, lean inventory levels with rapid turnover, and accurate, immediate information readily available [24, 25]. These align well with the classic dimensions of timeliness, availability, and condition outlined by Mentzer et al.[13] for physical logistics operations.

While LSQ and customer satisfaction are closely linked, they are distinct concepts. High-quality logistics service boosts customer satisfaction, but external factors can also influence consumer satisfaction beyond logistics providers' control [5,26,27]. Research primarily focuses on internal factors within LSP to enhance service delivery and customer satisfaction [13,28]. Theoretical frameworks, such as Gupta et al. [29] emphasis on operational quality, support this focus, showing that optimizing operational elements leads to more satisfied customers [5,24,29]. Recognizing LSQ as a multifaceted concept encompassing internal and external factors, we can better understand its relationship with customer satisfaction and develop more effective strategies for delivering excellent logistics service.

Leong et al. [30] define service quality as the gap between expected and perceived service performance, with the SERVQUAL and SERVPERF models identifying key dimensions for measuring this gap. Beyond these models, LSQ extends to creating value through timely, accurate, and condition-specific delivery [31]. The "Seven Rs" framework captures this notion, emphasizing crucial aspects of service quality [13,32]. LSQ goes beyond the physical delivery of goods, encompassing intangible elements like customer care, marketing, and consumer services, contributing to customer satisfaction [31]. Bienstock et al. [32] further refine this concept by differentiating physical distribution service quality, logistics process quality, and logistics outcomes quality.
The research draws inspiration from Mentzer et al. [13], emphasizing relational competence and the role of organizational learning in improving LSQ and achieving consistent performance [33]. Understanding how LSQ influences performance within the B2C context and across industries is crucial [26,34-36]. Service quality characteristics identified in models like SERVQUAL hold potential for enhancing customer satisfaction, particularly in B2C logistics. Moreover, Service quality characteristics identified in models like SERVQUAL hold potential for enhancing customer satisfaction, particularly in B2C logistics [5,37].

2.2 The relationship between logistics service quality and perceived organizational image

The integration of service quality concepts, as defined by Zeithaml, et al. [22], Zeithaml [23], Parasuraman, et al. [38], along with logistics quality dimensions, including touch quality, order fulfillment accuracy, information clarity, and efficient ordering processes [13], has significantly enriched the study of logistics service quality development and performance evaluation in service-oriented businesses. This enrichment is particularly relevant in cold supply chains, emphasizing the importance of meticulous care, maintenance, and protection of temperature-sensitive goods throughout the entire supply chain [11,12].

Preserving shipment integrity for customer receipt is crucial, as it directly influences their decision-making and purchasing behavior. Moreover, maintaining consistent delivery of professional service, social and environmental responsibility, and ethical business practices over time establishes a lasting positive impression and favorable attitude in customers' minds. Aligning a company's services with customer expectations in terms of characteristics, values, and operational efficiency results in a clear and positive organizational image. This positive image is associated with various benefits, including increased customer satisfaction and behavior intention [39-42], enhanced brand reputation, and market share [43-45], as well as stronger customer loyalty and repeat business intentions, and superior service and logistics experiences ultimately lead to more positive customer perception, fostering trust and reliability as well as positive word-of-mouth recommendations for quality logistics services (e.g., Fu, et al. [46], Alam and Noor [47]).

The following hypothesis is proposed:

Hypothesis 1 (H1): There is a positive impact of logistics service quality on perceived organizational image.

2.3 The relationship between logistics service quality and performance

High-quality logistics services exhibit responsiveness to customer needs, demonstrated through readily available employees and transparent solutions [4,26,34,48]. Promptness, encompassing lead time minimization and proactive communication, ensures swift and accurate delivery [4,26,35,48,49]. Availability involves clear and accurate delivery notes, accessible inventory, and efficient delivery services [4,26,34,36]. Condition refers to comprehensive support services, including proper packaging and product protection measures [4,36,48]. Flexibility entails adapting to variations in customer needs, while assurance involves transparent reporting,

certifications, and professional conduct [4,10,50]. Assurance signifies reliability in service delivery, featuring transparent reporting of quality discrepancies, product and service certifications, and courteous and professional employee conduct, adhering to ethical guidelines and regulations [25,27]. Price competitiveness ensures service costs align with customer budgets [22,51,52]. Ultimately, high-quality logistics services aim to create a positive emotional experience for customers, fostering lasting loyalty and sustainable success [53,54].

Empirical evidence consistently demonstrates the positive impact of high-quality logistics services on a company's performance [55]. This impact manifests in several key areas: (1) Delivery efficiency refers to streamlined logistics processes ensure quicker turnaround times and reduced delivery costs (e.g., Fernandes, et al. [49], Fugate, et al. [55], Wang [56]), (2) Timely delivery of orders refer to consistent on-time deliveries enhance customer satisfaction and build trust (e.g., Liu and Lyons [50], Forslund [57]), (3) Product and packaging safety refer to Reliable logistics protocols protect products from damage, ensuring their safe arrival in customers' hands (e.g., Huma, et al. [51], Li [52]), (4) Product and packaging suitability refer to Appropriate packaging and handling methods prevent product deterioration and maintain quality (e.g., Tran [34], Huma, et al. [51]), and (5) Availability of products refer to Efficient logistics systems keep inventory levels optimized, minimizing stockouts and maximizing sales opportunities (e.g., Fernandes, et al. [49], Fugate, et al. [55]).

Enhanced customer satisfaction, a direct consequence of these benefits, further bolsters a company's performance: (1) Positive customer experience refers to timely and accurate deliveries, coupled with safe and suitable packaging, reinforce customer satisfaction and loyalty (e.g., Tran [34], Fernandes, et al. [49], Huma, et al. [51]), (2) Brand advocacy refers to satisfied customers become brand advocates, promoting the company and its products through positive word-of-mouth and willingness to try new offerings (e.g., Tran [34], Huma, et al. [51]), (3) Increased customer retention refers to strong logistics capabilities fostering customer loyalty, leading to repeat business and sustained revenue growth, and (4) Improved brand reputation refers to the consistent delivery of excellent customer service strengthens a company's brand image and credibility [58].

Thus, by prioritizing quality logistics, companies can reap significant rewards in terms of operational efficiency, enhanced customer satisfaction, and ultimately, a more competitive and thriving business.

The following hypothesis is proposed:

Hypothesis 2 (H2): There is a positive impact of logistics service quality on performance.

2.4 The relationship between perceived organizational image and performance

The corporate image formed through service provision significantly influences the purchasing decisions of current and potential customers, playing a crucial role in maintaining customer loyalty and engagement [44]. A positive organizational image is associated with higher customer satisfaction [1,34,47,59]. and stronger behavioral intentions [34,59]. This positive image acts as a competitive advantage, making it challenging for competitors to replicate [47,60].

Organizational image is a multifaceted concept shaped by tangible and intangible factors like product variety, service experience, company information, reputation, communication quality, and customer interactions [44,61]. This overall impression ultimately influences customers' perceptions of firm performance [13,62]. A strong organizational image increases brand preference and customer loyalty, reducing marketing risks [63]. It positively impacts customer satisfaction and loyalty evaluations, [15,44], and contributes to positive customer satisfaction and service continuation intentions [46,54,64].

Consistently positive customer experiences serve as a key driver of a positive image, creating a sense of specialness and positive feelings [46,64,65]. Customers with a positive organizational image are more likely to consider its products and services as reliable and of reasonable quality [46,65].

The formation of this image involves both direct experiences and indirect exposure, such as word-of-mouth [1,44,59]. It is closely linked to the organization's reputation, including employee support for marketing and service activities [65,66] and commitment to social responsibility, ethics, and the environment [24,35,67]. A strong, positive image benefits the organization beyond customer loyalty, enhancing market position, building stakeholder confidence, and translating into financial success [65,67]. It also fosters a favorable public opinion through positive customer attitudes and recommendations. The above literature supports a positive link between perceived organizational image and key performance indicators, including efficiency in delivery, customer satisfaction customer retention, and intention to continue using the logistics service.

The following hypothesis is proposed:

Hypothesis 3 (H3): There is a positive impact of perceived organizational image on performance.

2.5 The mediating effect of perceived organizational image logistics service quality and performance

Organizational image is not just a snapshot, but a dynamic picture built from past experiences, emotions, and perceptions of an organization's name, reputation, and service quality [44]. Attributes like name, reputation, and service quality collaborate seamlessly, shaping customers'

overall impressions through a constellation of feelings, thoughts, attitudes, and experiences. This constellation, etched in the minds and hearts of consumers, forms the very essence of a brand, evoking a specific sense of meaning and feeling, this perspective is in harmony with Keller's concept, underscoring the significance of holistically managing brand image by considering all facets of the organization [63,68,69].

The previous study, Abd El Salam, et al. [70] research emphasizes the powerful link between exceptional supplier service quality, customer satisfaction, and loyalty towards both the organization and its distributors, especially those with strong reputations. Satisfied and loyal customers become vocal brand advocates, sharing positive experiences and post-purchase feelings and experiences are crucial [71]. As, Özkan, et al. [72], Choi [73], Hossain, et al. [74] show how customer satisfaction, influenced by service quality and organizational image, impacts overall satisfaction, influencing future behavior, and repurchase intent.

In addition, Chien and Chi [1] supports the idea that organizational service quality enhances supplier service quality, fostering organizational satisfaction, and loyalty. Service quality and organizational image mediate between service quality and satisfaction. Logistics service quality influences company performance directly (logistics efficiency, customer satisfaction) and indirectly through the enhanced organizational image [47]. Investing in superior enterprise service quality will raise the level of supplier service quality, helping to drive greater organizational satisfaction and loyalty with service quality and the corporate image it serves. Important bridges are like a domino effect [1]. Logistics service quality has a powerful impact on firm performance, as evidenced by studies from Alam and Noor [47], Özkan, et al. [72], Hossain, et al. [74]. This impact occurs through both direct and indirect influences.

The following hypothesis is proposed:

Hypothesis (H4): There is a positive mediation of perceived organizational image on the relationship between logistics service quality and performance.

These reviews encapsulate valuable recommendations for both research and practical applications. The articles featured in this special issue not only complement the existing reviews but also offer additional insights derived from the realms of marketing, logistics service quality, performance evaluations, and related fields. We present the organizing framework in Figure 1.

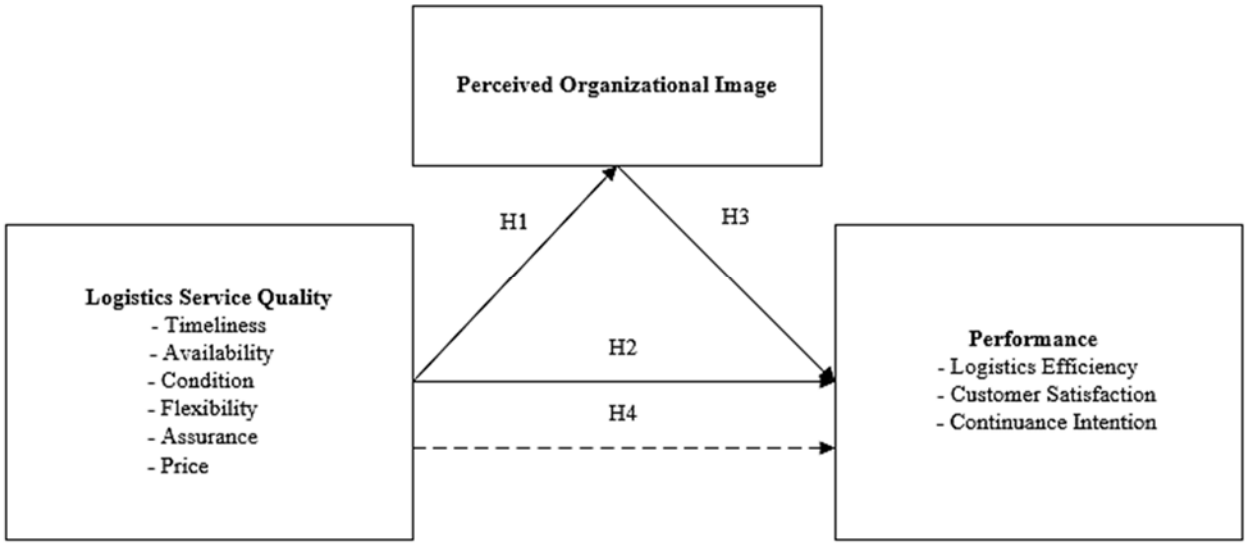

Figure 1 Conceptual frame work

3 Methodology

As an empirical research, we focus on using questionnaires as a data collection tool, focusing on customers who The group of customers within the MK company's network utilizes the cold chain supply logistics services provided by XYZ Company. Statistical analysis uses structural equation modeling techniques to answer research objectives and research hypotheses.

3.1 Research instruments

Logistics service quality measures were adapted from Mentzer et al. (1999) and Mentzer et al. (2001). The last one is composed of 12 items. The data collection instrument consists of questionnaires, consisting of quantitative attitude and demographic data questionnaires, which measure 3 latent and manifest variables Logistics Service Quality (LSQ), Perceived Organizational Image (POI), and Performance (PER). We use the Likert scale, in which a 6-point scale was scored as 1 = strongly disagree,

2 = disagree, 3 = somewhat disagree, 4 = somewhat agree, 5 = agree, and 6 = strongly agree. In addition, the test results for the validity of each variable had an alpha Cronbach coefficient of .938-.979 (n = 541), appropriate for cognitive tests such as intelligence tests.

3.2 Sampling method and data collection

We chose to use a simple random sample to estimate the population proportion. Data collection was carried out using a questionnaire. The questionnaire data analyzed were used to determine the size of the sample data collected from the population consisted food cold chain companies, MK Restaurant Group Public Company Limited = 443 branches, Yayoi Restaurant = 182 branches, Laem Charoen Seafood = 32 branches, GRAM & PABLO = 15 branches, and Sushiro GH (Thailand) Ltd. = 10 branches, total 682 branches.

Set the sample size programmatically. G*Power 3.1.9.4 is equal to 497 samples, which is sufficient for analysis of the Structural Equation Model. Questionnaires were sent to all branches and were returned and completed for 541 respondents, these branches are already being serviced by XYZ Company, which provides logistics services for constant-temperature food products. The number of complete questionnaires from respondents, including MK Restaurant Group Public Company Limited = 356 branches (65.80%), Yayoi Restaurant = 145 branches (26.80%), Laem Charoen Seafood = 25 branches (4.62%), GRAM & PABLO = 8 branches (1.48%), and Sushiro GH (Thailand) Ltd. = 7 branches (1.29%), total 541 branches (100.00%).

4 Data analysis

4.1 Descriptive statistics

Descriptive statistics on demographic profile. Among all the respondents (n = 541), only 69.69 percent are female, the average age is 34, 448 respondents (82.81%) in Gen Y, Completed a bachelor's degree 65.62%.

4.2 Structural equation model analysis results

The analysis of the Structural Equation Model (SEM) required a simple model with large samples should be held to strict fit standards [75]. We take precautions given the large sample size used for structural equation model analysis. The test of consistency between the goodness of fit measures in the model was found to be in harmony with the fit of the model, with result: Chi-square (χ^2) = 72.971, *df* = 55, CMIN/DF (χ^2/df) = 1.327, *p*-value = .053, GFI = .981, AGFI = .963, CFI = .998, NFI = .994, TLII = .997, RMSEA = .025, and HOELTER (.05) = 543 (Table 1 and Figure 2).

It could be concluded that the form of the structural equation of the variables affecting performance was consistent with the empirical data. Accordingly, the statistics of Goodness of fit as shown in Table 1.

Table 1 Statistics Goodness of fit

Relevant Statistics	Criteria	Test Value
Relative Chi-square	$\chi^2/df <$ 2.00	1.327
p-value	*p*>.05	.053
Goodness of Fit Index	GFI >.95	.981
Adjusted Goodness of Fit Index	AGFI>.95	.963
Comparative Fit Index	CFI >.95	.998
Normed Fit Index	NFI>.95	.994
Tucker-Lewis Index	TLII >.95	.997
Root Mean Square Error of Approximation	RMSEA <.05	.025
Default model, HOELTER	HOELTER (.05)>200	543

4.3 Results of testing of the hypotheses

Hypothesis testing shall provide the same as the Structural Equation Modelling by considering the C.R.(t-value) and *p*-value used for the test of the hypothesis. The hypothesis analysis (Table 2) was executed using the IBM SPSS AMOS software [76,77]. It indicates that values higher than 1.96 for all hypotheses of statistical significance. It can be concluded that the results support all assumptions and that the results of they are shown in Table 3 and Table 4, and the final model Figure 2.

Hypothesis 1: Logistics service quality has a direct effect on perceived organizational image. The hypothesis testing is concerned with standardized effect =.867, that supports a statistically significant hypothesis at $p<0.001$.

Hypothesis 2: Logistics service quality on performance. The hypothesis is concerned with standardized effect =.203, that supports a statistically significant hypothesis at $p<0.001$.

Hypothesis 3: Perceived organizational image has a direct effect on performance. The hypothesis testing is concerned with standardized effect =.807, that supports a statistically significant hypothesis at $p<0.001$.

Hypothesis 4: The mediating effect of perceived organizational image on the relationship between logistics service quality and performance. The hypothesis testing is concerned with standardized effect =.700, that supports a statistically significant hypothesis at $p<0.001$.

The results of the Structural Equation Modeling analysis equations were formed (1), (2):

$$Perceied\ Organizational\ Image = .867(Logistics\ Service\ Quality), R^2 = .976 \quad (1)$$

$$Performances = .203(Logistics\ Service\ Quality) + .807(Perceied\ Organizational\ Image), R^2 = .600 \quad (2)$$

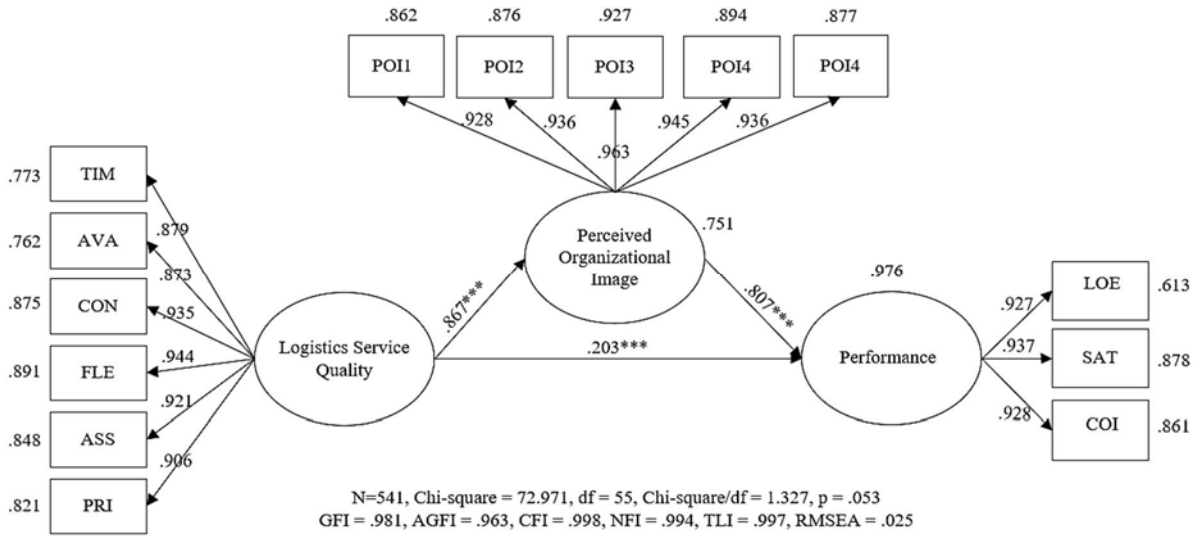

Figure 2 Final model

Table 2 Analysis on the relationship of the variables

Relationship of Variables			Standardized Regression Weights	S.E.	C.R.	p-value	Squared Multiple Correlations
LSQ	--->	POI	.867	.035	25.583	*p*<.001	.751
LSQ	--->	PER	.203	.032	6.446	*p*<.001	.976
POI	--->	PER	.807	.045	17.618	*p*<.001	.861
LSQ	--->	TIM	.879	-[a]	-[a]	-[a]	.773
LSQ	--->	AVA	.873	.026	35.665	*p*<.001	.762
LSQ	--->	CON	.935	.027	34.426	*p*<.001	.875
LSQ	--->	FLE	.944	.028	35.105	*p*<.001	.891
LSQ	--->	ASS	.921	.028	33.084	*p*<.001	.848
LSQ	--->	PRI	.906	.028	31.623	*p*<.001	.821
POI	--->	POI1	.928	-[a]	-[a]	-[a]	.862
POI	--->	POI2	.936	.022	46.494	*p*<.001	.876
POI	--->	POI3	.963	.021	46.749	*p*<.001	.927
POI	--->	POI4	.945	.023	43.306	*p*<.001	.894
POI	--->	POI5	.936	.024	41.737	*p*<.001	.877
PER	--->	LOE	.927	-[a]	-[a]	-[a]	.613
PER	--->	CSAT	.937	.036	26.520	*p*<.001	.878
PER	--->	COI	.928	.037	26.182	*p*<.001	.861

Note: Logistics Service Quality = LSQ, Perceived Organizational Image = POI, Performance = PER, Timeliness = TIM, Availability=AVA, Condition = CON, Flexibility = FLE, Assurance = ASS, Price = PRI, Logistics Efficiency = LOE, Satisfaction = SAT, Continuance Intention = COI.
-[a]; Fixed parameter does not display the Standard Error (S.E.), Critical Ratio (C.R.)

Table 3 Hypothesis test results

Hypothesis	coef.	Results
H1: Logistics Service Quality ---> Perceived Organizational Image	.867***	Supported
H2: Logistics Service Quality ---> Performance	.807***	Supported
H3: Perceived Organizational Image ---> Performance	.203***	Supported
H4: Logistics Service Quality ---> Perceived Organizational Image ---> Performance	.700***	Supported

Note: * = *p*<.05; : ** = *p*<.01; *** = *p*<.001

Table 4 Standardized direct, indirect, and total effects of the factors test results

Effects	Total	direct			Indirect		
Variables	LSQ	LSQ	POI	PER	LSQ	POI	PER
POI	.867	.867	-	.807	-	-	-
PER	.903	.203	.807	-	.700	-	-

5 Discussion and implementation

This comprehensive research study provides valuable insights into the critical role of perceived organizational image in mediating the relationships between logistics service quality and key performance outcomes in the cold chain logistics provider sector industry.

5.1 Management implications

This study analyzes the restaurant industry in Thailand by surveying 5 4 1 branches of reputable restaurant companies. It examines the impact of logistics service quality and perceived organizational image on the Performance of transportation and logistics providers. Employing structural equation modeling, our analysis unveils a robust causal pathway (p< .001) where superior logistics service quality (LSQ) directly boosts both perceived organizational image (PIO) and firm performance. This connection is demonstrably mediated by the resulting improved image acting as a key driver of performance gains. As shown in Tables 3 and Table 4, a one-unit increase in LSQ leads to a significant 86.7% increase in PIO (.867) and a subsequent 80.7% improvement in firm performance (.807). Interestingly, the mediating effect of PIO explains 70% of the total impact of LSQ on performance (.700), highlighting its crucial role in this relationship. While LSQ exerts a direct effect on performance (.203), the indirect effect through PIO is significantly stronger. The findings of this study may assist the marketing business and organizations of the cold chain logistics providers:

Prioritizing exceptional logistics: Our research demonstrates the profound impact of superior logistics service quality (LSQ) on both brand perception and the bottom line. Investing in efficient, reliable, and customer-centric logistics strategies is not just an operational concern; it's a strategic driver of competitive advantage.

Building image through excellence: The analysis reveals that improved PIO acts as a powerful mediator between LSQ and customer satisfaction, continuance intention, and logistics efficiency, which are crucial determinants of firm performance. By exceeding customer expectations through seamless deliveries and responsive service, businesses can cultivate a positive brand image that fosters trust, loyalty, and ultimately.

Direct and indirect pathways to success: While LSQ directly influences performance, its most significant impact comes through the indirect pathway of enhanced PIO. This underscores the importance of focusing on holistic logistics improvements that not only ensure timely deliveries but also prioritize customer satisfaction and brand building.

The findings highlight the importance for logistics providers to focus on both service excellence and cultivating a positive organizational reputation. Investing in service quality and brand management can maximize customer satisfaction, continuance intention, and overall logistics efficiency performance.

Logistics Service Quality and Customer satisfaction

The results demonstrate that higher logistics service quality, encompassing factors such as flexibility, conditions, guarantees, price, timeliness, and service availability, directly leads to greater customer satisfaction and continuance intention, efficient logistics operations that reduce costs and lead times also positively impact customer satisfaction and continuance intention.

The mediating role of perceived organizational image

Crucially, the study found that perceived organizational image plays a significant mediating role in the relationships between logistics service quality, customer satisfaction, continuance intention, and logistics efficiency. A positive organizational image enhances the perceived value of the logistics services, driving higher customer satisfaction and retention.

Actionable insights: Managers can leverage these findings to:

Quantify the ROI of logistics investments: Demonstrate the direct and indirect financial benefits of improving LSQ.

Prioritize customer-centric initiatives: Design logistics processes that deliver exceptional service experiences, fostering positive brand perceptions.

Align logistics with marketing and branding efforts: Leverage the positive spillover effect of superior logistics on brand image.

Monitor and measure key performance indicators (KPIs): Track LSQ, PIO, and their impact on firm performance to identify areas for continuous improvement.

By embracing a strategic approach to logistics, businesses can unlock its potential as a powerful tool for boosting both brand image and financial success. Finally, companies should support the development of reskills and upskills, and knowledge of employees in the quality of logistics services and the use of technology to support socio-economic changes, and for business sustainability [78-80].

5.2 Research implications

This research is a cross-sectional study. Therefore, longitudinal studies should be conducted so that changes can be more accurate and their application in studies to

look for other predictors, second precaution is concerned with the small sample size used for multivariate statistics analysis, and finally the sample size should be collected in consistency with the parameters in the research model.

6 Conclusions and limitations

6.1 Conclusions

This comprehensive research study provides valuable insights into the critical role of perceived organizational image in mediating the relationships between logistics service quality and key performance outcomes in the cold chain logistics provider sector industry.

This research establishes a significant link between logistics service quality (LSQ) and both perceived organizational image (POI) and Performance, confirming findings from previous investigations. We demonstrate that improved LSQ directly enhances POI, leading to positive performance outcomes like customer satisfaction, continuance intention, and efficient logistics. These findings inform cold chain supply logistics managers of the strategic importance of prioritizing LSQ improvements to attract and retain customers.

6.2 Limitations

These findings emphasize the need for logistics providers to prioritize both service quality and organizational image to maximize customer satisfaction, continuance intention, and overall logistics efficiency performance.

While offering valuable insights, this study acknowledges certain limitations:

Scope: The focus on MK restaurant customers and a single logistics provider in Thailand restricts the generalizability of findings. Future research should continue to study populations and samples in a variety of adjacent sectors and industries to gain a broader perspective.

Predictor variables: Exploring additional factors beyond this study's scope, such as trust, perceived value, risk, and relationship marketing, could enrich our understanding of performance influences.

Performance measurement: Expanding beyond traditional metrics to include sustainability indicators would provide a more holistic evaluation of operational success.

Future research directions

Addressing these limitations in future investigations can unlock a deeper understanding of the intricate relationship between LSQ, POI, and operational results across various contexts. Additionally, incorporating new predictor and performance measurement variables can enhance the practical implications and decision-making value of future research efforts.

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References

[1] CHIEN, L.H., CHI, S.Y.: Corporate image as a mediator between service quality and customer satisfaction: difference across categorized exhibitors, *Heliyon*, Vol. 5, No. 3, e01307, pp. 1-24, 2019. https://doi.org/10.1016/j.heliyon.2019.e01307

[2] BEHDANI, B., FAN, Y., BLOEMHOF, J.M.: *Sustainable Food Supply Chains*, Wageningen, Academic Press, 2019.

[3] COOPER, M.C., LAMBERT, D.M., PAGH, J.D.: Supply Chain Management: More Than a New Name for Logistics, *The International Journal of Logistics Management*, Vol. 8, No. 1, pp. 1-14, 1997. https://doi.org/10.1108/09574099710805556

[4] HSIAOA, H.I., KANGA, H.W., SHANGB, K.C.: *Cold chain capability for food cold chain management: Concept And Application*, Symposium on Logistics – Conference Proceedings, pp. 454-465, [Online], Available: https://www.researchgate.net/profile/Santi-Setyaningsih/publication/339401715 [2 Apr 2024], 2019.

[5] YAN, H., SONG, M.J., LEE, H.Y.: A Systematic Review of Factors Affecting Food Loss and Waste and Sustainable Mitigation Strategies: A Logistics Service Providers' Perspective, *Sustainability*, Vol. 13, No. 20, pp. 1-20, 2021. https://doi.org/10.3390/su132011374

[6] VAN DER VORST, J.G., PEETERS, L., BLOEMHOF, J.M.: Sustainability assessment framework for food supply chain logistics: empirical findings from dutch food industry, *International Journal on Food System Dynamics*, Vol. 4, pp. 130-139, 2013. https://doi.org/10.22004/ag.econ.164795

[7] BURGANOVA, N., GRZNAR, P., GREGOR, M., MOZOL, Š.: Optimalisation of Internal Logistics Transport Time Through Warehouse Management: Case Study, *Transportation Research Procedia*, Vol. 55, pp. 553-560, 2021. https://doi.org/10.1016/j.trpro.2021.07.021

[8] FISHER, M.L.: What is the right supply chain for your product?, *Harvard business review*, Vol. 75, pp. 105-117, 1997.

[9] TRACEY, M., LIM, J.S., VONDEREMBSE, M.A.: The impact of supply-chain management capabilities on business performance, *Supply Chain Management:*

An International Journal, Vol. 10, No. 3, pp. 179-191, 2005. https://doi.org/10.1108/13598540510606232

[10] GUO, S.M., TSAI, K.M.: *Cold chain operational standards and a certification case study in Taiwan*, Symposium on Logistics – Conference Proceedings, 2019, Vol. 447-453, [Online], Available: https://www.researchgate.net/profile/Santi-Setyaningsih/publication/339401715 [2 Apr 2024], 2019.

[11] KUO, J.C., CHEN, M.C.: Developing an advanced Multi-Temperature Joint Distribution System for the food cold chain, *Food Control*, Vol. 21, No. 4, pp. 559-566, 2010. https://doi.org/10.1016/j.foodcont.2009.08.007

[12] RODRIGUE, J.P., NOTTEBOOM, T.: *Reefers in north american cold chain logistics: evidence from western Canadian supply chains*, The Van Horne Institute, Calgary, [Online], Available: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=49a6d22dde5a367fa6888ef43792b27eb560da45 [2 Apr 2024], 2014.

[13] MENTZER, J.T., FLINT, D.J., HULT, G.T.M.: Logistics Service Quality as a Segment-Customized Process, *Journal of Marketing*, Vol. 65, No. 4, pp. 82-104, 2001. https://doi.org/10.1509/jmkg.65.4.82.18390

[14] RILIANDINI, P., DIANTI, E.N., HIDAYAH, S.R., PERTIWI, D.A.A.: Improved logistics service quality for goods quality delivery services of companies using analytical hierarchy process, *Journal of Soft Computing Exploration*, Vol. 2, No. 1, pp. 33-39, 2021.

[15] WALLIN ANDREASSEN, T., LINDESTAD, B.: Customer loyalty and complex services, *International Journal of Service Industry Management*, Vol. 9, No. 1, pp. 7-23, 1998. https://doi.org/10.1108/09564239810199923

[16] WALSH, G., BEATTY, S.E.: Customer-based corporate reputation of a service firm: scale development and validation, *Journal of the Academy of Marketing Science*, Vol. 35, No. 1, pp. 127-143, 2007. https://doi.org/10.1007/s11747-007-0015-7

[17] WEPENER, M., BOSHOFF, C.: An instrument to measure the customer-based corporate reputation of large service organizations, *Journal of Services Marketing*, Vol. 29, No. 3, pp. 163-172, 2015. https://doi.org/10.1108/JSM-01-2014-0026

[18] DEPARTMENT OF INTERNATIONAL TRADE PROMOTION (DITP), Logistics business, [Online], Available: https://www.tradelogistics.go.th/th/article/In-deptharticle/logistics-business [13 Mar 2023], 2023. (Original in Thai)

[19] KASIKORN RESEARCH CENTER, Cold-Chain Logistics delivers cold food to consumers, Shining brightly...from online orders for fresh food & fruits and vegetables, [Online], Available: https://www.kasikornresearch.com/th/analysis/k-social-media/Pages/Cold-Chain-FB-16-03-2022.aspx [27 Jan 2023], 2023. (Original in Thai)

[20] STOCK, J.R., LAMBERT, D.M.: Becoming a "World Class" Company With Logistics Service Quality, *The International Journal of Logistics Management*, Vol. 3, No. 1, pp. 73-81, 1992. https://doi.org/10.1108/09574099210804822

[21] ZEITHAML, V.A.: Consumer Perceptions of Price, Quality, and Value: A Means-End Model and Synthesis of Evidence, *Journal of Marketing*, Vol. 52, No. 3, pp. 2-22, 1988. https://doi.org/10.1177/002224298805200302

[22] ZEITHAML, V.A., BERRY, L.L., PARASURAMAN, A.: The Behavioral Consequences of Service Quality, *Journal of Marketing*, Vol. 60, No. 2, pp. 31-46, 1996. https://doi.org/10.1177/002224299606000203

[23] ZEITHAML, V.A.: Service quality, profitability, and the economic worth of customers: What we know and what we need to learn, *Journal of the Academy of Marketing Science*, Vol. 28, No. 1, pp. 67-85, 2000. https://doi.org/10.1177/0092070300281007

[24] SOH, K.L., CHIN, S.H., WONG, W.P.: A theoretical model to investigate customer loyalty on logistics service providers for sustainable business performance, *International Journal of Business Performance and Supply Chain Modelling*, Vol. 7, No. 3, pp. 212-232, 2015. https://doi.org/10.1504/IJBPSCM.2015.071609

[25] RESTUPUTRI, D.P., INDRIANI, T.R., MASUDIN, I.: The effect of logistic service quality on customer satisfaction and loyalty using kansei engineering during the COVID-19 pandemic, *Cogent Business & Management*, Vol. 8, No. 1, pp. 1-35, 2021. https://doi.org/10.1080/23311975.2021.1906492

[26] GIL SAURA, I., SERVERA FRANCÉS, D., BERENGUER CONTRÍ, G., FUENTES BLASCO, M.: Logistics service quality: a new way to loyalty, *Industrial Management & Data Systems*, Vol. 108, No. 5, pp. 650-668, 2008. https://doi.org/10.1108/02635570810876778

[27] UVET, H.: Importance of logistics service quality in customer satisfaction: An empirical study, *Operations and Supply Chain Management: An International Journal*, Vol. 13, No. 1, pp. 1-10, 2020. https://doi.org/10.31387/oscm0400248

[28] HUO, B., YE, Y., ZHAO, X., ZHU, K.: Supply chain quality integration: A taxonomy perspective, *International Journal of Production Economics*, Vol. 207, pp. 236-246, 2019. https://doi.org/10.1016/j.ijpe.2016.05.004

[29] GUPTA, A., SINGH, R.K., MATHIYAZHAGAN, K., SURI, P.K., DWIVEDI, Y.K.: Exploring relationships between service quality dimensions and customers satisfaction: empirical study in context to Indian logistics service providers, *The International Journal of Logistics Management*, Vol. 34, No. 6, pp.

1858-1889, 2023. https://doi.org/10.1108/IJLM-02-2022-0084

[30] LEONG, L.Y., HEW, T.S., LEE, V.H., OOI, K.B.: An SEM–artificial-neural-network analysis of the relationships between SERVPERF, customer satisfaction and loyalty among low-cost and full-service airline, *Expert Systems with Applications*, Vol. 42, No. 19, pp. 6620-6634, 2015. https://doi.org/10.1016/j.eswa.2015.04.043

[31] MENTZER, J.T., GOMES, R., KRAPFEL, R.E.: Physical distribution service: A fundamental marketing concept?, *Journal of the Academy of Marketing Science*, Vol. 17, No. 1, pp. 53-62, 1989. https://doi.org/10.1007/BF02726354

[32] BIENSTOCK, C.C., ROYNE, M.B., SHERRELL, D., STAFFORD, T.F.: An expanded model of logistics service quality: Incorporating logistics information technology, *International Journal of Production Economics*, Vol. 113, No. 1, pp. 205-222, 2008. https://doi.org/10.1016/j.ijpe.2007.03.023

[33] PANAYIDES, P.M.: The impact of organizational learning on relationship orientation, logistics service effectiveness and performance, *Industrial Marketing Management*, Vol. 36, No. 1, pp. 68-80, 2007. https://doi.org/10.1016/j.indmarman.2005.07.001

[34] TRAN, L.: *The factors affecting Logistics Service Quality - case study at Saigon New Port Logistics (SNPL)*, Vietnam, Bachelor's Thesis, International Business, [Online], Available: https://urn.fi/URN:NBN:fi:amk-201904084583 [2 Apr 2024], 2019.

[35] THAI, V.V.: Logistics service quality: conceptual model and empirical evidence, *International Journal of Logistics Research and Applications*, Vol. 16, No. 2, pp. 114-131, 2013. https://doi.org/10.1080/13675567.2013.804907

[36] KAMBLE, S.S., RAUT, R., DHUME, S.: *Validating the logistics service quality (LSQ) scale in Indian logistics industry*, International Conference on Business and Economics Research – Conference Proceedings, Vol. 1, pp. 81-85, 2011.

[37] KILIBARDA, M., ANDREJIĆ, M., POPOVIĆ, V.: Research in logistics service quality: A systematic literature review, *Transport*, Vol. 35, No. 2, pp. 224-235, 2020. https://doi.org/10.3846/transport.2019.11388

[38] PARASURAMAN, A., BERRY, L.L., ZEITHAML, V.A.: More on improving service quality measurement, *Journal of retailing*, Vol. 69, No. 1, pp. 140-147, 1993.

[39] OLIVER, R.L.: *Satisfaction: A Behavioral Perspective on the Consumer*, Boston, Irwin, 1997.

[40] OLIVER, R.L.: *Value as excellence in the consumption experience, Consumer value: a framework for analysis and research*, New York, Routledge, pp. 43-61, 1999.

[41] OLIVER, R.L.: *Customer Satisfaction*, Wiley International Encyclopedia of Marketing, 2010. https://doi.org/10.1002/9781444316568.wiem03008

[42] OLIVER, R.L.: *Satisfaction: A Behavioral Perspective on the Consumer*, M.E. Sharpe, 2010.

[43] LAI, F., GRIFFIN, M., BABIN, B.J.: How quality, value, image, and satisfaction create loyalty at a Chinese telecom, *Journal of Business Research*, Vol. 62, No. 10, pp. 980-986, 2009. https://doi.org/10.1016/j.jbusres.2008.10.015

[44] NGUYEN, N., LEBLANC, G.: Corporate image and corporate reputation in customers' retention decisions in services, *Journal of Retailing and Consumer Services*, Vol. 8, No. 4, pp. 227-236, 2001. https://doi.org/10.1016/S0969-6989(00)00029-1

[45] FOMBRUN, C.J., GARDBERG, N.A., SEVER, J.M.: The Reputation Quotient SM: A multi-stakeholder measure of corporate reputation, *Journal of brand management*, Vol. 7, No. 4, pp. 241-255, 2000.

[46] FU, X.M., ZHANG, J.H., CHAN, F.T.S.: Determinants of loyalty to public transit: A model integrating Satisfaction-Loyalty Theory and Expectation-Confirmation Theory, *Transportation Research Part A: Policy and Practice*, Vol. 113, pp. 476-490, 2018. https://doi.org/10.1016/j.tra.2018.05.012

[47] ALAM, M.M.D., NOOR, N.A.M.: The Relationship Between Service Quality, Corporate Image, and Customer Loyalty of Generation Y: An Application of S-O-R Paradigm in the Context of Superstores in Bangladesh, *SAGE Open*, Vol. 10, No. 2, pp. 1-19, 2020. https://doi.org/10.1177/2158244020924405

[48] RAFIQ, M., JAAFAR, H.S.: Measuring customers perceptions of logistics service quality of 3PL service providers, *Journal of Business Logistics*, Vol. 28, No. 2, pp. 159-175, 2007. https://doi.org/10.1002/j.2158-1592.2007.tb00062.x

[49] FERNANDES, D.W., MOORI, R.G., FILHO, V.A.V.: Logistic service quality as a mediator between logistics capabilities and customer satisfaction, *Revista de Gestão*, Vol. 25, No. 4, pp. 358-372, 2018. https://doi.org/10.1108/REGE-01-2018-0015

[50] LIU, C.-L., LYONS, A.C.: An analysis of third-party logistics performance and service provision, *Transportation Research Part E: Logistics and Transportation Review*, Vol. 47, No. 4, pp. 547-570, 2011. https://doi.org/10.1016/j.tre.2010.11.012

[51] HUMA, S., AHMED, W., IKRAM, M., KHAWAJA, M.I.: The effect of logistics service quality on customer loyalty: case of logistics service industry, *South Asian Journal of Business Studies*, Vol. 9, No. 1, pp. 43-61, 2020. https://doi.org/10.1108/SAJBS-10-2018-0114

[52] LI, L.: Assessing the relational benefits of logistics services perceived by manufacturers in supply chain,

International Journal of Production Economics, Vol. 132, No. 1, pp. 58-67, 2011.

[53] LIM, W.M., GUPTA, G., BISWAS, B., GUPTA, R.: Collaborative consumption continuance: a mixed-methods analysis of the service quality-loyalty relationship in ride-sharing services, *Electronic Markets*, Vol. 32, No. 3, pp. 1463-1484, 2022. https://doi.org/10.1007/s12525-021-00486-z

[54] ZAMEER, H., TARA, A., KAUSAR, U., MOHSIN, A.: Impact of service quality, corporate image and customer satisfaction towards customers' perceived value in the banking sector in Pakistan, *International Journal of Bank Marketing*, Vol. 33, No. 4, pp. 442-456, 2015. https://doi.org/10.1108/IJBM-01-2014-0015

[55] FUGATE, B.S., MENTZER, J.T., STANK, T.P.: Logistics performance: Efficiency, Effectiveness, and Differentiation, *Journal of Business Logistics*, Vol. 31, No. 1, pp. 43-62, 2010. https://doi.org/10.1002/j.2158-1592.2010.tb00127.x

[56] WANG, C.Y.: Service quality, perceived value, corporate image, and customer loyalty in the context of varying levels of switching costs, *Psychology & Marketing*, Vol. 27, No. 3, pp. 252-262, 2010. https://doi.org/10.1002/mar.20330

[57] FORSLUND, H.: The impact of performance management on customers' expected logistics performance, *International Journal of Operations & Production Management*, Vol. 27, No. 8, pp. 901-918, 2007. https://doi.org/10.1108/01443570710763822

[58] CRETU, A.E., BRODIE, R.J.: The influence of brand image and company reputation where manufacturers market to small firms: A customer value perspective, *Industrial Marketing Management*, Vol. 36, No. 2, pp. 230-240, 2007. https://doi.org/10.1016/j.indmarman.2005.08.013

[59] FARIA, N., MENDES, L.: Organizational image's partial mediation role between quality and users' satisfaction, *The Service Industries Journal*, Vol. 33, No. 13-14, pp. 1275-1293, 2013. https://doi.org/10.1080/02642069.2013.815733

[60] KANT, R., JAISWAL, D., MISHRA, S.: The Investigation of Service Quality Dimensions, Customer Satisfaction and Corporate Image in Indian Public Sector Banks: An Application of Structural Equation Model(SEM), *Vision*, Vol. 21, No. 1, pp. 76-85, 2017. https://doi.org/10.1177/0972262916681256

[61] KANG, A.S., JAYARAMAN, K., SOH, K.L., WONG, W.P.: Convenience, flexible service, and commute impedance as the predictors of drivers' intention to switch and behavioral readiness to use public transport, *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 62, pp. 505-519, 2019. https://doi.org/10.1016/j.trf.2019.02.005

[62] OGUNNOWO, B.E., SULE, S.S.: Measurement of Customer Perceptions of Logistics Service Quality, *Jurnal Teknik Industri*, Vol. 22, No. 1, pp. 43-56, 2021. https://doi.org/10.22219/JTIUMM.Vol22.No1

[63] KELLER, K.L.: Conceptualizing, Measuring, and Managing Customer-Based Brand Equity, *Journal of Marketing*, Vol. 57, No. 1, pp. 1-22, 1993. https://doi.org/10.1177/002224299305700101

[64] TAQI, I., MUHAMMAD, G.: Brand Loyalty and the Mediating Roles of Brand Image and Customer Satisfaction, *Market Forces*, Vol. 15, No. 1, pp. 101-119, 2020.

[65] DAM, S.M., DAM, T.C.: Relationships between service quality, brand image, customer satisfaction, and customer loyalty, *The Journal of Asian Finance, Economics and Business*, Vol. 8, No. 3, pp. 585-593, 2021. https://doi.org/10.13106/jafeb.2021.vol8.no3.0585

[66] EL MOUSSAOUI, A.E., BENBBA, B., EL ANDALOUSSI, Z.: Impact of logistics performance on the store image, consumer satisfaction and loyalty: a quantitative case study, *Arab Gulf Journal of Scientific Research*, Vol. 41, No. 3, pp. 226-239, 2023. https://doi.org/10.1108/AGJSR-09-2022-0201

[67] MARINA, S., PASHA, K., RICARDIANTO, P., OCTORA, T.Y., OLFEBRI, O., RAHMAWATI, A., SIANTURI, T.F.D., WIGUNA, E.S., SITORUS, P., ENDRI, E.: Corporate image and service quality: Evidence from Indonesia Mass Rapid Transport, *Uncertain Supply Chain Management*, Vol. 11, No. 3, pp. 1265-1274, 2023. http://dx.doi.org/10.5267/j.uscm.2023.3.021

[68] KELLER, K.L.: *Strategic branding management: building measuring, and managing brand equity*, New Jersey, Pearson Education, Inc, 2003.

[69] WIJAYA, B.S.: Dimensions of brand image: A conceptual review from the perspective of brand communication, *European Journal of Business and Management*, Vol. 5, No. 31, pp. 55-65, 2013.

[70] ABD EL SALAM, E.M., SHAWKY, A.Y., EL-NAHAS, T.: The impact of corporate image and reputation on service quality, customer satisfaction and customer loyalty: testing the mediating role. Case analysis in an international service company, *The Business & Management Review*, Vol. 3, No. 2, pp. 177-196, 2013.

[71] GANDHI, S.K., SACHDEVA, A., GUPTA, A.: Impact of service quality on satisfaction and loyalty at manufacturer-distributor dyad, *Journal of Advances in Management Research*, Vol. 16, No. 1, pp. 91-122, 2019. https://doi.org/10.1108/JAMR-12-2017-0120

[72] ÖZKAN, P., SÜER, S., KESER, İ.K., KOCAKOÇ, İ.D.: The effect of service quality and customer satisfaction on customer loyalty, *International Journal of Bank Marketing*, Vol. 38, No. 2, pp. 384-405, 2020.

https://doi.org/10.1108/IJBM-03-2019-0096

[73] CHOI, S.H.: The effect of logistics services, corporate image, product reliability & customer services on customer satisfaction and repurchase intention in e-commerce, *Journal of Digital Convergence*, Vol. 17, No. 6, pp. 159-167, 2019. https://doi.org/10.14400/JDC.2019.17.6.159

[74] HOSSAIN, M.A., YESMIN, M.N., JAHAN, N., KIM, M.: Effects of Service Justice, Quality, Social Influence and Corporate Image on Service Satisfaction and Customer Loyalty: Moderating Effect of Bank Ownership, *Sustainability*, Vol. 13, No. 13, pp. 1-13, 2021. https://doi.org/10.3390/su13137404

[75] KLINE, R.B.: *Principles and practice of structural equation modeling*, 5th ed., Guilford publications, 2023.

[76] BYRNE, B.M.: *Structural Equation Modeling With AMOS: Basic Concepts, Applications, and Programming*, 3rd ed., Routledge, New York, 2016.

[77] ARBUCKLE, J.L.: *IBM SPSS Amos 26 user's guide*, Amos Development Corporation, SPSS Inc, 2019.

[78] ZHAO, G., CHEN, H., LIU, S., DENNEHY, D., JONES, P., LOPEZ, C.: Analysis of factors affecting cross-boundary knowledge mobilization in agri-food supply chains: An integrated approach, *Journal of Business Research*, Vol. 164, No. September, pp. 1-20, 2023. https://doi.org/10.1016/j.jbusres.2023.114006

[79] WAHAB, S.N., RAJENDRAN, S.D., YEAP, S.P.: Upskilling and reskilling requirement in logistics and supply chain industry for the fourth industrial revolution, *LogForum*, Vol. 17, No. 3, pp. 399-410, 2021.

[80] ELLINGRUD, K., GUPTA, R., SALGUERO, J.: *Building the vital skills for the future of work in operations*, Eds. Sneader, K., Singhal, S., & Sternfels, B. What now, pp. 66-73, 2020.

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Optimization of strategic management of marketing and logistics of companies as part of the implementation of artificial intelligence
Hassan Ali Al-Ababneh, Safa Suliman Al-Olimat, Salem A. S. Alrhaimi, Ayed Moh'd Al Muala, Olga Popova, Valentyna Khrapkina

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Optimization of strategic management of marketing and logistics of companies as part of the implementation of artificial intelligence

Hassan Ali Al-Ababneh
Zarqa University, Department of Electronic Marketing and Social Media, 13132 Zarqa, Jordan, hassan_ababneh@zu.edu.jo (corresponding author)
Safa Suliman Al-Olimat
Al Al-Bayt University, Department of Civil Engineering, Mafraq, Jordan, P. O. Box 130040, 25110 Mafraq, Jordan, safasalolimat@aabu.edu.jo
Salem A. S. Alrhaimi
Sharjah Police Science Academy, P. O. Box 29, 31 Block F Street, 32223 Sharjah 2, United Arab Emirates, salrhaimi@psa.ac.ae
Ayed Moh'd Al Muala
Irbid National University, Department of E – Marketing and Social Communication, Irbid Amman International Road - Near Naima Triangle, 21110 Irbid, Jordan, a.almuala@inu.edu.jo
Olga Popova
Donetsk National Technical University, Department of Management and Financial and Economic Security, Potebny str. 56, 43003 Lutsk, Ukraine, olha.popova@donntu.edu.ua
Valentyna Khrapkina
National University of Kyiv-Mohyla Academy, Department of Marketing and Business Management, Skovorody 2, 04070 Kyiv, Ukraine, valentina_31@i.ua

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Abstract: The goal of the study is determining the key aspects of optimizing the strategic management of marketing and logistics of modern companies as part of the realization of artificial intelligence technologies. It has been determined that scaling a business and ensuring its profitability is possible by optimizing business processes and management strategies using the implementation of artificial intelligence technologies. The key aspects of automation of marketing and logistics management strategies of companies and their optimization based on the application of artificial intelligence technologies are substantiated. The main trends in the development of artificial intelligence technologies in the global economy are conceptualized. The evolution of artificial intelligence technologies in the world and its impact on the activities of companies is structured with an argument for the main directions and tools. It has been proven that the application of artificial intelligence into the marketing and logistics strategies of companies determines their transformational development and maximum optimization. To determine the key aspects of optimizing the strategic management of marketing and logistics of companies under the influence of artificial intelligence, multifactor correlation and regression analysis tools were used. The correlation between key indicators of marketing (sales volumes) and logistics (logistics efficiency index), their close relationship and an assessment of the impact of artificial intelligence technologies on the transformation of management strategies of modern companies has been determined. Theoretical and scientific-practical recommendations have been formed that are complete and reliable and can be applied in practice when optimizing the marketing and logistics management strategy companies.

1 Introduction

The evolution of the foundation and managing the business of companies in the conditions of transparency of global markets is due to the need to increase efficiency and profitability through the introduction of innovative artificial intelligence technologies. The growing share of innovative and information and telecommunication technologies in all spheres of the world economy creates a dependence of business segments on the intensity and speed of their evolution. Innovative technology stacks contribute to increased optimization and maximum automation of business processes of companies that are characterized by the use of artificial intelligence tools. Digital evolution increases the role of artificial intelligence technologies in organizing the activities of companies and their management, which makes them a conceptual factor of modification. Considering their implementation through the prism of strategic management of marketing and logistics, it should be noted that both marketing and logistics have undergone strong transformations in their conceptual components of management concepts. Which are determined by the development of digital channels of communication and interaction with consumers, promotion and service, optimization of monitoring processes and

transport management, machine learning, growth forecasting, transport routing and others, which confirms the relevance of this area and requires study that is more detailed. It is important to state that artificial intelligence today is an integral tool that has widespread and everyday use in the life of every person and business segments.

Artificial intelligence technologies are characterized by the ability to recognize speech and mastery of machine vision, which allows one to determine the basic parameters of a person (age, gender, emotionality and the value of a particular product or service). The capabilities of artificial intelligence technologies are expanding and improving every day, which confirms the relevance of this issue and the need for a detailed study and identification of key aspects of optimizing the strategic management of marketing and logistics of companies in contemporary circs. For constructive formation of the main aspects of strategic management of marketing and logistics of companies within the framework of the use of artificial intelligence technologies, it is necessary to evaluate the modification of business processes of companies from the point of view of justifying the evolutionary specifics of these technologies and their subsequent reflection in marketing and logistics tools. The interpretation of the features of strategic management of marketing and logistics and their modification based on the implementation of artificial intelligence technologies is relevant, in demand and requires detailed study to justify their practical implementation and further evolution.

1.1 Evolution of the theory of artificial intelligence and modification of marketing and logistics strategy management

The efficiency of the functioning of modern business is a priority and necessary through the prism of strategic goals and objectives, the implementation of which is possible only with the help of maximum optimization and automation in the ambush of artificial intelligence. The use of artificial intelligence technologies is because companies can achieve strategic business goals only through the prism of technological solutions that significantly simplify the management and decision-making process. Modern management solutions are mainly aimed at optimizing the activities of companies and developing technological solutions based on the use of artificial intelligence, which, first, significantly simplify strategic management and determine the efficiency and profitability of companies. The study of the evolution of artificial intelligence technologies and its impact on the functioning of a business, including its marketing and logistics activities, is in demand, which is confirmed by the variety of approaches and scientific hypotheses in this direction; the key ones should be argued.

A review of the theoretical background for the use of artificial intelligence technologies based on the integration of industry information is presented by Zhang, C. [1]. These approaches define the areas of application of artificial intelligence as the main effective mechanism that will contribute to the modification of the global economy. Attention is focused on the intensity of the processes of applying artificial intelligence technologies, but the conceptual trends in the development of artificial intelligence and its impact on the marketing and logistics of companies, which needs to be improved and studied in more detail, have not been studied. Bharadiya, J. [2], presents the argumentation of the premises of a comparative study of business analytics and artificial intelligence and their application in the analysis of large volumes of data. Business analytics a significant role in the management decision-making process and, for its reliability and accuracy, uses artificial intelligence technologies, which ensures the rapid collection and analysis of large volumes of data. Large volumes of data are typical for all areas of the company's activities, these prerequisites can serve as the basis for decision-making, the creation of a business intelligence system, but the essence and tendency in the evolution of the company is marketing, and logistics under the influence of artificial intelligence technologies have not yet been revealed. It was revealed that this approach requires improvement and further study.

A constructive approach to considering the use of artificial intelligence in business is presented by Feuerriegel, S. [3], which focuses on the obstacles to the implementation of these technologies and substantiates the need to delegate the management decision-making process to artificial intelligence technologies. Maximum automation of routine processes of companies is provided by artificial intelligence technologies and ensures their efficiency. The proposed aspects of delegation of the decision-making process are relevant in modern realities and will save time and resources of companies, but do not reveal its impact on the strategic management of marketing and logistics of companies, which requires the development of this approach through further research. Particular attention should be paid to the systematic literature review on the use of artificial intelligence tools in marketing and logistics, which is presented in the scientific article by Chintalapati, S. [4]. Digitalization has been stated, which is caused by the growing demand for the use of artificial intelligence technologies, which are a decisive mechanism for the prospects of business evolution. The main scientific works in the field of application of artificial intelligence technologies in marketing and logistics are substantiated, which can serve as a theoretical basis for studying this issue, but the transformation of these areas under the influence of artificial intelligence technologies is not disclosed, which determines the relevance and need for further study.

Features of using artificial intelligence technologies for B2B marketing and focusing on the problems and opportunities of their implementation are disclosed in the article by Dwivedi, Y. [5]. Aspects of stimulating innovation and using supply chain networks based on

artificial intelligence are substantiated, which significantly improves the quality of service and builds relationships with B2B clients. This approach reveals the main specific elements that allow you to improve your business through automation. It should be noted that the use of artificial intelligence technologies in the B2B business segment is disclosed, but the essence of the modification of marketing and logistics under their influence is not disclosed, which requires research.

Focusing on tendency in the introduction of electronic marketing in contemporary circs is revealed in the scientific research of Thakur, J., and others [6]. Consolidated the main aspects of the implementation of innovations and artificial intelligence technologies in marketing, which reveal the main aspects of implementation in marketing activities and can be used as practical recommendations. However, this approach does not reveal the main aspects related to the strategic management of marketing and logistics of modern companies, which requires detailed study and research.

The study of the features of the use of artificial intelligence in logistics systems and digital marketing strategies of companies is disclosed in the scientific approach of Ponomarenko, I. [7]. This sight is aimed at determining the impact on companies of the simultaneous use of logistics and digital marketing based on artificial intelligence when promoting and selling products in domestic and foreign markets. The proposed methodology used in this study includes statistical analysis of the dynamics of the logistics market and the artificial intelligence market, as well as specialized software for digital marketing. However, this approach does not cover the key aspects of strategic management of marketing and logistics of companies under the influence of artificial intelligence, which requires improvement and further study. Noteworthy is the study of Al-Ababneh, H. and others [8], which examines conceptual approaches to the digitalization of marketing and logistics of companies under the influence of innovation. This approach argues for the conceptual role of technology in the marketing and logistics strategy of modern companies, which is relevant and necessary when building a long-term development strategy. It is worth noting that this glance is aimed more at studying innovations and technologies in the context of digitalization of the marketing and logistics system, but does not determine the features of strategic management under the influence of artificial intelligence, which requires further study.

It is important to focus on studying the promising features of marketing development based on innovative technologies, which are presented by Adeola, O. and others [9]. This approach argues that the future evolution of companies' marketing and logistics is possible only through the introduction of artificial intelligence, virtual reality, demand forecasting, machine learning and neuromarketing technologies that contribute to the achievement of companies' strategic business goals. Based on this, it should be noted that this approach is relevant and can be applied in practice when forming a company's strategic plan.

However, it does not reveal the specifics of modification of marketing and logistics under the influence of artificial intelligence technologies, which requires further study. The use of artificial intelligence in today's realities is relevant and in demand, which is confirmed by many studies in this direction. Noting the theoretical aspects discussed, it should be noted that artificial intelligence and the technologies arising from it are maximally are scalable in the global economy, generating massive processes of modifications and changes that need to be identified and applied in strategic planning. Since the existence of business segments is impossible without marketing and logistics, it is therefore necessary to identify trends in marketing changes under the influence of artificial intelligence.

1.2 The evolution of artificial intelligence technologies and application features

The evolution of artificial intelligence plays a conceptual role in the global economy and is scaling into more and more new industries and areas of activity of companies, while creating innovative advantages that are generated by technology development trends in the field of artificial intelligence. Artificial intelligence is an innovative technology for creating programmed intelligent mechanisms and applications for a deeper understanding of human intelligence, which is not limited to biologically plausible methods. Based on this, it should be stated that the evolution of artificial intelligence and its key technologies contributes to maximum automation and optimization of business processes in various sectors of the global economy to achieve maximum results of strategic management. The evolution of artificial intelligence began as a result of decades of research and many scientific developments. It is important to note that from the first attempts to simulate human thinking on mechanical devices to modern achievements in the field of deep neural networks of artificial intelligence, a difficult path has been passed. Today, artificial intelligence technologies have learned to solve many complex problems, study and research, analyze huge amounts of information, recognize speech, temperature, sounds and create art.

The conceptual basis for the implementation and motivation for the development of artificial intelligence technologies is the availability, openness, reliability and sufficiency of information infrastructure, the quality of communication and Wi-Fi coverage, which will significantly increase the efficiency of the modification process of both marketing and logistics of companies. The use of artificial intelligence technologies requires huge amounts of data, which are filtered using system creation algorithms. It is important to note that implementation occurs because of models and machine learning, which are combined and reflected in artificial intelligence

technologies and its tools, programs that influence individual segments or the activities of companies as a whole [10]. To establish the demand for artificial intelligence technologies in modern business segments of the global economy, one should consider the conceptual directions of the evolution of artificial intelligence technologies in the world, which are presented in Table 1.

Table 1 Conceptual directions for the evolution of artificial intelligence technologies in the world

DIRECTIONS OF EVOLUTION	ARTIFICIAL INTELLIGENCE TECHNOLOGIES
HYPER-AUTOMATION OF COMPANY BUSINESS PROCESSES	Hyper-Automation is the use of innovative artificial intelligence technologies to automate company tasks. This direction is characterized by the following artificial intelligence technologies: Robotic Process Automation; Machine Learning; Automation of cognitive processes; Intelligent Business Process Management Software that optimizes operations and increases profitability.
CYBERSECURITY	Artificial intelligence technologies provide an evolution in approaches to organizing cybersecurity based on automation and risk-freeness through cloud-based data storage solutions and increasing the productivity of data volume technologies.
TECHNOLOGIES OF ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING IN IOT	Implementation of these technologies in the Internet of Things, which is aimed at automating the processes of recognizing sounds, temperature, movement, various changes from human health indicators to speech recognition and data management in order to maximize the automation.
ANALYTICAL FORECASTING AND DATA ANALYSIS	The use of mechanisms for forecasting and studying behavior in markets, database systems, which are based on artificial intelligence technologies.
AUGMENTED INTELLIGENCE	Technologies that combine automation and manual labor to provide companies with cognitive productivity. Collection, analysis, study, consolidation and management of data, which allows you to form the most reliable picture of the situation in a particular area.
TRANSPORT ROUTING AND INVENTORY MANAGEMENT	Artificial intelligence algorithms can optimize delivery chains, taking into account many factors affecting the restrictions on the movement of the supply chain. Artificial intelligence can analyze inventory and production data to optimize inventory levels and avoid overstocking or understocking.
FRAUD DETECTION	Machine learning algorithms can analyze transaction data and identify signs of fraud or security breaches in logistics operations.
DELIVERY TIME FORECASTING	Artificial intelligence can analyze data on transport routes and road conditions to accurately predict delivery times.

The presented directions for the introduction of artificial intelligence technologies can be applied in any industry and company activity. The emphasized features of the evolution of artificial intelligence technologies with the argumentation of the main directions of introduction of artificial intelligence technologies should highlight the features of their pressure on the strategic management of marketing and logistics of companies.

2 Methodology

Peer review process

Scaling innovation and keeping up with the times in business, taking into account ensuring a competitive position in the global market, is incomparable without the use of artificial intelligence technologies. Artificial intelligence has penetrated into all areas, developing all sectors of the global economy, including marketing and logistics. To substantiate the optimization of strategic management of marketing and logistics under the influence of artificial intelligence technologies, the study was based on the analytical collection and business analysis of data on the dynamics of indicators of the evolution of artificial intelligence in the business structure of companies: the use of artificial intelligence technologies in organizing a business, %; Average share of artificial intelligence technology capabilities used by businesses, %; Level of investment in artificial intelligence technologies, %; Share of artificial intelligence technologies in service maintenance, %; Share of artificial intelligence technologies in marketing, %; Logistics efficiency index for high-income countries (analysis was carried out on the logistics efficiency index of the UAE (United Arab Emirates)), Share of artificial intelligence technologies in production, %; Share of artificial intelligence technologies in strategic management, %.

The rationale for the modification and tactics of the influence of artificial intelligence on the strategic management of marketing and logistics of the current business is based on the use of tools of correlation and regression analysis and assessment of the influence of indicators of the evolution of artificial intelligence technologies in the business of companies on the efficiency indicators of marketing and logistics: Sales volume through digital marketing, trillion dollars. USA and Logistics Performance Index (LPI). To clarify the processes of modification of strategic management of marketing and logistics under the influence of artificial intelligence technologies, the use of multifactor correlation-regression analysis with a linear type of regression is justified. The following linear regression (1)

models were formed as the basis for a multifactor correlation and regression analysis of marketing modification under the pressure of artificial intelligence technologies:

$$Y = f\,(x, b) + \varepsilon \quad (1)$$

where, b - are the main attributes of the regression model; ε - random error of the regression model; is called linear regression if the regression function $f\,(x,\ b)$ has the following form (2):

$$f(x, b) = b_0 + b_1 x_1 + b_2 x_2 + \cdots + b_k x_k \quad (2)$$

where, b_j - main attributes of the regression model for modifying strategic management of marketing and logistics under the pressure of artificial intelligence technologies; x_j - regressors (artificial intelligence technologies) pressure the strategic management of marketing and logistics and their performance indicators.

The main attributes of the linear regression model justify the speed of optimization of strategic management of marketing and logistics, namely the performance indicators: Sales volume through digital marketing, trillions of dollars. USA and Logistics Performance Index (LPI), taking into account other factors of artificial intelligence technologies (3):

$$b_j = \frac{d_f}{dx_i} = const \quad (3)$$

Basic parameters b_0 in which there are no factors influencing performance indicators is a constant. In essence, this is the value of the optimization function for strategic management of marketing and logistics with a zero value of all artificial intelligence technologies. To interpret the results by default, the constant is the base parameter with "artificial intelligence technologies" equal to 1. However, if you resort the factor signs and parameters of the original regression model taking this into account (leaving the designation of the total number of factors influencing artificial intelligence technologies - k), then the linear a regression function without a constant should be expressed (4):

$$f(x, b) = b_0 + b_1 x_1 + b_2 x_2 + \cdots + b_k x_k = \sum_{j=1}^{k} b_j\, x_i = x^t b \quad (4)$$

where, $x^t = (x_1, x_2, \ldots x_k)$ - vector of model regressors, $b=(b_1, b_2, \ldots b_k)^t$ vector of model regressors (column with indicators of artificial intelligence technologies).

A linear model can be either with or without a constant. Then in this representation the first factor is either equal to one or is an ordinary factor, respectively. Having stated the above, it should be noted that to determine the optimization of strategic management of marketing and logistics under the pressure of artificial intelligence technologies, exactly the same tools were chosen to substantiate the close interdependence and influence of the factor characteristics of the regression model. Establishing the relationship between effective marketing and logistics performance and artificial intelligence technologies.

3 Result and discussion

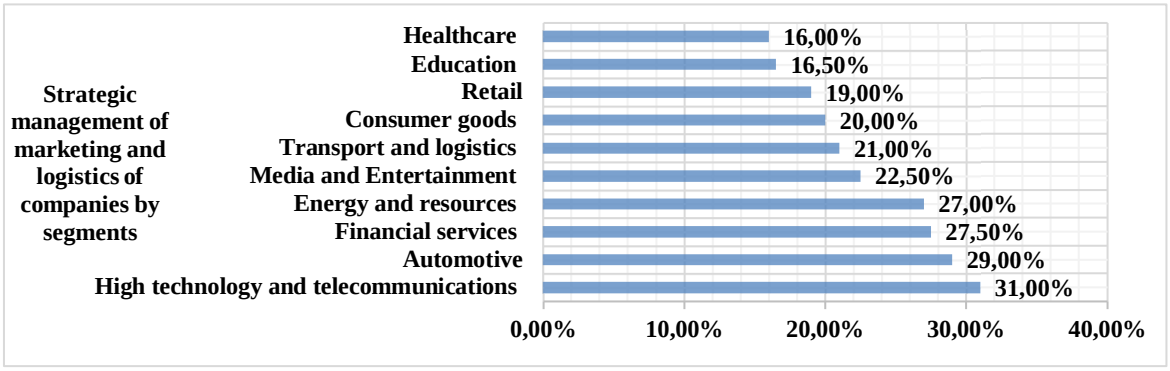
The evolution of management and increasing requirements for the functioning of business constructively determine improvement based on innovative technologies. Competition and the need to scale a business and expand its boundaries require companies to use artificial intelligence technologies that will ensure increased profitability, optimize business processes and increase market presence. It should be noted that artificial intelligence in the contemporary world is a set of technologies, algorithms and control systems that allow computers to perform complex business tasks, usually associated with the mental activity of people and mainly having their application for automating routine tasks, decision making, building processes and maximum optimization of business processes. The use of neural networks implemented on artificial intelligence is based on the use of algorithms and models adapted to decision-making based on the company's accumulated experience. Artificial intelligence technologies are opening up many benefits and opportunities for businesses, causing changes in the strategic management of marketing and logistics under their influence [12].

It is important to note that the optimization of strategic management of marketing and logistics is characterized by the fact that artificial intelligence technologies significantly improve the process of interaction with consumers, optimize promotion, advertising, analysis and study of competitors, while maximizing profitability, improve transport management processes, predicting demand and managing the supply chain.

To argue for the features of the organization and optimization of strategic management of marketing and logistics within the framework of the implementation of artificial intelligence technologies, the relationship between logistics and marketing should be considered. Based on this, it should be noted that marketing is a management system that allows you to adapt production to market requirements in order to ensure profitable sales of goods. Marketing was in demand due to the difficulties that arose with the sale of goods historically in an earlier period than logistics. In the middle of the 20th century [13]. The orientation of production towards the production of goods needed on the market and the use of marketing methods for studying demand and influencing demand turned out to be a decisive factor in increasing competitiveness. The task of creating systems that ensure end-to-end management of material flows was not relevant then, firstly, due to the lack of technical capabilities for building such systems in the economy, and secondly, due to the fact that through the use

of marketing techniques that were new for that time it was possible to dramatically go ahead. In modern conditions, the strategic management of a company cannot be based only on marketing. The demand identified by marketing must be met in a timely manner through fast and accurate delivery and logistics. Historically, having entered the economic arena in a later period, logistics complements and develops marketing, linking the consumer, transport and supplier into a mobile, technical, technological and economically planned system. Marketing monitors and determines the demand that has arisen, answers the questions: what product is needed, where, when, in what quantity and of what quality. Logistics ensures the physical movement of the in-demand commodity mass to the consumer. Logistics integration allows you to deliver the required product to the right place at the right time at minimal cost. Marketing poses the task of a systematic approach to the organization of product distribution; with the effective organization of product distribution, each of the stages of this process must be planned as an integral part of a well-balanced and logically constructed overall system. However, methods of technical and technological integration of all participants in the product distribution process are the main subject of study not of marketing, but of logistics. Marketing is focused on studying the market, advertising and their psychological impact on the buyer. Logistics is focused, first of all, on the creation of technically and technologically related systems for the delivery of materials along commodity distribution chains, as well as systems for monitoring their passage. Arguing the above, it is important to note that effective strategic management of current companies is only possible with integrated management of marketing and logistics as a single system, which should be based on the introduction of artificial intelligence technologies [14].

a)



b)

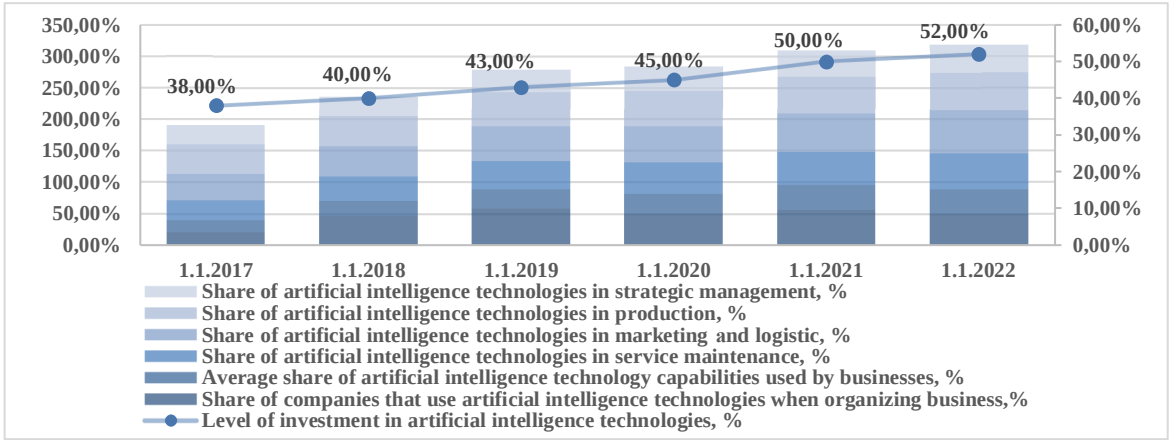


Figure 1 Artificial intelligence in the world, %: a) - the share of artificial intelligence in the strategic management of marketing and logistics of companies by segment as of 01.01.2023 in %; b) the evolution of artificial intelligence and strategic management of marketing and logistics

The intensive use of artificial intelligence technologies in almost all sectors of the global economy has not spared marketing and logistics. The use of such technologies often causes serious changes and optimization in the functioning of a particular industry; marketing and logistics are no exception. Based on this, it should be stated that the optimization of strategic management of marketing and logistics is mainly caused by neural networks based on artificial intelligence technologies and is aimed at optimizing marketing business processes through maximum automation. The effectiveness of artificial technologies is growing every day, which confirms their relevance and demand in business, regardless of industry and segment. It is necessary to consider the share of

artificial intelligence in the strategic management of marketing and logistics of companies by segment as of 01.01.2023 in %, as well as the dynamics of factor indicators of the use of artificial intelligence technologies, which will be assessed by their impact on the optimization of strategic management of marketing and logistics of companies (Figure 1).

Arguing what is presented in Figure 1, it is important to argue that strategic management of marketing and logistics is ahead of many industries in its development and the number of innovative tools used based on artificial intelligence technologies. Business processes of marketing and logistics that are subject to optimization based on artificial intelligence technologies are listed in the Table 2.

Table 2 Business processes of marketing and logistics that are subject to optimization based on artificial intelligence technologies

BUSINESS PROCESSES	DEFINITION MARKETING AND LOGISTICS OPTIMIZATION AND UNIQUENESS
PREPARING THE TEXT	Robotization of the process of writing or editing text, which is aimed at identifying errors, structure and essence, depending on the expectations and business goals.
RELEASE OF CONTENT	Using artificial intelligence technologies, image creation, background editing, contrast elements and quality improvement are ensured without manual manipulation.
CONTENT VISUALIZATION	The use of automated video release with the necessary material and prepared content.
ANALYTICAL COMPONENT OF MARKETING	Carrying out analytical work on data collection, consolidation, analysis and assessment of the target audience and the formation of personal proposals.
IMPROVEMENT OF COMMUNICATIONS	Creation of robotic assistants, chat bots, which provide efficiency in customer service and enormous savings in resources by automating service and sales.
ADVERTISING OPTIMIZATION	Collection of analytical data, consolidation and analysis of key segments of the target audience based on artificial intelligence with personal advertising programs.
SEARCH OPTIMIZATION	Automation of search algorithms based on query processing and their maximum personalization based on the expectations and preferences of the audience.
USER EXPERIENCE	Consolidation of data and study of analytics of user behavior patterns in order to improve interaction.
PERSONIFICATION	The use of technologies for studying preferences and needs in consumer behavior models in order to offer an individual approach to service and provision of services.
ROUTE OPTIMIZATION	Optimize the analysis of large amounts of data on traffic, weather conditions and other external factors to create the most efficient delivery routes. This reduces travel time and fuel costs.
WAREHOUSE AUTOMATION	Works and automated systems controlled by artificial intelligence can perform loading, unloading, sorting and packaging of goods. This improves order processing speed and reduces errors.
INVENTORY MANAGEMENT	Artificial intelligence systems can predict product demand by analyzing past sales data, market trends, and other factors. This allows companies to optimally manage inventory, reducing storage costs and the risk of stock-outs.

The use of this type of technology allows for the maximum modification of classical approaches to marketing and logistics into a more innovative digital form, which has a number of advantages and brings companies tremendous success by optimizing business processes, automation and increasing profitability. Artificial intelligence technologies lead to optimization of marketing and its components in terms of automation and optimization of routine processes [15]. Determining factor indicators for optimizing strategic management of marketing and logistics is impossible without identifying the connection and influence between effective indicators of marketing, logistics and indicators of the use of artificial intelligence technologies based on the method of statistical groupings [16]. For this purpose, indicators of the introduction of artificial technologies and their impact on the strategic management of marketing and logistics for the period from 01.01.2012 to 01.01.2022 were calculated and collected over time.

The presented direction for optimizing strategic management of marketing and logistics under the impact of artificial intelligence technologies is characterized by the fact that modern processes are fundamentally different from classical ones, which is due to the use of neural networks and maximum automation of business processes to achieve the strategic business goals of companies. When discussing the directions of strategic management of marketing and logistics under the impact of artificial intelligence technologies, it is advisable to conduct a correlation and regression analysis of their influence and assess the close relationship in optimization processes. To substantiate the dependence of strategic management of marketing and logistics and their optimization under the impact of artificial intelligence technologies, the method of correlation and regression analysis based on a linear trend was used.

Where, $У_1$ - Sales volume through digital marketing, trillion dollars. USA; $У_2$ - Logistics Performance Index (LPI). Digital Marketing Sales, Trillions of dollars. USA. - are characterized by the fact that they determine the level of effectiveness of marketing development through the implementation of translation technologies such as artificial intelligence. The introduction of artificial intelligence technologies determines the optimization of

marketing processes, increasing their efficiency and profitability.

The basis for assessing the impact of artificial intelligence technologies on the optimization of strategic management of marketing and logistics based on the methods of correlation and regression analysis are given in Table 3.

Table 3 Key performance indicators of marketing and logistics and optimization of their strategic management under the influence of artificial intelligence technologies for correlation and regression analysis

YEARS (STAGES OF MARKETING AND LOGISTIC OPTIMIZATION)	MARKETING / LOGISTIC PERFORMANCE INDICATORS		INDICATORS OF APPLICATION OF ARTIFICIAL INTELLIGENCE TECHNOLOGIES						
	y_1	y_2	X_1	X_2	X_3	X_4	X_5	X_6	X_7
01.01.2017	3307.00	3.40	20.0%	19.0%	38.0%	32.0%	42.0%	46.0%	31.0%
01.01.2018	3368.00	3.72	47.0%	23.0%	40.0%	39.0%	47.0%	48.0%	32.0%
01.01.2019	3351.00	3.94	58.0%	30.0%	43.0%	45.0%	55.0%	55.0%	36.0%
01.01.2020	4213.00	4.00	50.0%	31.0%	45.0%	49.5%	58.0%	56.0%	39.0%
01.01.2021	4921.00	4.10	56.0%	39.0%	50.0%	52.0%	61.0%	59.0%	41.0%
01.01.2022	5545.00	4.21	50.0%	38.0%	52.0%	57.0%	68.0%	61.0%	43.0%

The Logistics Performance Index (LPI) is a ranking index for benchmarking the performance of logistics systems around the world. compiled by the World Bank based on a worldwide survey of logistics operators that measures performance across a country's entire logistics supply chain. This index characterizes the weighted average assessment of the country according to six key parameters: the efficiency of the customs inspection process; quality of trade and transport infrastructure; ease of organizing supplies at competitive prices; competence and quality of logistics services; ability to track shipments and ensure timely delivery to destination within planned or expected delivery times [17]. This index allows you to directly determine the introduction of artificial intelligence technologies in various areas of logistics. which is determined by the level of optimization and efficiency of business processes. Based on what has been presented. these key indicators were selected to determine the main directions for optimizing strategic management of marketing and logistics under the impact of artificial intelligence.

It is important to state that by considering the main tendency in the introduction of artificial intelligence technologies in the strategic management of marketing and logistics of modern companies. the authors present the structural dynamics of the logistics efficiency index for 25 developed countries with high incomes. In the context of each group of structural indicators. the following are presented: customs clearance. which shows the degree of automation and optimality of business processes for processing documents by border control agencies. including customs; the quality of logistics infrastructure. which is characterized by the quality of trade and transport infrastructure of the analyzed countries. which depend on technology; the simplicity and cost of organizing supplies. the introduction of technologies and the level of routine of these processes; the quality of service provision and the ability to track and control cargo and timely delivery. which determines the level of automation and introduction of artificial intelligence technologies [18]. Structural dynamics of the logistics efficiency index for countries with developed economies and high income levels by category: customs clearance; quality of logistics infrastructure; the quality of service provision and the ability to track and control cargo and timely delivery are presented in Figure 2.

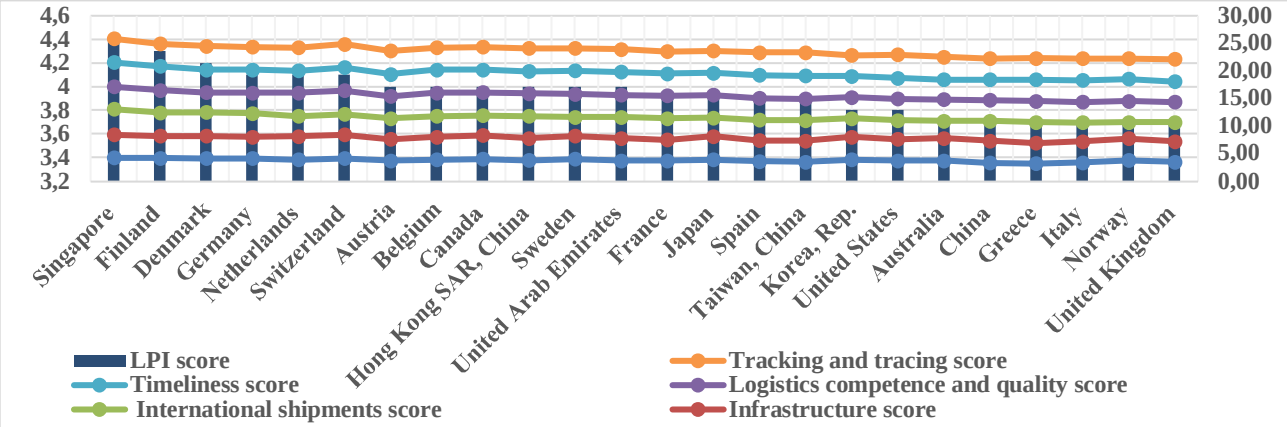


Figure 2 Structural dynamics of the logistics efficiency index for countries with developed economies and high-income levels by category as of 01.01.2023 [17]

Optimization of strategic management of marketing and logistics of companies as part of the implementation of artificial intelligence

Hassan Ali Al-Ababneh, Safa Suliman Al-Olimat, Salem A. S. Alrhaimi, Ayed Moh'd Al Muala, Olga Popova, Valentyna Khrapkina

From what is presented. it should be noted that all countries are almost in the same range. and the efficiency of logistics depends on the dynamics of its structural indicators. which are presented. However. this logistics performance index fully reveals all aspects of strategic management of marketing and logistics of companies as a whole. which requires an assessment and identification of key aspects for their optimization.

The closeness of the relationship and impact on the presented conceptual indicators of marketing and logistics will be determined by the basic areas of introduction of artificial intelligence technologies in the strategic management of modern companies. namely: X_1- Share of companies that use artificial intelligence technologies when organizing business %; X_2 - Average share of artificial intelligence technology capabilities used by businesses %; X_3 - Level of investment in artificial intelligence technologies %; X_4 - Share of artificial intelligence technologies in service maintenance %; X_5 - Share of artificial intelligence technologies in marketing and logistic %; X_6 - Share of artificial intelligence technologies in production %; X_7 - Share of artificial intelligence technologies in strategic management %.

Conducting correlation and regression analysis on the presented factor indicators. which have a close relationship with strategic management. marketing and logistics of modern companies. to ensure the identification of key areas of optimization and indicators that have a significant impact on key business processes. Based on the presented basic data. a correlation-regression analysis was carried out based on trend analysis. which will allow us to determine the impact of factor indicators on the use of artificial intelligence technologies and their impact on the modification of marketing based on correlation matrices. Correlation matrix of the impact of artificial intelligence technologies on marketing modification (resultative indicator - Sales volume through digital marketing, trillion US dollars) Table 4.

Table 4 Correlation matrix of the impact of artificial intelligence technologies on the strategic management of marketing and logistics of companies (resulting indicator – Sales volume through digital marketing tools, trillion US dollars)

	y_1	X_1	X_2	X_3	X_4	X_5	X_6
y_1	1						
X_1	0.974022	1					
X_2	0.9625	0.96381	1				
X_3	0.958046	0.970364	0.993479	1			
X_4	0.98014	0.962456	0.981149	0.986388	1		
X_5	0.968405	0.980309	0.980754	0.984226	0.984398	1	
X_6	0.872829	0.956764	0.884635	0.89657	0.860794	0.926518	1

This matrix made it possible to highlight indicators of the introduction of artificial intelligence technologies in the strategic management of companies in terms of marketing business processes. Based on the results of this correlation. the most influential aspects of the introduction of artificial intelligence technologies will be argued in order to consider them in the future when optimizing the business processes of companies. Correlation matrix of the impact of artificial intelligence technologies on the strategic management of marketing and logistics of companies (the resulting indicator is the Logistics Efficiency Index (for the analysis, the dynamics of the LPI for the United Arab Emirates was selected) Table 5.

Table 5 Correlation matrix of the impact of artificial intelligence technologies on the strategic management of marketing and logistics of companies (the resulting indicator is the Logistics Efficiency Index (for the analysis, the dynamics of the LPI for the United Arab Emirates)

	y_2	X_1	X_3	X_4	X_5
y_2	1				
X_1	0.7396334	1			
X_3	0.73994308	0.962499	1		
X_4	0.695969	0.958045	0.970364	1	
X_5	0.7262631	0.980140	0.962456	0.98119	1

As presented. the LPI is an interactive benchmarking tool designed to help countries identify the challenges and opportunities they face in their trade logistics activities and what they can do to improve their performance. It is important to note that the LPI includes quantitative data on the performance of key supply chain components in countries. Thus. the LPI consists of both qualitative and quantitative indicators and helps create logistics profiles for these countries. It measures performance along a country's logistics supply chain and offers two different perspectives: international and domestic [19].

The most significant indicators (more than 0.55) of the evolution of artificial intelligence and its application in the strategic management of marketing and logistics to optimize key business processes were selected. The correlation between indicators of the modification of artificial intelligence technologies confirmed the hypothesis about their impact and connection with the

transformation and optimization of strategic management processes of marketing and logistics of modern companies. Interpretation of the results of correlation and regression analysis of optimization of strategic management of marketing and logistics of companies as part of the introduction of artificial intelligence technologies is presented in Table 6.

Table 6 Interpretation of the results of correlation and regression analysis of optimization of strategic management of marketing and logistics of companies within the framework of the introduction of artificial intelligence technologies

<table>
<tr><th rowspan="2">INDICATORS OF APPLICATION OF ARTIFICIAL INTELLIGENCE TECHNOLOGIES</th><th colspan="2">PERFORMANCE INDICATORS OF STRATEGIC MANAGEMENT OF MARKETING AND LOGISTICS</th><th rowspan="2">THE CLOSENESS OF THE RELATIONSHIP AND ASSESSMENT OF THE IMPACT ON THE OPTIMIZATION OF STRATEGIC MANAGEMENT OF MARKETING AND LOGISTICS OF COMPANIES</th></tr>
<tr><th>y_1</th><th>y_2</th></tr>
<tr><td>X_1</td><td rowspan="6">Strong connection and influence</td><td>Strong connection and influence</td><td>Artificial intelligence directly contributes to the optimization of business processes for managing the marketing and logistics of companies. The implementation of technologies simplifies processes. increasing their efficiency and rational use of resources.</td></tr>
<tr><td>X_2</td><td>Low connection and influence</td><td>Optimization of business processes for strategic management of marketing and logistics based on the implementation of artificial intelligence technologies has a close connection and dependency. An increase in the share of technologies and their implementation in the marketing and logistics of companies directly leads to an increase in efficiency. throughput in servicing. delivery and provision of services.</td></tr>
<tr><td>X_3</td><td rowspan="3">Strong connection and influence</td><td rowspan="3">Growing investments in artificial intelligence technologies directly affect the strategic management of marketing and logistics of companies. This is due to the increase in automation of routine business processes. improvement in quality. service and speed of service provision. delivery and order tracking.</td></tr>
<tr><td>X_4</td></tr>
<tr><td>X_5</td></tr>
<tr><td>X_6</td><td rowspan="2">Low connection and influence</td><td rowspan="2">Artificial intelligence in production and strategic management of marketing and logistics has its impact on processes and their optimization. but has a close relationship that depends on the type of activity and business segment. Artificial intelligence is not intensively used in all industries. which is explained by the specificity and complexity and versatility of the process that is subject to optimization.</td></tr>
<tr><td>X_7</td><td>Low connection and influence</td></tr>
<tr><td>MULTIPLE CORRELATION COEFFICIENT</td><td>0.987</td><td>0.863</td><td>X</td></tr>
</table>

Interpretation of the results of correlation-regression analysis of optimization of strategic management of marketing and logistics of a company under the influence of the introduction of artificial intelligence technologies allows us to confirm the hypothesis put forward. It should be noted that the proposed hypothesis for assessing the impact of artificial intelligence technology implementation indicators on the strategic management of marketing and logistics provided confirmation of the advanced theoretical assumptions on the impact. closeness of communication and their significance. It is important to note that based on the obtained multiple correlation coefficients of interdependence and close influence of artificial intelligence technologies on the optimization of strategic management of marketing and logistics confirm the accuracy and reliability of the results obtained [20,21]. The proposed approach will allow us to argue for the need and determine tendency in the introduction of artificial intelligence technologies in the strategic management of marketing and logistics of companies. in contrast to existing ones. it determines the main directions for optimizing the business processes of marketing and logistics. and identifies the key tools that ensure their transformation from the classical concept to the digital one. The interpreted results can be applied in practice by highlighting the factors impact business strategy. followed by their analysis and emphasis when forming a marketing and logistics strategy and planning the optimization of companies' business processes.

The relevance of using artificial intelligence technologies in all sectors of the world economy is justified by the conceptual need to search for new and improve existing management methods. A hypothesis has been put forward to assess the impact of artificial intelligence technologies on the optimization of strategic management of marketing and logistics based on indicators of the use of these technologies in the world and their interpretation in the economic development of countries. The proposed methodology for correlative-regression analysis of assessing the relationship. impact and main factors of optimizing the strategic management of marketing and logistics. Within the framework of the implementation of artificial intelligence technologies is in demand and applicable taking into account the purpose of the study. but

can be supplemented and improved depending on the focus of the problem and the tasks set. The justification of factor indicators for the modification of artificial intelligence technologies is conceptual and based on data from the World Bank and analytical reports in the field of organizing and managing the effectiveness of marketing and logistics of companies in the world. but is not an exhaustive list. which can be supplemented or shortened as part of further research using tools correlation and regression analysis or other methods and tools for conducting economic and statistical analysis and modeling. The results obtained provided confirmation of the put forward theoretical premises and hypotheses with justification for the type of relationship. closeness and interdependence. as well as the characteristics of the influence on the optimization of strategic management of marketing and logistics of companies within the framework of the introduction of artificial intelligence technologies. The developed approaches are in demand in modern conditions of global market volatility and the need for constant optimization of business processes and maximum scaling with minimal costs in order to maximize profitability at a normalized level of risks.

4 Conclusions

The main results of the study are characterized by the fact that the need to improve and optimize modern mechanisms for strategic management of marketing and logistics of companies is stated. which substantiates the demand for artificial intelligence and its spread to all spheres of human life. A critical analysis and study of scientific approaches and research in the field of marketing and logistics made it possible to verify that the evolution and application of artificial intelligence. as well as the optimization of marketing and logistics management processes require improvement and more detailed study to determine key aspects and algorithms. A classification of the main directions for the revolutionary development of artificial intelligence technologies in the world has been developed. focusing on the technologies themselves and the key industries where they have their practical application.

The evolution of artificial intelligence technologies and its introduction in the industry and segment of the global economy are revealed. It is substantiated that in most cases. the introduction of artificial intelligence technologies is focused and aimed at strategic management of company processes. including marketing and logistics. It is argued that the introduction of artificial intelligence technologies has a positive impact on the business processes of marketing and logistics and leads to their maximum automation of routine work and optimization. In order to evaluate the evolution of artificial intelligence and its impact on the strategic management of marketing and logistics of companies and more aspects of their optimization to justify the close relationship and impact of artificial intelligence. tools of correlation and regression analysis were used.

These tools are relevant and in demand in contemporary circs. which are characterized by their versatility and the possibility of application regardless of the field of scientific research. The construction of regression models and their dependence on factor indicators ensures the creation of mathematical models depending on the indicators. their close impact and significance. Key indicators of strategic management of marketing and logistics have been determined (sales volumes using digital marketing and logistics efficiency index). Data on the implementation of artificial intelligence technologies in the world in the context of industries and tools are formulated as factor indicators. Interpretation of the main results of correlation and regression analysis provided evidence that the introduction of artificial intelligence technologies in marketing and logistics processes and their strategic management have a direct impact and contribute to constant transformations and optimizations in order to minimize costs. improve the quality of service and the speed of service and logistics. The developed methodology can be used in practice when planning stages of optimization of strategic management of marketing and logistics of companies as part of the introduction of artificial intelligence technologies.

The formed theoretical aspects of the introduction of artificial intelligence can serve as the basis for studying the evolution of their development. The introduction of these technologies and the argumentation of key indicators can be taken as basic indicators for prospective assessment of their impact on the strategic management of companies. regardless of the type and specificity of activity. The results obtained are a completed study. which is confirmed by the accuracy and reliability of the results obtained. which can be used in practice.

References

[1] ZHANG, C., LU, Y.: Study on artificial intelligence: The state of the art and future prospects, *Journal of Industrial Information Integration*, Vol. 23, 100224, pp. 1-9, 2021. https://doi.org/10.1016/j.jii.2021.100224

[2] BHARADIYA, J.: A Comparative Study of Business Intelligence and Artificial Intelligence with Big Data Analytics, *American Journal of Artificial Intelligence*, Vol. 7, No. 1, pp. 24-30, 2023. https://doi.org/10.11648/j.ajai.20230701.14

[3] FEUERRIEGEL, S., SHRESTHA, Y., VON KROGH, G., ZHANG, C.: Bringing artificial intelligence to business management, *Nature Machine Intelligence*, Vol. 4, No. 7, pp. 611-613, 2022. https://doi.org/10.1038/s42256-022-00512-5

[4] CHINTALAPATI, S., PANDEY, S.: Artificial intelligence in marketing: A systematic literature review, *International Journal of Market Research*, Vol. 64, No. 1, pp. 38-68, 2022. https://doi.org/10.1177/14707853211018428

[5] DWIVEDI, Y., WANG, Y.: Guest editorial: Artificial intelligence for B2B marketing: Challenges and opportunities, *Industrial Marketing Management*, Vol. 105, pp. 109-113, 2022. https://doi.org/10.1016/j.indmarman.2022.06.00

[6] THAKUR, J., KUSHWAHA, B.: Artificial intelligence in marketing research and future research directions: Science mapping and research clustering using bibliometric analysis, *Global Business and Organizational Excellence*, Vol. 43, No. 3, pp. 139-155, 2024. https://doi.org/10.1002/joe.22233

[7] PONOMARENKO, I., PONOMARENKO, D.: AI-Powered Logistics and Digital Marketing for Business Optimisation, *Economics & Education*, Vol. 8, No. 4, pp. 27-33, 2023. https://doi.org/10.30525/2500-946X/2023-4-4

[8] AL-ABABNEH, H.A., DALBOUH, M.A.A., ALRHAIMI, S.A.S., SIAM, I.M., IBRAGIMKHALILOVA, T.: Digitalization, innovation and marketing in logistics, *Acta logistica*, Vol. 10, No. 4, pp. 615-624, 2023. https://doi.org/10.22306/al.v10i4.440

[9] ADEOLA, O., EVANS, O., NDUBUISI EDEH, J., ADISA, I.: *The Future of Marketing: Artificial Intelligence, Virtual Reality, and Neuromarketing*, In: Adeola, O., Hinson, R.E., Sakkthivel, A.M. (eds) Marketing Communications and Brand Development in Emerging Economies Volume I., Palgrave Studies of Marketing in Emerging Economies, Palgrave Macmillan, Cham., Vol. 1, pp. 253-280, 2022. https://doi.org/10.1007/978-3-030-88678-3_12

[10] DOGRA, P., KAUSHAL, A.: The impact of Digital Marketing and Promotional Strategies on attitude and purchase intention towards financial products and service: A Case of emerging economy, *Journal of Marketing Communications*, Vol. 29, No. 4, pp. 403-430, 2023. https://doi.org/10.1080/13527266.2022.2032798

[11] ENHOLM, I., PAPAGIANNIDIS, E.: Artificial intelligence and business value: A literature review, *Information Systems Frontiers*, Vol. 24, No. 5, pp. 1709-1734, 2022. https://doi.org/10.1007/s10796-021-10186-w

[12] SCHIESSL, D., DIAS, H., KORELO, J.: Artificial intelligence in marketing: A network analysis and future agenda, *Journal of Marketing Analytics*, Vol. 10, No. 3, pp. 207-218, 2022. https://doi.org/10.1057/s41270-021-00143-6

[13] MARIANI, M.M., MACHADO, I., MAGRELLI, V., DWIVEDI, Y.K.: Artificial intelligence in innovation research: A systematic review. conceptual framework, and future research directions, *Technovation*, Vol. 122, 102623, pp. 1-25, 2023. https://doi.org/10.1016/j.technovation.2022.102623

[14] CHINTALAPATI, S., PANDEY, S.: Artificial intelligence in marketing: A systematic literature review, *International Journal of Market Research*, Vol. 64, No. 1, pp. 38-68, 2022. https://doi.org/10.1177/14707853211018428

[15] KSHETRI, N., DWIVEDI, Y.K., DAVENPORT, T.H., PANTELI, N.: Generative artificial intelligence in marketing: Applications, opportunities, challenges, and research agenda, *International Journal of Information Management*, Vol. 75, No. April, 102716, pp. 1-10, 2024. https://doi.org/10.1016/j.ijinfomgt.2023.102716

[16] SCHIESSL, D., DIAS, H.B.A., KORELO, J.C.: Artificial intelligence in marketing: a network analysis and future agenda, *Journal of Marketing Analytics*, Vol. 10, No. 3, pp. 207-218, 2022. https://doi.org/10.1057/s41270-021-00143-6

[17] LO STORTO, C., EVANGELISTA, P.: Infrastructure efficiency. logistics quality and environmental impact of land logistics systems in the EU: A DEA-based dynamic mapping, *Research in Transportation Business & Management*, Vol. 46, 100814, pp. 1-19, 2023. https://doi.org/10.1016/j.rtbm.2022.100814

[18] WOSCHANK, M., RAUCH, E., ZSIFKOVITS, H.: A review of further directions for artificial intelligence. machine learning. and deep learning in smart logistics, *Sustainability*, Vol. 12, No. 9, 3760, pp. 1-23, 2020. https://doi.org/10.3390/su12093760

[19] ROSENDORFF, A., HODES, A., FABIAN, B.: Artificial intelligence for last-mile logistics-Procedures and architecture, *Online Journal of Applied Knowledge Management*, Vol. 9, No. 1, pp. 46-61, 2021.

[20] YANG, B., HUANG, Z.: *The application research of artificial intelligence in logistics field*, 2021 International Conference on Intelligent Computing, Automation and Applications (ICAA), Nanjing, China, pp. 203-208, 2021. https://doi.org/10.1109/ICAA53760.2021.00043

[21] KALKHA, H., KHIAT, A., BAHNASSE, A., OUAJJI, H.: The rising trends of smart e-commerce logistics, *IEEE Access*, Vol. 11, pp. 33839-33857, 2023. https://doi.org/10.1109/ACCESS.2023.3252566

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Working from abroad - workation as a mobility flow benefit
Michal Beno, Dagmar Caganova, Bohdana Bobinics

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Working from abroad - workation as a mobility flow benefit

Michal Beno
Prague City University, School of Business, Hybernská 24, 110 00 Nové Město, Czech Republic, EU, michal.b@praguecityuniversity.cz (corresponding author)
Dagmar Caganova
Newton University, 5. května 1640/65, 140 00 Praha 4, Czech Republic, EU, dagmar.caganova@newton.university
Bohdana Bobinics
Technical University of Košice, FBERG, Institute of Logistics and Transport, Park Komenského 14, 042 00 Košice, Slovak Republic, EU, bohdana.bobinics@tuke.sk

Keywords: Austria, e-working, mobility flow, workation, working method.
Abstract: This paper explores the status quo of the concept workation in Austria among business executives. The objective of this quantitative study is to gain an understanding of this dislocated work form. The following research questions were set to find answers to: 1) What is the status quo of the workation in Austria in times of multiple crises? and 2) Will the workation help employers to retain their workforce? Based on the data, for managers workation means recharging one's batteries and at the same time working productively and efficiently. Additionally, this survey illustrates a possible way that organisations can retain the talent on their teams. Organisations offering workations accept that their managers and workforce will be out of the office for a while. Most managers stay away for less than a week. Three reasons given by managers to explain why the workation is a success are: 1) an increase in job satisfaction, 2) an increase in productivity and 3) improved work-life balance. We tested our hypotheses in a survey study of 178 respondents in Austria. H1.4, H2 and H3 were supported. The paper concludes with a discussion of whether workations will continue to be important for employers and employees in the future.

1 Introduction

The existence of work went through some tectonic changes including the place where work can be conducted, from traditional to Taylorist cubicles [1]. Research demonstrates that e-work has been shown to be an enabler of work-life balance [2]; but research is uncertain about whether e-work has beneficial or unfavourable effects [3-4].

Uriely [5] distinguished between travelling workers and working tourists in terms of their work characteristics and their demographic profile. Cohen [6] described working holidays as a form of tourism "in which youth from one country travel into another to work for short periods, mostly during summer school vacations". The boundaries between leisure and work are blurring. In addition to the much-cited COVID-19 crisis, there are a) pull and b) push factors regarding the popularity of e-work:

a) increased productivity, time saving, less or no commuting, better work-life balance;
b) inadequate office infrastructure, noise, distraction, toxic work culture [7].

Modern digital tools provide exemplary perceptions into human patterns of mobility including workflow. The elaboration and application of such data are tantamount to gaining a reasoned advantage in today's data-driven society. The movements of human beings within and among urban centres influence essential aspects of society. Generally, traffic congestion, migration flows, the spread of infectious diseases "are processes in which the presence of mobility flows induces a net change of the spatial distribution of some quantity of interest" [8]. Measuring human mobility is critical to understanding population wellbeing [9].

As a consequence, an interesting area of analysis is the initiative of some organisations to consider the expansion of workations. More specifically, this paper will try to find answers to the following research questions:

1. What is the status quo of the workation in Austria in times of multiple crises?
2. Will the workation help employers to retain their workforce?

2 Literature review

The workation seems to be the beginning of a post-Covid era where remote work meets vacation (yielding a portmanteau word from "work" and "vacation") or as mentioned by Yoshida [10] "a neologism combining the words 'work' and 'vacation' ". Pecsek [11] defines workations as "a hybrid type of tourism when tourists travel for either leisure or dual (business and leisure) motive and due to the modern technology, they perform both work and leisure activities away from home". It is a combination of work and vacation for a fixed interval that encompasses both work time and leisure time. The distinction between "workationing" and "e-working" is focused on the amount of time spent on a workation versus

working remotely. The e-worker works entirely off-site (commonly at a fixed location), whereas the workationer works remotely on a short-term trip. To sum up, the workation is characterised by the performance of work from a holiday locality on an uninterrupted cause with different workable amounts of time without consuming holidays or other forms of paid leave and without any pay cut.

The office as a place of work evolved into having a more specific function. It can be seen as a spatial interface for a team where people meet for informal conversations, personal exchanges or to hold creative meetings. The home office is the place where you can work undisturbed and can therefore concentrate better. Working in the digital age requires these important skills that need to be developed: dealing with a flood of information, boundary management, digital-social collaboration and maintaining a work-life balance. The temporal and spatial flexibility of knowledge and office work means that new places are opening up where professional activities can be pursued. In 2022, the holiday travel intensity of the Austrian population was 75.5%, with 10.58 million holiday trips made abroad, and 3.06 million trips for business purposes [12].

3 Methodology

In order to find the answers to these research questions, a quantitative study using a Google form was undertaken. The study was conducted between 1 June and 30 August 2023. The distribution of e-questionnaires was done via email and WhatsApp. The respondents accessed an online survey through a link specifically set up for this research [13]. As Glazier & Topping [14] highlighted, "social media is a powerful tool that can be used to build connections and share information." Data collection through this remote online platform is feasible, safe and very convenient [15].

The e-survey was sent to 354 organisations across Austria where e-work can be done, and we received 256 responses. After deleting incomplete responses and no-variance responses, we had a final sample of 178 respondents (usable response rate: 50.28%).

Four out of 10 managers were from to the top management with men dominant. Women dominated on the middle and low management levels. Among the managers, 37.64% (67) were female and 62.36% (111) male. Generation Millennials (Generation Y) dominated with 68.54% of respondents, followed by Generation X with 25.84%, Generation Z with 5.06% and 0.56% of Boomers II. The average age of respondents was 37,1 years as shown in Figure 1 (the youngest manager was 27 years old and the oldest was 60).

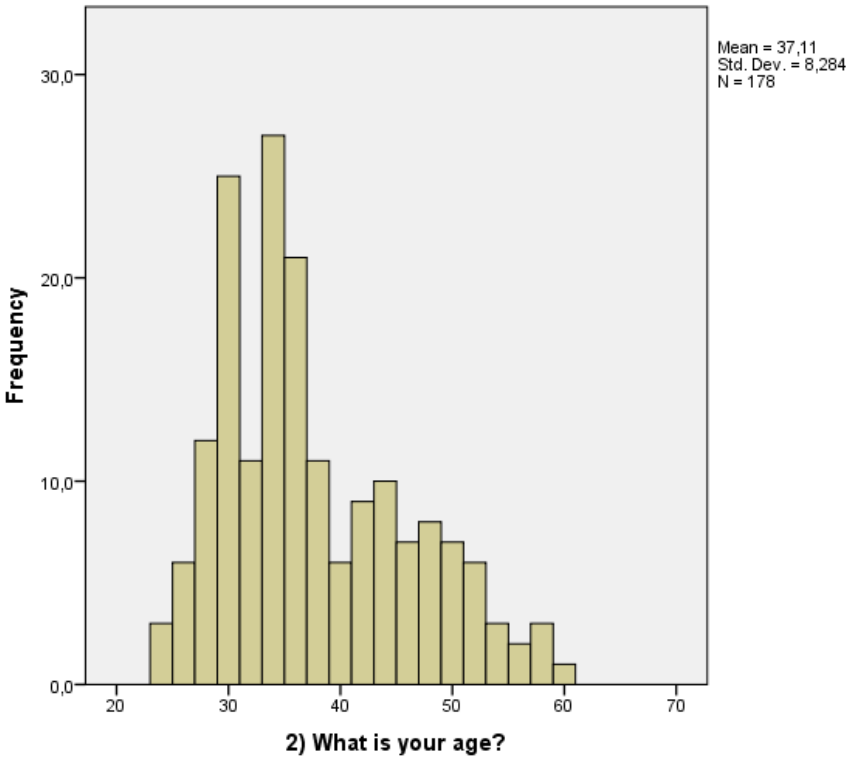

Figure 1 Age of respondents

Male managers were more frequently single than were their female counterparts. But 41.79% of female managers were married, compared to 36.27% of men. Overall, 26.4% of managers had obtained secondary education; with 25.3% with a bachelor's degree and 32% with a master's degree. A total of 115 (64.6%) managers out of 178 respondents were childless.

All participating managers were informed of the purpose of the study and assured that responses would be confidential. Participation was voluntary. The questions were posed using an online questionnaire to evaluate the status quo of workations in Austria from the point of view of managers. Questions were rated on a dichotomous (yes/no), 5-point Likert-type scale (consideration) from positive to critical. Two open ended questions were included, and periodicity of workations (from less than one week to two months or more) was taken into reckoning. A cross-tabulation analysis was used. The results obtained were investigated by means of statistics software.

The sample was a heterogeneous group of managers working in the service sector, including customer service, marketing, startups, e-commerce, IT, recruiting and business to business.

4 Results

In the modern working world and the alternative ways of working without human contact, the workation is getting a facelift. Whether it is known as a workation, workcation, worcation, workoliday, woliday or some other term, it simply means working during a vacation. A total of 45.5% (81) out of all managers were able to do a workation, compared with 34.3% (61 managers) who had no experience of this. A total of 20.2% of managers (36) are willing to work in this way in the future (Table 1).

Table 1 Do you allow your workforce workations?

	n	%
No	**61**	**34.3**
Not yet, but will	**36**	**20.2**
Yes	**81**	**45.5**
Total	**178**	**100**

Organisations globally have been forced to come up with strategies to cope with shortages of skilled workforce. They have to compete harder for a smaller pool of talent and spend more time and funds on hiring. For this reason, the authors were interested in identifying this tool as a hiring strategy among managers. A total of 65.5% (117) of managers would like to implement this in communication in recruiting. More than three fifths of managers consider the workation as positive and rather positive. Only 22.5% see this flexibility tool as critical as demonstrated in the next table (Table 2).

Table 2 How are workations viewed by employees?

	n	%
positive	**64**	**36.0**
rather positive	**43**	**24.2**
neither positive nor negative	**10**	**5.6**
critical	**40**	**22.5**
no data available	**20**	**11.2**
prefer not to say	**1**	**0.6**
Total	**178**	**100**

The success or failure of a workation team hinges on whether everybody feels included. A total of 49 (60.5%) out of 81 managers regarded the team workation as very positive and 32 (39.5%) as positive. It seems that by implementing a workation, managers created an optimal learning experience for everybody by building and managing their team. Crafting an effective workation strategy begins by emphasising whatever is working, adjusting whatever is not working and adapting the strategy as lessons are learned. The greatest challenges of this flexible working approach according to managers (n=117) include organisational (36.8%), legal (23.1%), taxes (19.7%), childcare (11.1%) and data protection (9.4%). But the workation is creating a need for better coordination both at work and on holiday, since both are remote-capable collaboration stations. Organisations must cope with non-essential workforce completing their work not only from home but also on holiday. Shifting from working in an office to a holiday location is a change. How long should we work from the holiday destination? The majority of the 117 managers prefer less than one week (35.9%), almost three tenths would prefer 1-2 weeks and more than one sixth 3-4 weeks. Interestingly, few managers would prefer a workation of over a month (11) or two or more months (7). Possible explanations may be that the hardest part of a workation is the loneliness and lack of social interaction between team members.

Generally, everything is about balance. A workation schedule becomes beneficial, creating a balance between all motivations and satisfying the needs of managers, including the freedom that they need for productivity. The three reasons why the workation works best (Table 3), according to managers, are: 1) increase in job satisfaction (31.6%), 2) increase in productivity (29.1%) and 3) improved work-life balance (17.9%).

Table 3 What are top three reasons to implement workations?

Top 1	n	%	Top 2	n	%	Top 3	n	%
Increased job satisfaction	**37**	**31.6**	Positive impact on employees' physical health	**16**	**13.7**	Increased work-life balance	**21**	**17.9**
Increased productivity	**34**	**29.1**	Breaking the daily routine	**15**	**12.8**	Increased loyalty	**18**	**15.4**
Increased quality of work	**14**	**12.0**	Increased quality of work	**14**	**12.0**	Increased creativity	**15**	**12.8**
Positive impact on employees' mental health	**8**	**6.8**	Increased creativity	**13**	**11.1**	No need to use any paid time off	**13**	**11.1**
Positive impact on employees' physical health	**8**	**6.8**	Getting to know new places and people	**11**	**9.4**	Shape company culture	**13**	**11.1**
Getting to know new places and people	**6**	**5.1**	Increased work-life balance	**10**	**8.5**	Breaking the daily routine	**10**	**8.5**
Shape company culture	**5**	**4.3**	Increased loyalty	**9**	**7.7**	Increased quality of work	**10**	**8.5**
Ability to work remotely	**2**	**1.7**	Shape company culture	**9**	**7.7**	Ability to work remotely	**8**	**6.8**
Increased work-life balance	**2**	**1.7**	No need to use any paid time off	**8**	**6.8**	Increased productivity	**7**	**6.0**
Increased loyalty	**1**	**0.9**	Positive impact on employees' mental health	**7**	**6.0**	Getting to know new places and people	**2**	**1.7**
			Ability to work remotely	**5**	**4.3**			
Total	**117**	**100**	Total	**117**	**100**	Total	**117**	**100.0**

H1: There is a significant positive or negative relationship between the perception of the workation mode (age, gender, education, parents).

H1.1: There is no statistically significant relationship between age and workation rating (Kruskal Wallis Test, Chi-square 3.043, Asymp. Sig. 0.385, see Table 4) – hypothesis not supported.

Table 4 Test Statistics

How are workations viewed by employees?		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
What is your age?	possitive	**0.147**	**64**	**0.002**	**0.932**	**64**	**0.002**
	rather positive	**0.113**	**43**	**0.200***	**0.956**	**43**	**0.095**
	neither positive nor negative	**0.166**	**10**	**0.200***	**0.913**	**10**	**0.305**
	critical	**0.158**	**40**	**0.014**	**0.920**	**40**	**0.008**

Test Statistics[a,b]	
	What is your age?
Chi-Square	**3.043**
df	**3**
Asymp. Sig.	**0.385**
a. Kruskal Wallis Test	
b. Grouping Variable: How are workations viewed by employees?	

H1.2: There is no statistically significant relationship between workation rating and gender (to test the hypothesis, the $\chi 2$ test of independence in the contingency table was used; based on the performed test ($\chi 2(3) = 1.098$; p-value = 0.778 (Table 5)), we do not reject the tested hypothesis at the level of significance $\alpha = 5\%$) – hypothesis not supported.

H1.3.: The evaluation of the workation does not depend on the highest level of education achieved (tested with Spearman correlation coefficient, R = -0.056 with p 0.513) – hypothesis not supported.

H1.4: There is a statistically significant relationship between the workation rating and the number of children. It can be seen from the Table 6 that as the number of children increases, the positive relationship to workations grows (test of independence: $\chi 2$ test ($\chi 2(6) = 30.949$; p-value<0.001 (Table 7)) – **hypothesis supported**.

Table 5 Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	**1.098**[a]	**3**	**0.778**
Likelihood Ratio	**1.089**	**3**	**0.780**
N of Valid Cases	**157**		

a. 1 cells (12.5%) have expected count less than 5. The minimum expected count is 3.63.

Table 6 Evaluation of workations by Paretal status

		How are workations viewed by managers?				Total
		positive	rather positive	neither positive nor negative	critical	
5) How many children do you have?	None	**30 (31.3 %)**	**23 (24 %)**	**6 (6.3 %)**	**37 (38.5 %)**	**96 (100 %)**
	1	**14 (42.4 %)**	**12 (36.4 %)**	**4 (12.1 %)**	**3 (9.1 %)**	**33 (100 %)**
	2 or more	**20 (74.1 %)**	**7 (25.9 %)**	**0 (0 %)**	**0 (0 %)**	**27 (100 %)**
Total		**64 (41 %)**	**42 (26.9 %)**	**10 (6.4 %)**	**40 (25.6 %)**	**156 (100 %)**

Table 7 Chi-Square Test

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	**30.949**[a]	**6**	**0.000**
Likelihood Ratio	**38.291**	**6**	**0.000**
N of Valid Cases	**156**		

a. 2 cells (16.7%) have expected count less than 5. The minimum expected count is 1.73.

H2: Managers' (very positive/positive) behaviours have an impact on the length of workations.

H2: With a growing positive attitude towards workations, the time that managers are willing to provide for workations increases statistically significantly (tested with Spearman correlation coefficient, R = -0.616; p-value<0,001). There is a statistically significant relationship between workation rating and workation permission ($\chi 2$ test of independence in cont. table; $\chi 2(6) = 190.088$; p-value <0.001). It is logical that managers who are critical of workations will absolutely not allow it – **hypothesis supported**.

H3: Managers' perceptions of workations (positive/rather positive/critical) have an impact (positive/negative) on carrying out team workations.

H3: Those who are very satisfied with workations are also more satisfied with teamwork; those who are rather satisfied are less satisfied with teamwork. It is therefore not surprising that there is a statistically significant relationship between the observed variables ($\chi 2$ test of independence in the cont. table; $\chi 2(1) = 81.0$; p-value <0.001) – **hypothesis supported**.

The table below (Table 8) shows that people who have already completed team workations rate it positively or very positively. These are people who overall evaluate workations positively or rather positively. As mentioned above, people who view workations negatively do not support workations and therefore cannot have team workations either. People who support workations have a positive attitude toward them and are also satisfied with team workations.

Table 8 Evaluation of workations by team spirit

		How did workforce feel about the team workations?					
		very positive		positive		Total	
		n	%	n	%	n	%
How are workations viewed by managers?	positive	**49**	**100**	**0**	**0.0**	**49**	**60.5**
	rather positive	**0**	**0.0**	**32**	**100**	**32**	**39.5**
	Total	**49**	**100.0**	**32**	**100**	**81**	**100**

H4: There is a relationship between the evaluation of workations and the evaluation of challenges that managers must solve with the theme of workations.

This hypothesis looked at the relationship between the workations assessment and the assessment of the challenges that managers have to solve with the workations system. From the above tables, we know that the most common ones are organization, legality and taxes. However, the distribution of challenges is not statistically significantly different between ratings. From the point of view of the challenges that managers have to face during workations (Table 9), the distribution of challenges does not statistically significantly differ between workation evaluations (modified Fisher's exact test (p-value = 0.861)) – hypothesis not supported.

Table 9 Evaluation of workations by challenges

		How are workations viewed by managers?							
		positive		rather positive		neither positive nor negative		Total	
		n	%	n	%	n	%	n	%
What challenges do you see when organising a workation?	organisational	**24**	**37.5**	**17**	**39.5**	**2**	**20.0**	**43**	**36.8**
	legal	**15**	**23.4**	**9**	**20.9**	**3**	**30.0**	**27**	**23.1**
	taxes	**13**	**20.3**	**7**	**16.3**	**3**	**30.0**	**23**	**19.7**
	childcare	**6**	**9.4**	**5**	**11.6**	**2**	**20.0**	**13**	**11.1**
	data protection	**6**	**9.4**	**5**	**11.6**	**0**	**0**	**11**	**9.4**
	Total	**64**	**100**	**43**	**100**	**10**	**100**	**117**	**100**

5 Discussion

The findings of this study provide strong evidence that the workation works. The number of paid vacation days differs across European countries. In Austria, contracts allow 25 paid vacation days based on a 5-day working week [16]. As in Yoshida's study [10], the workationers in this study were employed, in our case managers. Thus, in this study, the workation is heavily influenced only by companies' intentions. Based on the data, 45.5% (81) of all managers were able to do workations compared with 34.3% (61 managers) who had no experience with it. This analysis supports the theory that the COVID-19 pandemic demonstrated that the impossible turns out to be possible [17]. Atkinson & Sandiford [18] highlight that organisations using flexible work options in recruitment practices attract a wider range of applicants. As shown by the data obtained, 65.5% (117) of managers would like to implement the workation in communication in recruiting.

A total of 49 (60.5%) out of 81 managers regarded team workations as very positive and 32 (39.5%) as positive. These results are in the vein of a qualitative study where the workationers see workations as the ideal way of working and living [19]. The greatest challenges of this flexible working approach according to managers (n=117) include: organisational (36.8%), legal (23.1%), taxes (19.7%), childcare (11.1%) and data protection (9.4%). The situation is similar with general work flexibility challenges [20-22].

The majority of the 117 managers prefer less than one week (35.9%), almost three tenths would prefer 1-2 weeks and more than one sixth 3-4 weeks. Interestingly, few managers would prefer workations of over one month (11) and two or more months (7). Possible explanations may be that the hardest part of workations is the loneliness and lack of social interaction between team members. Interestingly, no general time span for a digital nomad has been set. Some perceive it as a temporary workation that ranges from two weeks to one year [23]. Digital technologies continuously enable a higher degree of flexibility and mobility [24,25], as demonstrated in this study. This means that the work location is less about what it is intended for but more about how the location is perceived to be used.

The three reasons why a workation works best, according to managers, are: 1) increase in job satisfaction (31.6%), 2) increase in productivity (29.1%) and 3) improved work-life balance (17.9%). This is comparable to the results of Beňo [20]. As satisfaction in the workation increases, length increases. Further, the positive evaluation of team workations also increases.

Hernandez-Tamurejo et al. [26] highlighted the telework impact travel patterns as follows: frequency of days working remotely, commute distance and travel time.

Generally, it is the worst part of the workforce's day. Unlike working anywhere at any time or location-independence, the results seem to suggest that location is the first concern of managers in this study. As the number of children increases, the positive relationship with workations grows. It is interesting how the place seems to shape relationships as today's workplaces become more independent [27-29].

In accordance with Galinsky et al.'s [30] data and those in this study, we agree that "increased flexibility can make work 'work' for increasing numbers of employers, employees, employees' families, and communities".

6 Conclusions

The place where work can be conducted has changed considerably in recent years. Prior research has studied e-working topics within a physical work environment (on-site and/or at home). Thus, the underlying moved physical workplace (woraction) is being left in the background and the workforce's experiences overlooked. The authors address the following research questions:

1. What is the status quo of the workation in Austria in times of multiple crises?

For managers, the workation means a recharging of the life batteries and working productively and efficiently at the same time. Organisations offering workations accept that their managers and workforce will be out of the office for a while. Most managers stay away for less than a week. Three reasons given by managers to explain why the workation is a success are: 1) an increase in job satisfaction, 2) an increase in productivity and 3) improved work-life balance.

- There is no statistically significant relationship between age and workation rating.
- There is no statistically significant relationship between workation rating and gender.
- The evaluation of workations does not depend on the highest level of education achieved.
- There is a statistically significant relationship between the workation rating and the number of children. It can be seen from the table and the graph that as the number of children increases, the positive relationship to workations grows.
- There is a relationship between the length of workations and the evaluation of workations. Persons critical of the workation (generally those who do not allow it at all) choose zero length workations. As satisfaction increases, length increases.
- There is a statistically significant relationship between workation rating and team workations rating. with increasing satisfaction with workations in general, and the positive evaluation of team workations also increases.
- From the point of view of the challenges that managers have to face during workations, the distribution of challenges does not statistically significantly differ between workation evaluations.

2. Can workations help employers retain workforce?

The majority of the 117 managers prefer less than one week (35.9%), almost three tenths would prefer 1-2 weeks and more than one sixth 3-4 weeks. Interestingly, few managers would prefer workations of over one month (11) and two or more months (7). This survey illustrates a possible way that organisations can retain the talent on their teams. But it comes down to personal preferences. A workation remains working hours and is only a win-win situation if enterprises create the necessary freedom and make them a voluntary option.

Human mobility data flow in this study provides an unprecedented opportunity to understand business executives' behaviour, preferences and trends, leading to informed decision making.

This study has some limitations. The main limitation is its novelty. Secondly, it was conducted solely in Austria with a cross-sectional research design. A longitudinal study could extend the current research. Thirdly, only a quantitative method for data collecting and analysis was employed. Further, a native language questionnaire, in this case German, allows the respondents to express themselves better, but may limit the interpretation when translated into English.

It can be assumed that the potential of workations has not yet been fully exploited. For this reason, there are other possibilities for future studies as well. We recommend longitudinal research to capture future developments for both employers and employees. A possible qualitative approach could analyse to what degree workations offer work-life balance and how this affects the overall desire to continue to go on workations.

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References

[1] DUFFY, F.: *The New Office*, London, UK: Conran Octopus Limited, 1997.
[2] HILL, E.J., FERRIS, M., MÄRTINSON, V.: Does it matter where you work? A comparison of how work and personal/family life, *Journal of Vocational Behavior*, Vol. 63, No. 2, pp. 220-241, 2003. https://doi.org/10.1016/S0001-8791(03)00042-3
[3] BAILEY, D.E., KURLAND, N.B.: A review of telework research: findings, new directions, and lessons for the study of modern work, *Journal of*

Organisational Behavior, Vol. 23, No. 4, pp. 383-400, 2002. https://doi.org/10.1002/job.144

[4] DUXBURY, L., HIGGINS, CH., NEUFELD, D.: *Telework and the balance between work and family: is telework part of the problem or part of the solution?*, The Virtual Workplace, pp. 218-255, 1998.

[5] URIELY, N.: 'Travelling workers' and 'working tourists': variations across the interaction between work and tourism, *International Journal of Tourism Research*, Vol. 3, No. 1, pp. 1-8, 2001. https://doi.org/10.1002/1522-1970(200101/02)3:1<1::AID-JTR241>3.0.CO;2-M

[6] COHEN, E.: Nomads from Affluence: Notes on the Phenomenon of Drifter-Tourism, *International Journal of Comparative Sociology*, Vol. 14, No. 1-2, pp. 89-103, 1973.

[7] KLOPOTEK, M.: The advantages and disadvantages of remote working from the perspective of young employees, *Scientific Quarterly "Organization and Management"*, Vol. 4, No. 40, pp. 39-49, 2017. https://doi.org/10.29119/1899-6116.2017.40.3

[8] SIMINI, F., BARLACHI, G., LUCA, M.: A Deep Gravity model for mobility flows generation, *Nature Communications*, Vol. 12, 6576, pp. 1-13, 2021. https://doi.org/10.1038/s41467-021-26752-4

[9] ZUFIRIA, P.J., PASTOR-ESCUREDO, D., U´BEDA-MEDINA, L., HERNANDEZ-MEDINA, M.A., BARRIALES-VALBUENA, I., MORALES, A.J. ET AL.: Identifying seasonal mobility profiles from anonymized and aggregated mobile phone data. Application in food security, *PLOS ONE*, Vol. 13, No. 4, e0195714, pp. 1-20, 2018. https://doi.org/10.1371/journal.pone.0195714

[10] YOSHIDA, T.: How Has Workcation Evolved in Japan?, *Annals of Business Administrative Science*, Vol. 20, pp. 19-32, 2021. https://doi.org/10.7880/abas.0210112a

[11] PECSEK, B.: Working on holiday: The theory and practice of workcation, *Balkans Journal of Emerging Trends in Social Sciences*, Vol. 1, No. 1, pp. 1-13, 2018. https://doi.org/10.31410/Balkans.JETSS.2018.1.1.1-13

[12] STATISTICSAUSTRIA: More holiday trips than before the pandemic, [Online], Available: https://www.statistik.at/fileadmin/announcement/2023/05/20230504Reiseverhalten2022EN.pdf [06 Oct 2023], 2023.

[13] BARNES, L., BARCLAY, L., MCCAFFERY, K., ROLFE, M., ASLANI, P.: Using Facebook to recruit to a national online survey investigating complementary medicine product use in pregnancy and lactation: A case study of method, *Research in Social and Administrative Pharmacy*, Vol. 17, No. 5, pp. 864-874, 2021. https://doi.org/10.1016/j.sapharm.2020.07.01

[14] GLAZIER, R.A., TOPPING, M.P.: Using social media to advance Community-Based research, *PS Political Science & Politics*, Vol. 54, No. 2, pp. 254-258, 2021. https://doi.org/10.1017/s1049096520001705

[15] BENFIELD, J.A., SZLEMKO, W.J.: Internet-based data collection: Promises and realities, *Journal of Research Practice*, Vol. 2, No. 2, pp. 1-15, 2006.

[16] EURODEV: Europe Paid Vacation Days, [Online], Available: https://www.eurodev.com/blog/europe-paid-vacation-days [06 Nov 2023], 2023.

[17] CIPD: FLEXIBLE WORKING: LESSONS FROM THE PANDEMIC, [Online], Available: https://www.cipd.org/globalassets/media/knowledge/knowledge-hub/reports/flexible-working-lessons-from-pandemic-report_tcm18-92644.pdf [06 Nov 2023], 2021.

[18] ATKINSON, C., SANDIFORD, P.: An exploration of older worker flexible working arrangements in smaller firms, *Human Resource Management Journal*, Vol. 26, pp. 12-28, 2016.

[19] SPLITHOFF, J.: Remote working from abroad: exploring the lifestyle of workationers in the Canary Islands, [Online], Available: https://edepot.wur.nl/580393 [06 Nov 2023], 2021/2022.

[20] BEŇO, M.: The Advantages and Disadvantages of E-working: An Examination using an ALDINE Analysis, *Emerging Science Journal*, Vol. 5, pp. 11-20, 2021. https://doi.org/10.28991/esj-2021-SPER-02

[21] JOHSON, R.W.: Phased retirement and workplace flexibility for older adults: Opportunities and challenges, *The Annals of the American Academy of Political and Social Science*, Vol. 638, pp. 68-85, 2011.

[22] SVENSSON, S., HALLMAN, D.M., MATHIASSEN, S.E., HEIDEN, M., FAGERSTRÖM, A., MUTIGANDA, J.C., BERGSTRÖM, G.: Flexible Work: Opportunity and Challenge (FLOC) for individual, social and economic sustainability. Protocol for a prospective cohort study of nonstandard employment and flexible work arrangements in Sweden, *BMJ Open*, Vol. 12, No. 7, e057409, pp. 1-8, 2022. https://doi.org/10.1136/bmjopen-2021-057409

[23] STOUGHTON, I.: Have Macbook, will travel, [Online], Available: https://www.economist.com/1843/2017/07/11/have-macbook-will-travel [06 Nov 2023], 2017.

[24] AGUINIS, H., LAWAL, S.O.: eLancing: A review and research agenda for bridging the science–practice gap, *Human Resource Management Review*, Vol. 23, pp. 6-17, 2013. https://doi.org/10.1016/j.hrmr.2012.06.003

[25] COLBERT, A. YEE, N., GEORGE, G.: From the editors: The digital workforce and the workplace of

the future, *Academy of Management Journal*, Vol. 59, No. 3, pp. 731-739, 2016. https://doi.org/10.5465/amj.2016.4003

[26] HERNANDEZ-TAMUREJO, A., HERRAEZ, B.R., AGUDO, M.L.M.: Telework and the limited impact on traffic reduction – Case study Madrid (Spain), *Acta logistica*, Vol. 10, No. 3, pp. 423-434, 2023. https://doi.org/10.22306/al.v10i3.411

[27] JESUTHASAN, R., BOUDREAU, J.: *Reinventing jobs: A 4 step approach for applying automation to work*, Harvard Business School Press, 2019.

[28] KINNIE, N., SWART, J.: Cross-boundary working: Implications for HRM theory, methods, and practice, *Human Resource Management Journal*, Vol. 30, No. 1, pp. 86-99, 2020. https://doi.org/10.1111/1748-8583.12239

[29] SPREITZER, G.M., CAMERON, L., GARRETT, L.: Alternative work arrangements: Two images of the new world of work, *Annual Review of Organizational Psychology and Organizational Behavior*, Vol. 4, No. 1, pp. 473-499, 2017. https://doi.org/10.1146/annurev-orgpsych-032516-113332

[30] GALINSKY, E., SAKAI, K., WIGTON, T.: Workplace Flexibility: From Research to Action, *The Future of Children, 2011 Fall*, Vol. 21, No. 2, pp. 141-161, 2011.

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Logistics cost management in foundry production using the Activity – Based Costing method
Martina Zavrbska, Petr Besta

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Logistics cost management in foundry production using the Activity – Based Costing method

Martina Zavrbska
VSB - Technical University of Ostrava, 17. listopadu 2172/15, 708 00 Ostrava - Poruba, Czech Republic, EU, martina.zavrbska.st@vsb.cz (corresponding author)
Petr Besta
VSB - Technical University of Ostrava, 17. listopadu 2172/15, 708 00 Ostrava - Poruba, Czech Republic, EU, petr.besta@vsb.cz

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Abstract: The aim of the paper is to present the application of Activity-Based Costing (ABC) method in logistics cost management in foundry production and its practical use in differentiating logistics service levels. The study was carried out in a foundry specializing in custom and small batch production of castings. The implementation of the ABC method involved three key phases. Tools such as Pareto analysis and the Lorenz curve were used to analyse the customers, which enabled the classification of customers according to their contribution to profit. The main result of the research was the creation of a calculation formula allowing detailed allocation of logistics costs to individual activities. At the same time, the key benefits of the ABC method for logistics management of foundry production were identified. The method was also used to analyse customers, which led to differentiation of logistics service levels based on their economic benefits. The main benefit of the implementation of the ABC method was the accurate allocation of logistics costs to activities, which enabled a better understanding of the economic efficiency of logistics processes. However, the study was time and data intensive, with some of the data based on educated guesses, which may have affected the accuracy of the results. Moreover, the focus on custom foundry production limits the generalizability of the conclusions. However, the ABC method has opened up new opportunities for data automation and optimization of logistics processes through digital technology, which contributes to modernise logistics management in foundry production.

1 Introduction

In the current economic environment, defined by constant changes in customer preferences, the rapid pace of technological innovation, and growing competition, systematically strengthening the competitiveness of companies is a necessity. This aspect affects all business sectors, including foundry industry, which is classified as part of the metallurgical industry. It is a field with extraordinary capital intensity, requiring the allocation of a large amount of financial resources to technology, technical equipment and environmental protection of processes.

In an increasingly complex business environment, there is a growing demand to ensure the efficiency and speed of material and information flows associated with meeting product demand. These flows cover the entire cycle from demand generation to the final distribution of products, including their support and subsequent disposal [1]. Successful management of these logistics chains is essential to maintain the competitiveness of the company. With the increasing complexity of industrial supply chains and the growing division of labour, the share of logistics costs in total production costs is increasing significantly [2]. Accurate allocation of logistics costs, including the detailed identification of individual processes throughout the entire logistics chain, is becoming increasingly important. However, the high complexity of logistics operations and the limited information on indirect costs significantly complicate the allocation process [3]. Therefore, innovations in costing methods are becoming a prerequisite for the effective reduction of logistics costs [4].

The aim of the paper is to present the use of the Activity - Based Costing (ABC) method in managing logistics costs for foundry companies and its potential further applications for optimizing logistics processes.

2 Theoretical background

Logistics is defined in both academic and practical contexts through the physical flows and the associated information and financial flows, which are essential for meeting product demands. Typical logistics activities include demand forecasting, logistics chain design, sourcing, customer order processing, inventory management, production and service planning, material handling, packaging, warehousing, transportation, reverse logistics management, and post-sales support [5].

The objective of logistics is to achieve a high level of logistics service while meeting the requirements of end customers at an acceptable total cost for all parties involved. A process can be defined as a group of logically arranged activities during which input resources are transformed into output products, whether they are about products or services. By linking these processes, which are necessary for meeting customer product requirements, a logistics chain with a line structure is formed. A higher

level of complexity is found in a logistics network, where flows are disconnected or connected, and some processes run in parallel [6].

The mission of logistics management is to organise and direct flows to achieve logistics objectives, at both the intra-company and inter-company levels. A systems approach and process orientation must be applied. By adhering the system approach, it is useful to distinguish three functional areas of logistics management, namely purchasing, production and distribution logistics [5,6]. Logistics management tools are often associated with lean manufacturing principles, as the primary goal of logistics is to enhance process efficiency [7].

Organising, managing and operating the logistics chain incurs logistics costs. Logistics costs can be classified according to the nature and purpose of the flow:

- the costs of organising and managing the flow,
- the costs of implementing the flow,
- holding costs,
- costs arising from an inadequate level of logistics services [5,6].

In today's economic environment, logistics costs are a key factor in determining competitiveness across all industries. However, the high complexity of logistics processes and the lack of accurate data on indirect costs makes their effective allocation to cost objects significantly more difficult [4].

Under the traditional costing method, costs are divided into direct (variable) and indirect (overhead) costs. A large part of the logistics costs consists of overheads, which are included in the overall overhead. If overheads are presented in an aggregate form as supply, production, sales and administrative overheads, it is not possible to determine exactly how individual processes and products utilize resources. For the purposes of efficient logistics management, however, it is essential to understand how costs are affected by, for example, packaging methods or the chosen means of transport. This raises the question of how to fairly allocate logistics overheads fairly to individual products and which costing method to choose for this purpose [6]. To some extent, modern methods such as Activity-Based Costing and Time Driven Activity-Based Costing (TD-ABC) offer some answers to this challenge [8].

The foundations of Activity-Based Costing can be tracked back to Professor Kohler, who first introduced the concepts of cost allocation in 1952. In 1988, this idea was further developed by Robin Cooper and Robert Kaplan and formulated the ABC method [9]. The essence of ABC costing lies in the allocation of indirect costs to individual activities, through which these costs are assigned to cost objects based on a causal relationship between the economic resource and the cost object [10]. From a methodological perspective, it involves a full cost calculation (the absorption method), which can be combined with the non-absorption method. The implementation of the ABC method is divided into three key phases. In the first phase, the reasons for implementation are defined, and the structure of the ABC model is established. In the next step, an analysis of the implementation costs is conducted, and the expected outputs of the system are defined. The second phase is model creation, which includes the implementation of the individual steps for developing the ABC system creation. In the third phase, the system is put into operation, and the area of automatic retrieval is simultaneously addressed along with data processing to ensure the system's complexity [11,12].

The shortcomings in the application of the ABC method became the impetus for developing the modified TD-ABC method [13]. The calculation allocates costs to activities based on time usage. The logic of the TD-ABC method differs from that of the ABC approach in that, while the ABC method requires repeated identification of the actual occurrences of controlling factors for each activity, the TD-ABC method only requires a single temporal equation that mathematically models all possible variations in the course of a given activity. It expresses the dependence of activity time consumption on time factors. The TD-ABC method appears suitable in situations with significant heterogeneity in both input and output resource consumption that cannot be captured by the traditional ABC model [11,13].

A review of the literature in this area reveals that there are several case studies and research focused on logistics cost management and the application of the ABC method in various contexts.

Research conducted by Aksoylu and Demirel [1] explored the use of ABC in reverse logistics, specifically focusing on the recovery of end-of-life vehicles (ELV). The research critiques traditional accounting methods for their inadequacy in allocating overhead costs and demonstrates how ABC offers improved insight into costs. The case study focuses on a dismantling facility where vehicles are treated as inputs and reclaimed materials as outputs. The authors conclude that ABC is a valuable tool for companies to manage their reverse logistics costs effectively, and the presented model can be applied to other sectors engaged in reverse logistics.

Kučera [2] examined the application of the ABC method for calculating logistics costs in the automotive warehousing industry. The study emphasizes how accurate costing supports better decision-making and increases profitability. Through a case study of a logistics service provider, it demonstrates that ABC provides a detailed view of the cost structure, leading to a better cost optimization and pricing strategy. Kučera concludes that ABC is a key tool for effective cost management and improved competitiveness in the automotive industry.

Zhang and Li [3] focused on the use of the ABC method in logistics cost management, emphasizing its importance for cost reduction in a globalized economy. The case study

showed how the transition to ABC enhanced the accuracy of calculations and pricing strategies. The study also pointed out the delay in the application of ABC in the Chinese logistics sector. The authors conclude that ABC provides a more sophisticated approach to cost accounting compared to traditional methods. This is especially true for operations characterised by low performance, high indirect costs, and personalised services, which are typical features of logistics companies.

A study by Duran and Afonso [4] presents an Activity-Based Life Cycle Costing **(**AB-LCC) model for life cycle cost assessment in spare parts logistics. The model, which integrates the Weibull distribution to estimate demand and costs for non-repairable spare parts, offers more accurate costing and inventory optimisation than traditional methods. The case study shows that AB-LCC provides a more detailed view of costs and contributes to efficient inventory management. The authors recommend further research focused on technological change and risk simulation.

The authors Jin and Li [9] investigated how the competitiveness of third-party logistics (3PL) companies can be enhanced through cost optimisation. The authors combine the ABC method, programme analysis, and Flexsim simulation software to improve logistics operations at L Corporation. The study reveals that transport, warehousing, and distribution are the main cost areas and proposes optimisations that have led to a 12.5% cost reduction for selected customers. The results show that combining the ABC method with other tools effectively identifies and resolves operational problems, leading to increased efficiency and reduced costs in 3PLs.

3 Logistics cost management in foundry production using the ABC method

A case study was conducted to demonstrate the application of the ABC method in logistics cost management in foundry companies. The production programme of the foundry is focused on unit production and small-batch production of castings from steel (non-alloy, low-alloyed), cast iron with flake graphite (LLG), cast iron with spherical graphite (LKG) and non-ferrous metals (aluminium and copper alloys). Production commences only upon a specific customer order. The "customer order disconnection point" is situated in the material and raw material warehouses at the manufacturer's so-called Make-to-Order. The wide variability of materials used and the custom nature of production in the foundry lead to a high variety of cost structures that traditional costing methods cannot adequately capture. For this reason, the introduction of a modern ABC costing approach was proposed.

In the first phase, the reasons for implementation were identified, and the structure of the ABC model was established. The strategic variant of the model was chosen, characterised by fewer activities to which costs are allocated over a longer time period. Subsequently, the implementation costs were analysed and the expected outputs of the system were defined. The second phase included the actual creation of the model, with the implementation of the individual steps necessary for the implementation of the ABC system. In the third phase, the system was put into operation, ensuring automated data acquisition and processing to achieve full system comprehensiveness; see Figure 1. Due to the limited scope of the article, only the second phase of the application of the ABC method, focused on the calculation of logistics costs, is presented in the following section.

In the first phase of implementation, the key activities of the company and cost objects were defined. The main criteria for identifying activities were the nature of the selected foundry, which focuses on piece production with a high proportion of manual labour. The analysis of the technological process identified 18 primary activities covering the main production operations (e.g. core production, moulding, casting removal, finishing of castings, separation of sprues and risers, blasting, annealing, grinding, inbound logistics - purchasing, production logistics, output logistics - dispatch, etc.). In addition, support activities necessary for the operation and infrastructure of the business were identified that could not be attributed to primary activities. These activities were grouped into 7 support activities, including for example metallurgical and technological preparation, personnel activities, economic activities, maintenance, etc. Finally, the cost objects were identified as: specific product (casting), material (kg), order, and customer.

The assignment of costs to activities represented the next stage of the model development, aimed at quantifying the costs generated by each activity. The total costs of the company were broken down into direct, payroll, variable and fixed costs. Direct costs are allocated to cost objects in the final phase of implementation. Payroll and variable costs are allocated to primary activities, while fixed costs are assigned to support activities. Cost data from the accounting system, classified by type, including analytical accounts and centres, is imported into specialised software, where it is broken down by activity. The subsequent transformation of costs into calculated costs is carried out through the so-called activity cost matrix. Costs are assigned to activities based on a relational variable called the Resource Cost Driver, which enables direct assignment where there is a real link between the cost and the activity. The outcome of this matrix is a quantification of the total indirect costs allocated to each activity, the so-called cost pool. The next step involved allocating costs to support activities that cannot be directly assigned to cost objects, as their outputs are utilised by the primary activities. Fixed costs were allocated to support activities based on cost relationship variables using the application in the software, the so-called activity cost matrix [14].

The costs assigned to each activity are subsequently allocated to individual cost objects such as castings, materials, orders, and customers. For this purpose, it is necessary to measure the performance of activities and to express the relationship between activity costs and the cost object through metrics. This is done by using relational variables known as Activity Cost Drivers (ACD), which represent the causal factors influencing the cost of an activity and provide a metric for evaluating the performance of that activity. ACDs need to be quantifiable to accurately measure their impact. In collaboration with the consulting firm and the company's technical staff, relational variables for primary and secondary activities such as time (minutes), gross weight, and raw weight, were defined. The consumption of each activity was also quantified, for example, setting standards for time consumption in selected operations.

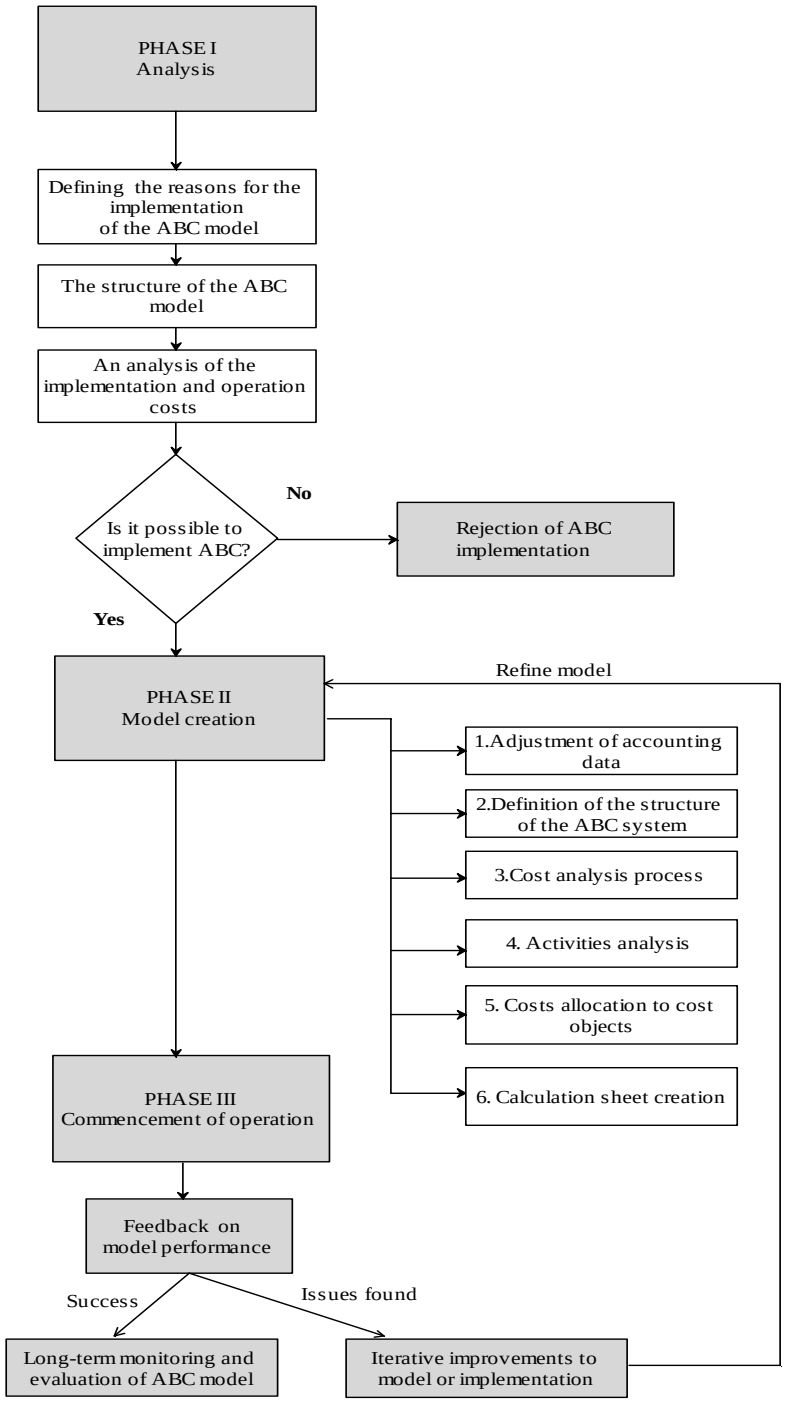

Figure 1 Methodology of implementation of the method ABC [modified by 11,13]

Based on the quantification of Activity Cost Drivers (ACD), a measure of the performance of each activity, referred to as the Activity Recovery Rate (ARR), was established. Subsequently, the unit cost of the activities, referred to as the Activity Primary Rate (APR), was calculated, which allowed the cost per unit of the activity to be determined. The APR is determined as the ratio between the total cost (Cost Pool) and the ARR. This procedure resulted in the derivation of primary activity unit costs, referred to as the Primary Activity Rate (PAPR). Similarly, the procedure for calculating the APR for secondary activities was applied to obtain the secondary activity unit cost (SAPR) [14].

The final step in the allocation of overhead costs per product (1 piece of casting) is the allocation of logistics activity costs, which is done through different cost objects and allocation keys, as shown in Figure 2. This process involves quantifying the amount of logistics activities consumed by a specific cost object (product, material, order). Based on the product of the quantity of logistics activities consumed and the unit costs, the total logistics costs of a given cost object can be calculated. The enterprise determines for each cost object which logistics activities it uses and identifies criteria (e.g., standards, technological procedures, qualified estimates) that automatically quantify the consumption of activity units (min, kg, pcs).

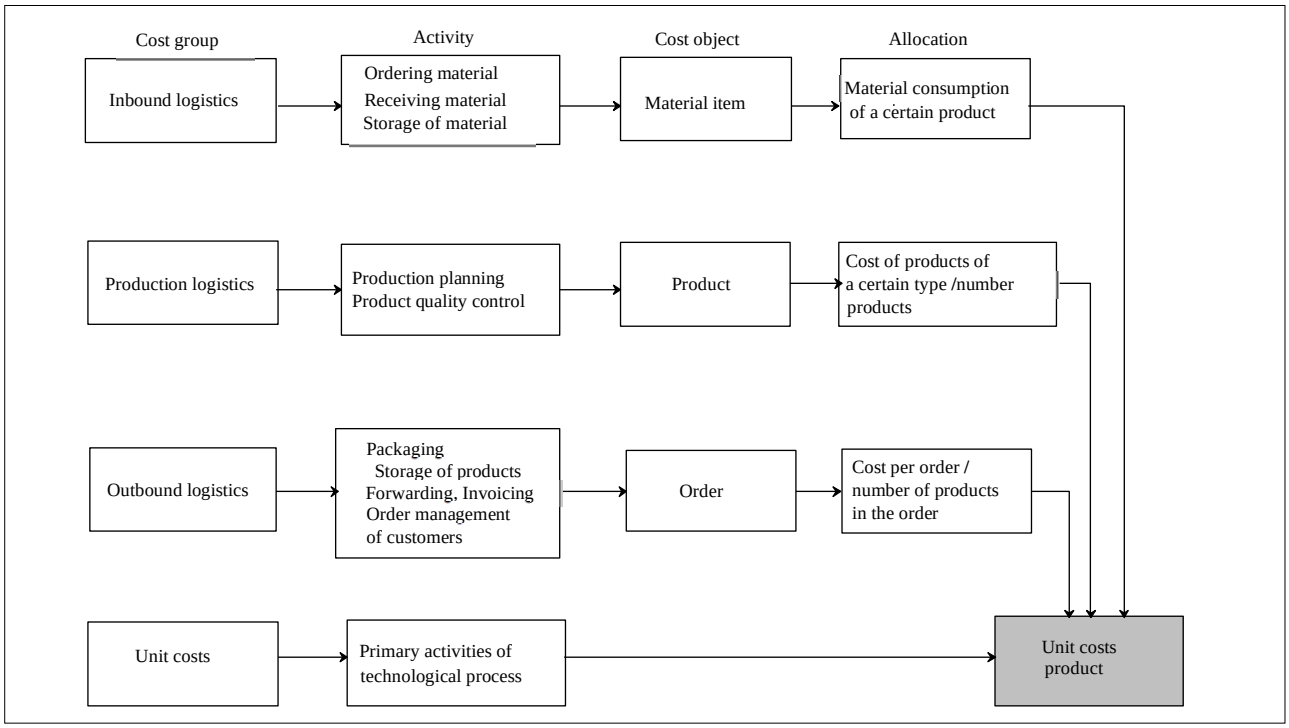

Figure 2 Allocation of logistics activity costs to cost objects and per product (own source)

4 Results and discussion

This chapter presents the main results of a case study conducted in a foundry company in the Czech Republic. One of the key outputs of the research was the development of a costing formula that enabled detailed allocation of logistics costs. The main benefits of the implementation of the ABC calculation method for logistics process management are summarized. The chapter also shows how this costing method has been specifically used in the analysis of customers and has enabled the differentiation of logistics service levels according to their economic benefits.

The aim of the application of the ABC method was to develop a new costing system, the output of which is the design of a costing sheet for a product (casting). ABC is a full costing method that includes not only direct costs but also activity costs, including the costs of logistics activities. The structure of the proposed costing sheet in abbreviated form, is shown in Table 1, where the calculation of the full cost of ownership per 1 piece of casting is provided. The cost was calculated as the product of the amount of units consumed (ARR) and the total unit cost (TUC), which is divided into the unit direct cost (UDC) and the unit cost of primary activities and secondary activities (PAPR, SAPR).

Table 1 The structure of a casting costing sheet in abbreviated form in € (own source)

Casting (1pc)		ARR	ACD	TUC	UDC	PAPR	SAPR	Total
Direct costs	Material	14.50	kg	**8.50**	8.50			**123.25**
Activities								
F110	Cores production 3165	23.20	min	**5.50**		5.00	0.50	127.60
F500	Knocking out castings	15.00	min	**2.30**		2.10	0.20	34.50
Total direct costs + activity costs								**285.35**
Logistics activities								
L100.1	Acceptance of the customer's order	1.20	min	**0.50**		0.40	0.10	0.60
L200.1	Internal quality control	2.20	min	**0.90**		0.65	0.25	1.98
L200.2	Product packaging	4.10	min	**1.20**		0.95	0.25	4.92
Total direct costs + activity costs + logistics costs								**292.85**

The ABC costing method is primarily designed to accurately calculate the cost of a specific cost object. Thanks to its specific characteristics, it is also a key cost management tool that enables not only cost reduction but also cost optimisation. The benefits of implementing the ABC method in the logistics management of a foundry can be summarized in the following points:

- Precise allocation of logistics costs to a specific cost object.
- Determination of the actual costs of individual logistics activities.
- Efficient logistics cost management through a new costing method that determines the actual profitability of products and provides information on cost drivers.
- Identification of unused resource capacity.
- Providing information for decision-making throughout the product life cycle.
- Ability to evaluate the profitability of individual product lines and identify those that generate losses.
- Supporting effective decision-making on changes in order volume.
- Providing relevant information for the evaluation of suppliers and customers.
- Continuous monitoring of the development of logistics costs, identification of deviations and analysis of their causes.
- Positive impact on company culture, especially in the area of internal communication.
- Expanding the management information base for decision making at different levels of management.

The result of the application of the ABC calculation method was not only the creation of a calculation formula that enabled a more accurate allocation of logistics costs, but also the identification of specific benefits of this method for logistics management in a foundry company. The implementation of this method contributed to more efficient management of logistics processes at all levels, which included accurate tracking of costs of individual activities as well as decision support in key areas. One of these areas that was key to improving service and optimising resources was the logistics services provided to customers. Therefore, the Activity-Based Costing method was also used in the analysis of customers, which enabled differentiation of logistics service levels based on their economic benefits.

Differentiation of logistics service levels based on customer analysis

Customer analysis is one of the key components of logistics processes. It is essential for strengthening customer relationships and for adequately differentiating the level of logistics services provided in order to maximise customer satisfaction. Not all customers bring the same economic benefits to a business. Even for similar products, specific customer requirements can vary considerably, affecting not only the logistics chain but also the logistics costs. The differentiation of logistics services should therefore be based on a detailed customer analysis. This analysis focuses on key metrics that reflect the importance of the customer, such as revenue share, profit contribution share and other relevant metrics.

Pareto analysis, based on the Pareto's 80/20 principle, is a suitable tool for classifying the importance of customers. This principle states that approximately 80% of the effects result from 20% of the causes. In practical application, this means that most problems can be attributed to just a few key factors. Thus, Pareto analysis allows for the identification of these key factors and the focusing of efforts on resolving them, resulting in maximum improvement with minimum effort. A graphical tool called a Pareto diagram is used to visualize the results of Pareto analysis. This diagram is used to visually illustrate which causes have the greatest impact and how significantly they contribute to the overall problem. In the Pareto chart, the bars are arranged according to the importance of each category (e.g., sales, profit) from the most important to the least important. The Lorenz curve shown in the diagram represents the cumulative percentage of the total values of these categories [6].

The research focused on the application of the Activity-Based Costing method in logistics management in the foundry industry, resulting in the creation of a complex

costing formula for detailed allocation of logistics costs. As a further example of the practical application of this costing method, an analysis of customers based on their 'contribution to profit' was carried out, demonstrating its ability to accurately cost both jobs and individual customers. The 'profit contribution' indicator includes the contribution to fixed costs and profit generation. The profit calculation was based on the Activity-Based Costing method applied in the company. This method allows not only costs to be allocated to individual cost objects, but also revenues. Thanks to the precise allocation of costs, it is possible to determine the profit generated by individual cost objects relatively accurately. The principles of the Activity-Based Costing method consider the customer as the main cost object because they are based on the assumption that the firm's revenues are generated by customers, not products. The profit of a cost object was determined as the difference between the revenue from that object and the direct costs and expenses of the activities associated with that object. In the first step, the amount of profit contribution for each customer was calculated for the observed period. Customers were then ranked in descending order of their contribution to profit, and the cumulative shares of their total contribution were calculated to profit, as shown in Table 2.

A Pareto diagram was created as part of the analysis (Figure 3). The data in Table 2 and the Pareto chart indicate that the key customers in terms of share of total profit contribution are B, D and F, which together account for 52% of the total profit contribution of €35 750. Customer B contributes 20% of the profit and is thus the most important customer. Although all customers contribute to profits, their returns gradually decrease. Based on the Lorenz curve (Figure 3), it can be concluded that the "vital minority", which represents 80% of the profit contribution, includes customers B, D, F, A and C. The second group, representing 20%, includes customers G, H and E.

Table 2 Pareto analyse of customers (own source)

Customers	Profits of orders (€)	Cumulative profits (€)	Structure (%)	Cumulative structure (%)
B	7 050	7 050	20	20
D	5 950	13 000	17	37
F	5 500	18 500	15	52
A	5 300	23 800	15	67
C	4 850	28 650	13	80
G	3 200	31 850	9	89
H	2 800	34 650	8	97
E	1 100	35 750	3	100
SUM	35 750		100	

Profitability analysis provides detailed information on the real added value of individual customers. This information enables the elimination of high-loss performances and thus contributes to an increase in the overall profit achieved. It also allows differentiation of the level of logistics services according to the specific needs of individual customers.

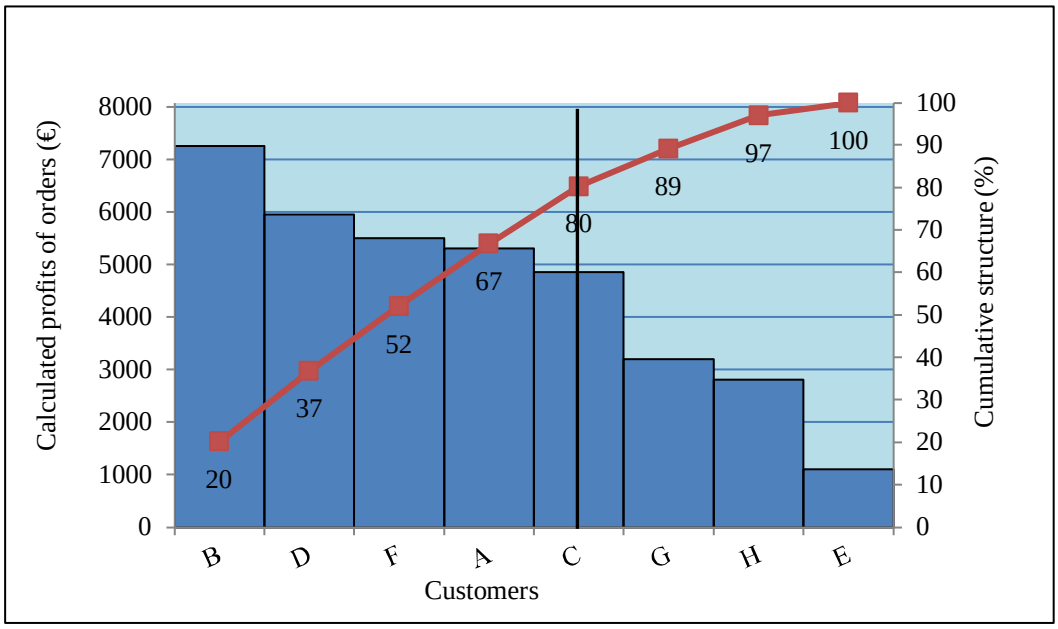

Figure 3 Customer Pareto analysis and Lorenz curve (own source)

The application of Activity-Based Costing in the management of logistics costs in foundry production has produced a number of significant results. A key benefit was the accurate allocation of logistics costs to activities, which enabled a better understanding of the economic efficiency of logistics processes and a detailed overview

of the actual costs of individual activities. This concept allowed detailed identification of cost factors that were often part of overhead costs in traditional costing systems. Higher levels of cost transparency and more accurate performance measurement of logistics processes have created the basis for strategic decisions and the introduction of technological innovations. Key benefits of the implementation include improved planning of logistics operations, such as warehousing processes and optimization of supply routing, as well as the discovery of unused capacity and the possibility of redirecting resources to higher value-added activities, etc. Another advantage was the introduction of differentiation of logistics service levels according to the contribution of customers to overall profit, which contributed to more effective management of key customer relationships.

Although the study had important contributions, it had limitations affecting its generalisability and the accuracy of the results. The introduction of the ABC method was time and data consuming, as it required a detailed analysis of logistics processes. In this study, some of the data were obtained through educated guesses, which may have affected the accuracy of some of the conclusions. Another challenge has been the complexity of the system, which includes staff training and the adoption of a new culture in process management. This transition can pose a significant challenge, especially for smaller businesses that are faced with limited human and financial resources. Furthermore, the results of this case study are specific to custom foundry manufacturing and may require adjustments for application in other industries.

The implementation of the ABC method has been challenging but has opened up new opportunities for innovation in logistics cost management and process optimization. One possible approach is to implement advanced technologies, such as software tools that allow automation of data collection and computation, which would reduce time and increase accuracy. The ABC method allows you to identify cost-consuming logistics activities and then optimise them in a targeted way through lean manufacturing or digital technologies. Detailed information on the costs of logistics activities can contribute to better planning and management of the entire supply chain. The ABC method also makes it easier to identify areas for reducing the environmental impact of logistics processes, for example by optimising transport, thereby contributing to business sustainability.

Based on the results obtained from this study, the following directions for future research can be recommended. One of which is the analysis of the long-term impacts of the implementation of the ABC method on the profitability and efficiency of business processes, with a focus on logistics costs. Another recommendation is to compare the effectiveness of the ABC method with other modern costing methods, such as Time Driven Activity-Based Costing, in relation to logistics process management. The linking of the ABC method with advanced technologies such as predictive models for logistics process management is also an interesting research direction.

5 Conclusions

The evolution of the business environment has brought changes in the structure of logistics processes and in the characteristics of supply chains, which has led to an increase in the differentiation of logistics costs. The complexity of cost relationships and drivers has reached a level where traditional cost management methods no longer provide sufficient information, creating the need for new, sophisticated systems [15,16]. In this context, the ABC method appears to be an effective tool for managing and allocating logistics costs.

The aim of the research was to apply the ABC method for logistics cost management in foundry companies and to investigate its potential in optimizing logistics processes. The case study focused on the application of the ABC method in the calculation of logistics costs in foundry production. The stated objective was achieved through the presentation of the individual steps of the method implementation and the creation of a costing sheet for the quantification of logistics costs.

The results of the research confirmed that the outputs of the ABC method have a wide application in the optimization of logistics processes. The method was successfully used to differentiate the level of logistics services based on the analysis of the profitability of individual customers according to the "Contribution to profit" indicator. Costs were allocated to individual contracts, which allowed the profit to be determined at the contract level. Pareto analysis and Lorenz curve were used to assess the significance of individual customers.

Finally, the study highlighted the significant benefits of implementing the ABC method, including accurate allocation of logistics costs to individual activities, improved transparency of cost structures and more efficient planning and decision-making in logistics operations. Moreover, the differentiation of logistics services based on customer profitability confirmed the practical use and value of this method.

However, the study also identified some limitations, such as the time and data complexity of implementing the ABC method and the dependence on some estimators, which may have affected the accuracy of the results. Moreover, the focus on custom foundry production limits the generalisability of the findings to other sectors.

Despite these limitations, the ABC method offers considerable potential for innovation, including automation of data collection and process optimization through advanced digital technologies. These capabilities underline its importance in modernising logistics management in the foundry industry.

Based on the results of the study, the following directions for future research can be recommended: focus on analysing the long-term impacts of the ABC method on

the profitability and efficiency of logistics processes and compare its effectiveness with alternative calculation approaches such as Time-Driven ABC.

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References

[1] AKSOYLU, S., DEMIREL, N.: Application of Activity based costing in reverse logistics environment: a case of end-of-life vehicle recovery in Turkey, *Journal of Business Research - Turk*, Vol. 10, No. 4, pp. 953-973, 2018. https://doi.org/10.20491/isarder.2018.557

[2] KUČERA, T.: Application of the Activity-based costing to the logistics cost calculation for warehousing in the automotive industry, *Communications - Scientific letters of the University of Zilina*, Vol. 21, No. 4, pp. 35-42, 2019. https://doi.org/10.26552/com.C.2019.4.35-42

[3] ZHANG, R., LI, H.: *Study on logistics cost control based on Activity-based costing*, Conference Proceedings, International Conference on Economic Management Science and Financial Innovation (ICEMSFI), Guangzhou, pp. 102-110, 2018.

[4] DURAN, O., AFONSO, P.: An activity-based costing decision model for life cycle economic assessment in spare parts logistic management, *International Journal of Production Economics*, Vol. 222, No. April, 107499, pp. 1-11, 2020. https://doi.org/10.1016/j.ijpe.2019.09.020

[5] GROS, I.: *The Big Book of Logistics*, Prague, University of Chemical Technology, 2016. (Original in Czech)

[6] MACUROVÁ, P., KLABUSAYOVÁ, N., TVRDOŇ, L.: *Logistics*, 2nd ed., Ostrava, VŠB-TU Ostrava, 2018. (Original in Czech)

[7] TEPLICKÁ, K., HART, M., HURNA, S.: Differentiation of stocks by the ABC approach in the synergy of the order penetration point of the logistics chain, *Acta logistica*, Vol. 11, No. 1, pp. 13-19, 2024. https://doi.org/10.22306/al.v11i1.445

[8] DRURY, C.: *Management and cost accounting*, 2nd ed., London, Chapman & Hall, 1988.

[9] JIN, Q., LI, T.: *Operation improvement of third-party logistics enterprise based on Activity-based costing method*, 4th International Conference on Management Engineering, Software Engineering and Service Sciences (ICMSS 2020), Wuhan, pp. 250-254, 2020. https://doi.org/10.1145/3380625.3380655

[10] DOYLE, D.: *Cost Control*, London, CIMA Publishing, 2002.

[11] POPESKO, B.: *Modern Cost Management Methods: How to Achieve Cost Efficiency and Their Reduction*, 2nd ed., Prague, Grada, 2016. (Original in Czech)

[12] GUI, P., NA, S.: Empirical study on the application of Activity-based cost model in marine third-party logistics cost management, *Journal of Coastal Research*, Vol. 98, No. sp1, pp. 195-198, 2019. https://doi.org/10.2112/SI98-048.1

[13] PETŘÍK, T.: *Process and Value Management of Companies and Organizations – Cost Technique and Complex Management Method: ABC/ABM (Activity-based Costing/activity-based Management)*, Prague, Linde, 2007. (Original in Czech)

[14] ZÁVRBKÁ, M., BESTA, P., DRASTICH, A.*: The application of modern methods of calculation in foundry production*, 30th International Conference on Metallurgy and Materials (Metal 2021), Ostrava, pp. 1303-1310, 2021. https://doi.org/10.37904/metal.2021.4285

[15] VILAMOVÁ, S., BESTA, P., KOZEL, R., JANOVSKÁ, K., PIECHA, M., LEVIT, A., STRAKA, M., SANDA, M.: Quality quantification model of basic raw materials, *Metalurgija*, Vol. 55, No. 3, pp. 375-378, 2016.

[16] YANG, Y., JIANG, J., WANG, R., XU, G., GU, J.: Study on the application of Activity-Based Costing in cold chain logistics enterprises under low carbon environment, *Sustainability*, Vol. 15, No. 18, pp. 1-20, 13808, 2023. https://doi.org/10.3390/su151813808

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Spatial differentiation of Poland's voivodeship in the context of linear infrastructure development in 2011-2021
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Lukasz Poplawski
Department of Public Finance, Cracow University of Economics, Rakowicka 27, 31-510, Cracow, Poland, EU, poplawsl@uek.krakow.pl
Pawel Dziekanski
Department of Economics and Finance, Jan Kochanowski University in Kielce, Uniwersytecka 15 str., 25-406, Kielce, Poland, EU, pawel.dziekanski@ujk.edu.pl (corresponding author)
Alina Danilevica
Institute of Humanities and Social Sciences, Daugavpils University, Parades Street 1-421, LV-5401, Daugavpils, Latvia, EU, alina.danilevica@du.lv
Bartosz Niescior
College of Business Studies, Warsaw School of Economics, Al. Niepodległości 162, 02-554, Warszawa, Poland, EU, bniesc@sgh.waw.pl

Keywords: linear infrastructure, transport infrastructure, provinces, synthetic measure, TOPSIS method.
Abstract: The development of linear infrastructure is important for the development of logistics, for the economic development of regions. The is at the same time spatially differentiated between regions. The regions are strongly developing their linear infrastructure in order to reduce the disparities in the development of facilities and roads. The aim of the study was to diagnose the condition of linear infrastructure and to indicate its spatial changes in the years 2011-2021 in Poland. The were used to build a synthetic measure using the Technique for Order Preference by Similarity to an Ideal Solution method. The synthetic measure of linear infrastructure ranged from 0.01 (warmińsko-mazurskie) to 0.60 (śląskie) in 2010 and 0.31 (świętokrzyskie, podlaskie) to 0.56 (śląskie, małopolskie) in 2021. A higher value of synthetic measure of linear infrastructure indicates a better position and higher competitiveness of the voivodeship within the research area. The provinces well equipped with linear infrastructure include the provinces of śląskie, dolnośląskie, małopolskie. The provinces where there is an improvement, and road connections are developing, include podlaskie, świętokrzyskie. They are not counted among the highly developed economically and do not make the best use of the opportunities offered by a developed road network. Action taken in this aspect must be based on analyses to facilitate comparisons and on current information necessary for effective action.

1 Introduction

The nation's transportation infrastructure is essential to its economic growth. Is a crucial sign of its economic expansion. Roads, highways, and railroads are examples of linear infrastructure. They provide serious hazards to the local ecosystem and biodiversity, but they can also have major positive social and economic effects. For linear infrastructure, a spatial planning tool that balances the costs and advantages of environmental and socioeconomic factors is required. A variety of infrastructures are necessary for the growth and welfare of human society. Linear infrastructures have created significant ecological and environmental issues in addition to their enormous economic benefits (Wu, Li 2022) [1].

Infrastructure plays an important role in promoting the socio-economic development of a region. In particular, the provision of transport infrastructure is important for agri-food supply chains, which have some specific characteristics that contribute to the complexity of external logistics. Transport infrastructure has an impact on green and sustainable development, on economic growth due to the investment during the construction period and the possible positive externalities after construction. More energy is used and, consequently, more CO2 is released during the building of transportation infrastructure, which has an adverse effect on the environment. Because it facilitates the movement of people and the trade of goods across space. The transport infrastructure plays a role in the growth and development of an area. In addition to causing landscape fragmentation, the construction of linear infrastructures has a variety of negative effects on biodiversity and natural habitats (Tan, Pan, Xu, He, 2022) [2].

The European Union (EU) has paid particular attention to the development of infrastructure, especially transportation, considering it a key element in ensuring territorial cohesion. Investing in transportation is key to sustainable development, enabling the free movement of people, goods and services, which translates into economic development and cooperation between countries. As part of its cohesion policy, the EU invests in the construction and modernization of road, rail, sea and air networks, aiming to close the gap in access to modern modes of transportation. Such policies aim not only to improve mobility, but also to integrate peripheral areas, which in the past were less developed and had difficult access to key markets [3]. The road system plays a key role in both maintaining the health of the economy and generating social benefits. With an ever-increasing awareness of climate change and sustainability, transportation infrastructure researchers, engineers, and practitioners are pursuing

innovations to conserve natural resources and reduce energy consumption and emissions. Roads are the backbone of transportation, which drives trade, tourism, and industry, which in turn drives economic growth. As a result, a well-developed road infrastructure promotes economic stability and attracts investment. The road system not only supports the economy but also has a tremendous impact on improving the quality of life of society, reducing geographic isolation, improving access to services, and integrating communities [4]. Differences in the efficiency of infrastructure and quality of logistics systems in different countries can be identified as the source of several problems in the global supply chain, such as lack of connectivity between countries, congestion, high costs, delays in shipment flows and the associated increase in logistics costs [5].

The aim of the research was to assess the spatial disproportion of linear infrastructure at the level of voivodeships in Poland. A voivodeship in Poland is a territorial subdivision that is an administrative part of the country, which is responsible for carrying out public tasks. The availability of data from Statistics Poland played a key role in their selection. The research process sought to identify the essence of linear infrastructure and areas affected by polarisation in the provincial economic system in 2011-2021. The Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method was used to build a synthetic measure. The analysis was performed for the years 2011-2021, and the results were presented for extreme years. This made it possible to indicate the dynamic aspects of the phenomena studied and to control deviations in the phenomenon associated with changes in, for example, the economic climate of the province. Implementation of the objective required answers to the research questions, i.e. What is linear infrastructure and what are its determinants? Is there territorial cohesion in terms of linear infrastructure? What is the strength of the interactions between the linear infrastructure diagnostic variables? To what extent have spatial disparities in linear infrastructure been bridged?

2 Literature review

Infrastructure systems are interconnected and influence each other. A better understanding of these interdependencies supports urban and provincial efforts. Recognizing these interdependencies allows one to see patterns that can help bring about changes in urban and provincial infrastructure systems, preventing unexpected consequences and eliminating systemic blockages. Effectively sorting out the reciprocal mechanisms between infrastructure systems can enhance the understanding of transition processes in the context of sustainable development. Infrastructure systems are part of broader socio-technical systems that produce, process and distribute specialized services, materials and resources, thereby supporting the well-being of citizens and the proper functioning of cities. One of the key functions of social infrastructure is to provide basic urban services, such as the provision of energy, water, heat, transportation and sanitation, which meet social needs and contribute to the quality of life of residents [6].

Social institutions influence the formation of infrastructure systems through political action, lobbying, coalition building, and the establishment of social norms, customs, and culture. Institutions and infrastructure systems develop simultaneously, adapting to and influencing the changing needs of society. Spatial interdependence refers to the geographic proximity and common location of different infrastructure systems, such as the sharing of networks, infrastructure elements, and space. Functional interdependencies, on the other hand, arise when different infrastructure systems play complementary or competing roles, which affects their mutual functionality. These interdependencies result from the exchange of material resources and information, as well as from complementary or competing functions [7].

Transportation infrastructure is a key component of a well-functioning economy, playing a vital role in its economic and social development. Transportation brings numerous benefits to society, providing access to education, jobs, goods, services, as well as enabling leisure and promoting physical activity in daily life. The development of transportation infrastructure is considered an essential foundation for economic growth, as it directly supports production and economic activity. Investment in transportation affects economic growth by increasing the efficiency of labor and capital, reducing costs through improved transportation efficiency, accelerating structural change in regions, including the industrial sector, and modifying aggregate market demand [8].

In neoclassical economic growth theory, the development of transportation infrastructure combines technological and political factors to create a residual period of technological progress. The theory of endogenous economic growth suggests that the externalities of infrastructure investment are the primary source of long-term economic growth. The development of transportation infrastructure should be viewed as the physical capital of the region [9]. Governments, non-governmental organizations, and local communities are striving for sustainable development, which underpins activities at all levels of infrastructure management and development. In the context of transportation infrastructure construction, a key goal is to minimize the negative impact that construction materials, construction processes, and related activities have by reducing emissions, natural resource consumption, and environmental degradation. Sustainable development of transportation infrastructure focuses on balancing economic, social, and environmental needs to ensure long-term efficiency and minimize side effects on future generations [10].

The development and implementation of transportation infrastructure has a significant impact on the location decisions of businesses and households, as it improves accessibility to various markets, services and resources. This makes it easier for businesses to reach new customers and suppliers. For households, better transportation infrastructure provides easier access to jobs, education, health care and other services, which improves quality of life. Increasing accessibility and improving transportation can lead to increased traffic congestion, resulting in more traffic jams and longer travel times. Therefore, developing transportation infrastructure requires balancing the benefits of accessibility and efficiency with social and environmental costs [11]. A developed transportation infrastructure is a key determinant of regional advantages, as it reduces transportation costs, which encourages the development of various industries and sectors. Good transportation infrastructure contributes to the growth of industrial agglomerations, as it enables companies to concentrate in one region, which generates economies of scale and improves

competitiveness [12]. The development of transportation infrastructure can reduce trade costs, narrowing the price gap and increasing inter-regional trade flows, leading to an improved trade environment, better market integration and an increase in gross domestic product (GDP) per capita [13]. Accessibility provided by transportation infrastructure helps people secure jobs, gives access to a variety of services, and allows businesses to interact with customers and manufacturers [14]. Transportation infrastructure is characterized by its durability, high construction and maintenance costs, long construction and use periods, and linear or point-to-point nature. Despite its many benefits, its development is associated with serious environmental consequences, including CO2 emissions from fossil fuels. Improving transportation infrastructure is key to allocating resources efficiently, creating a favorable business environment and providing higher returns on investment. In addition, government spending on transportation increases economic competitiveness, promotes trade, tourism, foreign investment and job creation [15].

The development of transportation infrastructure in cities should include not only automobile transportation, but also the development of public transport systems, pedestrian and bicycle paths, which positively affects the quality of life of residents. These investments must take into account measures to combat climate change, promoting low-carbon modes of transportation and investments in green infrastructure. The relationship between green infrastructure and transportation infrastructure is complex and dynamic, and their integration is key to achieving the goals of improving quality of life, reducing emissions and achieving social and economic sustainability.

Green infrastructure can mitigate problems associated with urbanization, support biodiversity, improve citizens' health, and increase resilience to climate change. The use of green infrastructure depends on financial resources and the urban environment, making it more accessible to wealthier neighborhoods. Economic barriers, such as entrance fees and transportation costs, can limit access to green spaces, so eliminating these obstacles is key to promoting social equity and inclusive access. Understanding inequalities in access to green infrastructure requires taking into account individual and neighborhood factors, the impact of which is still not fully understood [16].

Urbanization and growing urban populations are challenging existing transportation networks, requiring investment in new solutions and adaptation of current systems to meet the needs of modern agglomerations. It is crucial to ensure equal access to public transportation and infrastructure for all segments of society, especially the less affluent, in order to promote sustainable development. Transportation is a basic need that affects residents' independence, autonomy and quality of life [17].

3 Methodology

The process of constructing a synthetic measure using the TOPSIS method involves the following steps (Hajduk, Jelonek, 2021) [18]: (1) selection and verification of diagnostic variables (both substantive and statistical); (2) normalization variables and identification of stimulants and destimulants; (3) aggregation of the synthetic measure of linear infrastructure using the TOPSIS method; (4) ranking of voivodeships based on the synthetic measure of linear infrastructure; and (5), (6) interpretation of the results in relation to the studied entities.

To create a synthetic measure, diagnostic variables were chosen based on their substantive relevance, adequate coefficient of variation, and low correlation with other variables [19-20]. Table 1 presents the selected variables, which were gathered across the voivodeships of Poland.

Table 1 Diagnostic variables used in the analysis of linear infrastructure of voivodships in Poland

X1	Expenses Total transport and communications	pln/per capita	Stymulant
X2	Expenses - voivodship public roads	pln/per capita	Stymulant
X3	Roads for bicycles	km/100km2	Stymulant
X4	Total public roads	km/100km2	Stymulant
X5	Expressways and highways	km/100km2	Stymulant
X6	total bridges and viaducts	sz/100km2	Stymulant
X7	total railroads	km/100km2	Stymulant

A matrix of observations, denoted as X_{ij}, is used to represent the set of diagnostic variables:

$$X_{ij} = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

where: $X_{ij} \in R$ - denotes the values of the i-th test object relative to the j-th diagnostic variable, i - object number (i = 1, 2, ..., n), j - variable number (j = 1, 2, ..., m).

The zeroed unitarization method was applied to normalize the diagnostic variables, scaling all values to the interval [0,1]. The variables are normalized according to the specified formulas [21]:

$$Z_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \text{when } x_i \in S, \quad (2)$$

$$Z_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \text{when } x_i \in D, \quad (3)$$

where: S-stimulant, D-destimulant; $\max_{xij}$ - the maximum value of the j-th variable, $\min_{xij}$ - the minimum value of the j-th variable, x_{ij} – denotes the value of the j-th variable for the i-th object [22], Z_{ij} normalization value of the j-th variable for the i-th object [23].

The unitization process produces a value matrix represented by the function Z_{ij}, which is expressed as follows:

$$Z_{ij} = \begin{bmatrix} z_{11} & \cdots & z_{1n} \\ \vdots & \ddots & \vdots \\ z_{m1} & \cdots & z_{mn} \end{bmatrix}, \quad (4).$$

The following formulas were used to compute the voivodeship's Euclidean distances from the pattern and anti-pattern:
(a) the distances of objects from the pattern:

$$d_i^+ = \sqrt{\frac{1}{n}\sum_{j=1}^{m}\left(z_{ij} - z_j^+\right)^2} \quad (5)$$

(b) the distance of objects from the anti-pattern:

$$d_i^- = \sqrt{\frac{1}{n}\sum_{j=1}^{m}\left(z_{ij} - z_j^-\right)^2} \quad (6)$$

where: n- denotes the number of variables building a pattern or anti-pattern, z_{ij}- denotes the normalized value of the j-th characteristic for the unit under study (or the normalized value of the j-th variable i-th object), z_j^+ / z_j^- - denotes a pattern or anti-pattern object [24].

The Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method was used to determine the synthetic measure for each province according to the formula (7):

$$q_{i\,(synthetic\ measure\ of\ linear\ infrastructure)} = \frac{d_i^-}{d_i^- + d_i^+}, gdzie\ 0 \le q_i \le 1, i = 1, 2, \ldots, n; \quad (7)$$

where: $q_i \in [0; 1]$; d_i^- - denotes the distance of the object from the anti-pattern (from 0), d_i^+ - denotes the distance of the object from the pattern (from 1). A higher value of the measure indicates the better situation of an individual in the studied area [25].

Based on the mean ($\bar{x}$) and standard deviation (Sd), four groups were found ordering the synthetic measure's values, according to the formula (8):

Group I (highest level)	$S(\bar{x})+S(s) \le q_i$	(8)
Group II (high level)	$S(\bar{x}) \le q_i < S(\bar{x})+S(s)$	
Group III (medium level)	$S(\bar{x})-S(s) \le q_i < S(\bar{x})$	
Group IV (low level)	$q_i < S(\bar{x})-S(s)$	

In Statistica software, bag plots, Gini coefficient, maps of spatial differentiation of provinces according to the synthetic measure, Pearson's linear correlation coefficients, Sperman's rank, gamma, and Kendall's tau were created.

4 Results and discussion

As society progresses and international relations become more interconnected, the role of transport infrastructure as a driver of economic and social development is becoming increasingly significant. The synthetic measure of linear infrastructure ranged from 0.01 (Warmińsko-Mazurskie) to 0.60 (Śląskie) in 2010, and from 0.31 (Świętokrzyskie, Podlaskie) to 0.56 (Śląskie, Małopolskie) in 2021. A higher value of the synthetic measure (q) indicates a better position and greater competitiveness of the voivodeship within the analyzed region (Table 2). These variations highlight the disparities in the development of linear infrastructure across Poland's regions. The differences in the synthetic measure reflect not only the level of infrastructure development but also the varying capacities of these regions to support economic growth and improve accessibility. It provides valuable insight into the evolving patterns of regional development and competitiveness.

Table 2 Groups of synthetic measure of the attractiveness of linear infrastructure of voivodships in Poland in 2011 and 2021

gr	voivodeship	synthetic measure in 2011	voivodeship	synthetic measure in 2021
I	Śląskie	0.60	Małopolskie	0.56
	Małopolskie	0.42	Śląskie	0.56
	Dolnośląskie	0.39	Dolnośląskie	0.49
II	Opolskie	0.29	Łódzkie	0.41
	Wielkopolskie	0.25	Kujawsko-pomorskie	0.41
			Wielkopolskie	0.40
III	Kujawsko-Pomorskie	0.23	Mazowieckie	0.39
	Świętokrzyskie	0.23	Lubelskie	0.38
	Mazowieckie	0.21	Warmińsko-mazurskie	0.36
	Łódzkie	0.21	Zachodniopomorskie	0.36
	Lubuskie	0.20	Pomorskie	0.36
	Pomorskie	0.20	Lubuskie	0.34
	Zachodniopomorskie	0.18	Opolskie	0.34
	Podkarpackie	0.18	Podkarpackie	0.33
	Lubelskie	0.17		
	Podlaskie	0.13		
IV	Warmińsko-Mazurskie	0.07	Podlaskie	0.31
			Świętokrzyskie	0.31

In Poland, there is significant regional variation in key elements of transport infrastructure, particularly in the density of motorways, expressways, and operational railways. In 2019, the density of municipal and district hard-surfaced roads in Poland reached 82.6 km per 100 km², marking an increase of 25% compared to 2005, when the density was 66.2 km per 100 km². This indicates a considerable improvement in the accessibility of local areas across the country in recent years. Such developments should be seen as highly positive, as they enhance opportunities for further regional growth and better connectivity within Poland [26]. The development of road infrastructure in Poland is a necessity and guarantees great benefits for society. Developed road infrastructure strengthens the economic, spatial and social cohesion of the country and its regions, provides opportunities to save on storage and transport costs, facilitates the sale of goods and services outside local markets, enables the movement of workers to more efficient and attractive regions, and increases the level of mobility of society [27].

Table 3 Descriptive statistics of diagnostic variables and synthetic measures of attractiveness of linear infrastructure of voivodeships in Poland in 2011 and 2021

	Average	Minimum	Maximum	Range	Quartile Range	Standard deviation	Coefficient of variation	Skewness	Kurtosis
	2011								
synthetic measure of linear infrastructure	0.25	0.07	0.60	0.53	0.09	0.13	51.93	1.60	3.06
expenditures transport and communications	172.52	135.48	240.81	105.33	46.13	32.98	19.12	0.92	-0.02
expenses - voivodship public roads	99.24	41.25	150.34	109.09	31.79	30.06	30.29	0.20	-0.07
roads for bicycles	1.91	0.83	4.54	3.71	1.51	0.98	51.56	1.17	2.04
public roads	134.03	83.30	214.50	131.20	34.50	34.85	26.00	0.98	1.13
expressways and highways	0.61	0.00	1.98	1.98	0.62	0.52	84.59	1.15	1.99
bridges and viaducts	12.13	5.00	33.00	28.00	7.50	8.50	70.10	1.56	1.40
railroads	6.96	3.80	17.40	13.60	2.00	3.17	45.50	2.58	8.28
	2021								
synthetic measure of linear infrastructure	0.39	0.31	0.56	0.26	0.07	0.08	19.97	1.27	0.87
expenditures transport and communications	232.34	147.18	358.48	211.30	65.66	55.32	23.81	0.97	0.50
expenses - voivodship public roads	126.22	69.88	247.46	177.58	54.90	45.10	35.73	1.33	2.31
roads for bicycles	5.92	3.08	11.10	8.02	3.45	2.14	36.16	0.91	0.70
public roads	138.74	85.60	207.50	121.90	35.75	33.32	24.02	0.59	0.52
expressways and highways	1.49	0.81	2.95	2.14	0.81	0.66	44.11	1.15	0.61
bridges and viaducts	13.69	6.00	36.00	30.00	7.50	9.04	66.04	1.57	1.46
railroads	6.61	3.80	15.20	11.40	1.95	2.67	40.38	2.39	7.27

Effective transport infrastructure is crucial for the economy and society, but it also impacts the environment in various ways. Between 2011 and 2021, measures of central tendency (mean) increased (except for railways), while variability measures (standard deviation, coefficient of variation) showed both increases and decreases. Higher kurtosis values indicate a more concentrated distribution around the mean, while lower kurtosis reflects a wider spread of values. The synthetic measure showed left skewness for variables like bicycle roads, public roads, and railways (AS<0), and right skewness for transport and communication, spending on provincial roads, expressways, motorways, and bridges (AS>0). Left skewness means more units have values above the mean, while right skewness indicates the opposite. The degree of skewness reflects the distribution's asymmetry (Table 3).

Central and Eastern European countries have significant deficiencies in transport infrastructure, which affects economic development and production. Transport infrastructure should be evaluated both as a whole and by transport mode. Key factors for analysis include the level of transport, internationalisation, infrastructure quality, and efficiency of services. Among EU countries, the Netherlands leads in transport development, while Bulgaria ranks lowest. The Baltic States lag in transport internationalisation compared to EU leaders such as Germany, the UK, and Spain [28].

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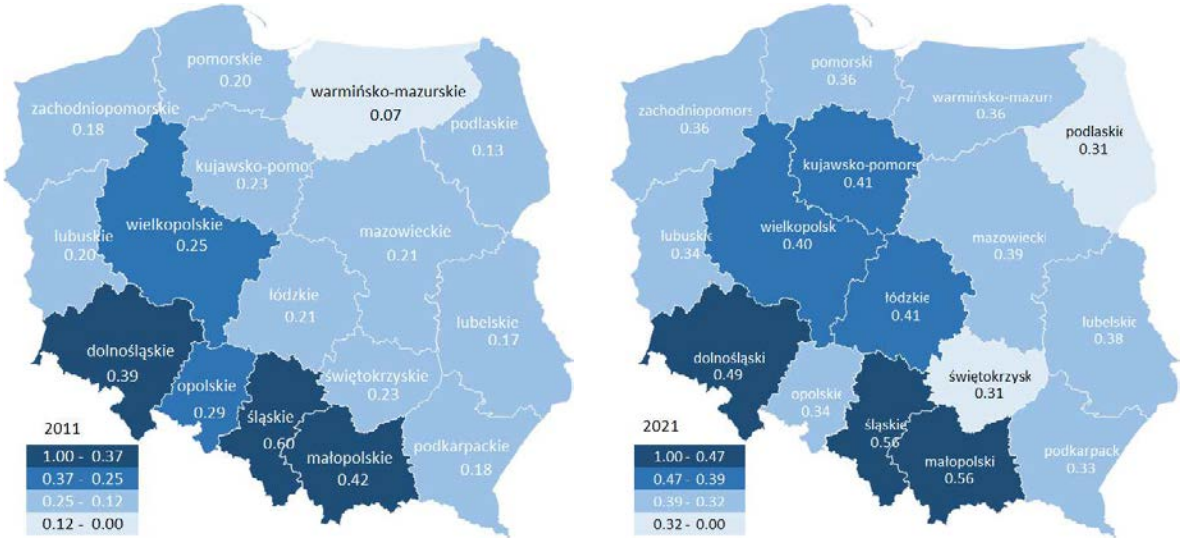

Figure 1 Division of provinces according to the value of the measure synthetic attractiveness of linear infrastructure of provinces in Poland in 2011 and 2021

The voivodeships with well-developed linear (transport) infrastructure include Śląskie, Dolnośląskie, and Małopolskie, where increased spending on public roads and the development of expressways and motorways are evident. These investments are crucial due to the underdeveloped railway network and the growing demand for both passenger and freight transport. Voivodeships such as Podlaskie and Świętokrzyskie, while showing progress in road infrastructure development, still lag economically and fail to fully capitalize on the advantages of a developed road network. Transport infrastructure plays a vital role in enhancing economic competitiveness, innovation, and territorial cohesion. As a result of insufficient transport infrastructure, areas with low spatial accessibility have emerged in Poland's regional and national system. Based on the mean value and standard deviation, the provinces were categorized, with darker colors indicating better-performing regions according to the primary criteria and lighter colors reflecting weaker regions (Figure 1).

In the voivodeships, expenditure on infrastructure development accounts for a significant part of the budget and is one of the most anticipated investments by the local community. The directions of development of transport infrastructure may include revitalisation, modernisation or construction of new transport routes. The length and density of the road network varies by province. The values of the individual indicators differ considerably, which is due to various conditions, the most important of which seem to be historical-geographical factors, the difference in area, the difference in population and the different economic characteristics of the provinces. The geographical indicator (per 100km2) was the highest in both Śląskie and Małopolskie voivodeships, and the lowest in Warmińsko-Mazurskie, Zachodniopomorskie, Lubuskie and Podlaskie. Other results, which are sometimes the inverse of the geographical indicator, occurred in the case of the demographic indicator, which is due to the population size of Polish voivodeships [29].

There is a systematic increase in the demand for transport in Poland. This is due to an increase in the volume of production, international exchange, concentration of production and service activities, changing lifestyles and increased mobility of the population. At the same time, despite the considerable involvement of the administration in the development of the road system, the quantitative and qualitative development of the road infrastructure and its condition are not adequate to Poland's expectations. The development of the road infrastructure will become increasingly difficult, the construction of new roads is not only a significant investment, it is also an often difficult to accept transformation and occupation of land. It is therefore becoming necessary to make better use of the existing road infrastructure [30]. It is therefore necessary to complete the road infrastructure in the east of our country as soon as possible.

The values of the individual indicators differ significantly from each other, which is due to various conditions, of which the most significant seem to be historical-geographical factors, the difference in area, the difference in population and the different economic specificities of the provinces. In terms of these variables, the provinces of group I are in a better situation than the others. The length and density of the road network varies from voivodeship to voivodeship in Poland (group I units are in a better situation, group IV units in a weaker one).

Figure 2 illustrates the relationship between the synthetic measure of linear infrastructure and two key indicators: gross domestic product (GDP) per capita and per capita household transport expenditure. The chart highlights the differentiation among voivodeships based on these factors, identifying outliers that belong to Group I, which stand out in terms of their unique characteristics. The shape and distribution of these groups in subsequent years may reveal trends of convergence or divergence, reflecting the evolving disparities or improvements in infrastructure development and its impact on economic performance and household transport expenditure across the regions.

Table 4 The average value of the synthetic measure and diagnostic variables by synthetic measure group attractiveness of linear infrastructure of voivodships in Poland in 2011 and 2021

groups	I	II	III	IV	I	II	III	IV
	2011				2021			
synthetic measure of linear infrastructure	0.47	0.27	0.19	0.07	0.54	0.41	0.36	0.31
number of units	3	2	10	1	3	3	8	2
expenses on transport and communications	184.56	183.67	169.42	145.09	221.2	190.43	252.01	233.24
expenses - voivodship public roads	93.74	94.1	105.13	67.14	112.91	103.68	132.19	156.08
roads for bicycles	2.79	2.5	1.63	0.88	7.35	7.09	5.49	3.74
public roads	177.53	127.3	126.17	95.5	178.9	146.13	119.98	142.45
expressways and highways	1.28	0.88	0.39	0.3	2.16	1.96	1.21	0.86
bridges and viaducts	28	11.5	8.1	6	30.67	9	10	10
railroads	11.23	8.1	5.64	5.1	10.4	6.3	5.71	5
gross domestic product per capita	41656.3	37719.5	35745.6	29175	70138.7	65425	61225.1	50339.5
household transportation expenditures (average monthly expenditure per person)	98.05	92.14	91.49	65.49	132.48	110.27	123.2	101.56

The role of infrastructure in the economic development process consists mainly in creating the conditions for production activities. The lack of transport infrastructure may be the cause of the marginalisation of regions, i.e. their exclusion from development processes and thus the exclusion of their inhabitants. It increases the production capacity of an area by increasing accessibility to resources, as well as extending the productivity of already existing resources. The influence of the diagnostic variables of the synthetic measure of lion infrastructure, gross domestic product per capita and per capita household transport expenditure on the level of the synthetic measure is presented in Table 5.

Table 5 Correlation of the synthetic measure of lion infrastructure attractiveness and the diagnostic variables of voivodships in Poland in 2011 and 2021 (Marked correlation coefficients are significant with p < .05000; N=16)

	synthetic measure of linear infrastructure							
	Pearson's linear correlation coefficient		Spearman's rank correlation coefficient		Gamma correlation coefficient		Kendall's tau correlation coefficient	
	2011	2021	2011	2021	2011	2021	2011	2021
expenses on transport and communications	0.03	-0.14	0.01	-0.11	0.03	-0.07	0.03	-0.07
expenses - voivodship public roads	-0.28	-0.27	-0.24	-0.33	-0.20	-0.25	-0.20	-0.25
roads for bicycles	0.72	0.53	0.61	0.54	0.52	0.38	0.52	0.38
public roads	0.76	0.70	0.56	0.55	0.40	0.35	0.40	0.35
expressways and highways	0.83	0.64	0.82	0.67	0.66	0.50	0.66	0.50
bridges and viaducts	0.93	0.82	0.68	0.28	0.56	0.21	0.55	0.21
railroads	0.89	0.68	0.88	0.45	0.73	0.32	0.73	0.32
gross domestic product per capita	0.35	0.38	0.64	0.61	0.45	0.40	0.45	0.40
household transportation expenditures (average monthly expenditure per person)	0.23	0.22	0.39	0.30	0.30	0.20	0.30	0.20

Spatial differentiation of Poland's voivodeship in the context of linear infrastructure development in 2011-2021

Lukasz Poplawski, Pawel Dziekanski, Alina Danilevica, Bartosz Niescior

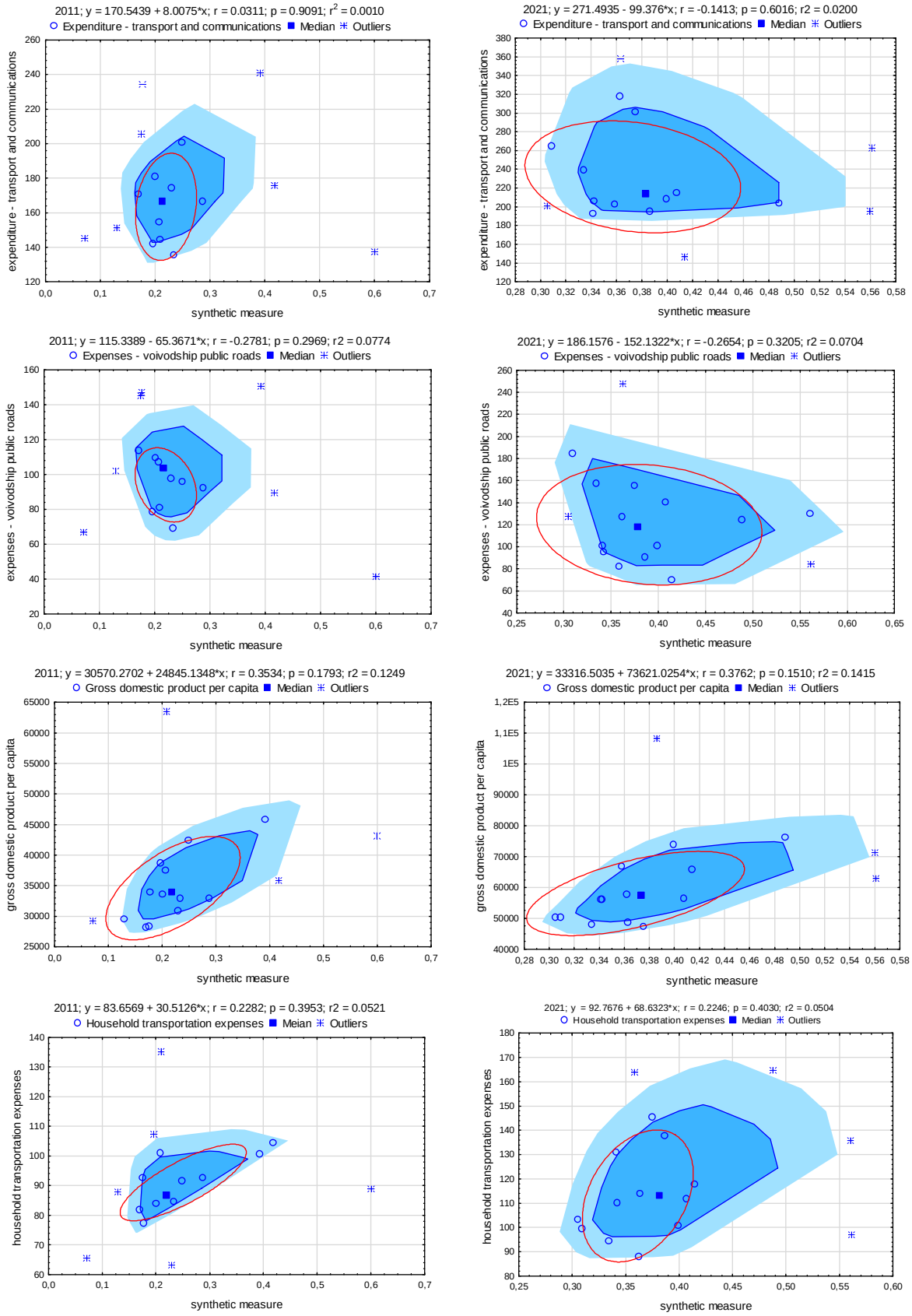

Figure 2 Scatter plot with fit line for the synthetic measure of attractiveness of linear infrastructure and the diagnostic variables of linear infrastructure of voivodeships in Poland in 2011 and 2021

The Gini coefficient of concentration (Table 6) reflects changes in the differentiation of voivodeships, showing either increasing or decreasing inequality. A higher Gini coefficient indicates greater regional disparities in terms of transport infrastructure, while a lower value suggests more equal development across regions. Barriers to improving transport infrastructure within voivodeships include the local economy's state and structure, as well as factors related to quality of life and environmental conditions. Additionally, historical development patterns, political decisions, and funding allocation can also impact the pace and extent of infrastructure improvements, further contributing to regional disparities. Overcoming these barriers requires targeted policy interventions and investments aimed at reducing inequalities.

Table 6 The Gini coefficient for the synthetic measure and diagnostic variables of the linear infrastructure of voivodships in Poland in 2011 and 2021

	2011	2021
	Gini coefficient	
synthetic measure of linear infrastructure	0.38	0.23
expenses on transport and communications	0.23	0.25
expenses - voivodship public roads	0.29	0.31
roads for bicycles	0.39	0.32
public roads	0.26	0.25
expressways and highways	0.57	0.35
bridges and viaducts	0.46	0.44
railroads	0.33	0.31
gross domestic product per capita	0.24	0.25
household transportation expenditures (average monthly expenditure per person)	0.22	0.23

A robust and efficient infrastructure is essential for the smooth functioning of the economy. In countries with high infrastructure quality ratings, such as Germany and the UK, well-established investment mechanisms are in place. These mechanisms provide benchmarks for decision-making and the assessment of investment effectiveness [31].

Infrastructure consolidations are characterized by a small average area and often face difficulties in building linear infrastructure, which can be a barrier to development. Infrastructure consolidation also provides opportunities to create public spaces and improve transportation and drainage networks, which supports rural development [32].

Transportation plays a key role in promoting social cohesion, creating connections between people and their needs. Transportation systems are usually evaluated in terms of economic efficiency, but sustainable urban development requires access to (sustainable) transportation. With rising real estate prices (e.g., housing), people with lower incomes may have to rely on cars, undermining sustainability goals. It is therefore important to better integrate transportation and land use planning [33].

5 Conclusions

Despite the ongoing intensive development of linear infrastructure, significant disparities remain between Poland's voivodships. The quality and extent of transport infrastructure are considered crucial factors for the economic development of both cities and entire regions. Well-developed infrastructure not only facilitates trade but also enhances the mobility of labor, which positively influences the flow of human resources. Furthermore, improved transport systems contribute to reducing regional disparities by providing more equitable access to economic opportunities, thereby strengthening the overall competitiveness of regions.

The synthetic measure of linear infrastructure ranged from 0.01 (warmińsko-mazurskie) to 0.60 (śląskie) in 2010 and 0.31 (świętokrzyskie, podlaskie) to 0.56 (śląskie, małopolskie) in 2021. The provinces well equipped with linear (transport) infrastructure include the provinces of śląskie, dolnośląskie, małopolskie. Voivodeships where road connections are visibly developing include podlaskie, świętokrzyskie.

Regional authorities constantly face challenges arising from a dynamic economic, technical, sociocultural, and natural environment. To effectively address these challenges, it is crucial to ensure not only rapid but also balanced and sustainable development of infrastructure across regions. Ongoing monitoring and analysis of linear infrastructure are essential for authorities to assess and adjust their policies based on real-time data, especially regarding the disparities between provinces. The changes observed in synthetic measures should be used as a tool for evaluating the outcomes of previous management strategies, particularly in terms of their impact on the key infrastructure indicators. A major concern for many regions, especially in relation to infrastructure, is depopulation. To counter this trend, authorities study demographic and migration patterns and assess residents' satisfaction with life in the region. In future studies, it will be important to incorporate additional variables such as the transition to a green economy, the expansion of green infrastructure, and the broader impacts on quality of life and the environment. These factors are vital for ensuring sustainable development and improving the living standards of local communities.

The limitations of the research conducted on on the evaluation of linear infrastructure are primarily related to the availability and accessibility of data within the framework of the Statistics Poland. Additionally, challenges arise from the comparability of the variables used to describe the phenomenon being studied, as some variables may differ across regions or over time. Changes in

legislation, which can affect the interpretation and collection of data, further complicate the research process. Moreover, the scope of tasks and responsibilities carried out by provincial authorities can vary, influencing the extent to which infrastructure development and other factors are addressed. These factors collectively present challenges in ensuring consistent and accurate analysis across different regions and time periods.

The value of this article lies in the presentation of the results regarding the spatial differentiation of linear infrastructure for the years 2011 and 2021. The findings contribute to ongoing discussions surrounding the development and condition of a country's linear infrastructure, as well as its broader environmental context. This topic gains particular relevance in light of the European Green Deal, which emphasizes the transition to cleaner, more sustainable forms of transportation. By examining infrastructure trends over the past decade, the article provides valuable insights into how transport networks can evolve to align with the goals of environmental sustainability, economic growth, and the reduction of carbon emissions.

References

[1] WU, S., LI, B.V.: Sustainable linear infrastructure route planning model to balance conservation and socioeconomic development, *Biological Conservation*, Vol. 266, No. February, 109449, pp. 1-11, 2022. https://doi.org/10.1016/j.biocon.2022.109449

[2] TAN, R., PAN, L., XU, M., HE, X.: Transportation infrastructure, economic agglomeration and non-linearities of green total factor productivity growth in China: Evidence from partially linear functional coefficient model, *Transport Policy*, Vol. 129, No. December, pp. 1-13, 2022. https://doi.org/10.1016/j.tranpol.2022.09.027

[3] CRESCENZI, R., RODRÍGUEZ-POSE, A.: Infrastructure and regional growth in the European Union, *Papers in Regional Science*, Vol. 91, No. 3, pp. 487-513, 2012. https://doi.org/10.1111/j.1435-5957.2012.00439.x

[4] HU, W., SHU, X., HUANG, B.: Sustainability innovations in transportation infrastructure: An overview of the special volume on sustainable road paving, *Journal of Cleaner Production*, Vol. 235, No. October, pp. 369-377, 2019. https://doi.org/10.1016/j.jclepro.2019.06.258

[5] GANTER, A., GABRIELLI, P., SANSAVINI, G.: Near-term infrastructure rollout and investment strategies for net-zero hydrogen supply chains, *Renewable and Sustainable Energy Reviews*, Vol. 194, No. April, 114314, pp. 1-17, 2024. https://doi.org/10.1016/j.rser.2024.114314

[6] LOORBACH, D., FRANZESKAKI, N., THISSEN, W.: Introduction to the special section: Infrastructures and transitions, *Technological Forecasting and Social Change*, Vol. 77, No. 8, pp. 1195-1202, 2010. https://doi.org/10.1016/j.techfore.2010.06.001

[7] SUNDNES, K.O., DICKE, W., BRUIJNE, M.: The transectional structure of society: The basic societal functions, *Scandinavian Journal of Public Health*, Vol. 42, pp. 36-47, 2014. https://doi.org/10.1504/IJPP.2009.025080

[8] ZHANG, Y., CHENG, L.: The role of transport infrastructure in economic growth: Empirical evidence in the UK, *Transport Policy*, Vol. 133, pp. 223-233, 2023. https://doi.org/10.1016/j.tranpol.2023.01.017

[9] ROMER, P.M.: Endogenous technological change, *Journal of Political Economy*, Vol. 98, No. 5, pp. 71-102, 1990.

[10] MITOULIS, S.A., BOMPA, D.V., ARGYROUDIS, S.: Sustainability and climate resilience metrics and trade-offs in transport infrastructure asset recovery, *Transportation Research Part D: Transport and Environment*, Vol. 121, 103800, pp. 1-22, 2023. https://doi.org/10.1016/j.trd.2023.103800

[11] CHAMPAGNE, M.P., DUBÉ, J.: The impact of transport infrastructure on firms' location decision: A meta-analysis based on a systematic literature review, *Transport Policy*, Vol. 131, No. February, pp. 139-155, 2023. https://doi.org/10.1016/j.tranpol.2022.11.015

[12] LIU, Z., ZENG, S., JIN, Z., SHI, J.J.: Transport infrastructure and industrial agglomeration: Evidence from manufacturing industries in China, *Transport Policy*, Vol. 121, No. June, pp. 100-112, 2022. https://doi.org/10.1016/j.tranpol.2022.04.001

[13] WU, M., YU, L., ZHANG, J.: Road expansion, allocative efficiency, and pro-competitive effect of transport infrastructure: Evidence from China, *Journal of Development Economics*, Vol. 162, No. May, 103050, pp. 1-21, 2023. https://doi.org/10.1016/j.jdeveco.2023.103050

[14] LEE, J.K.: Transport infrastructure investment, accessibility change and firm productivity: Evidence from the Seoul region, *Journal of Transport Geography*, Vol. 96, 103182, pp. 1-11, 2021. https://doi.org/10.1016/j.jtrangeo.2021.103182

[15] MOHMAND, Y.T., MEHMOOD, F., MUGHAL, K.S., ASLAM, F.: Investigating the causal relationship between transport infrastructure, economic growth and transport emissions in Pakistan, *Research in Transportation Economics*, Vol. 88, 100972, pp. 1-9, 2021. https://doi.org/10.1016/j.retrec.2020.100972

[16] WU, Y., WEI, Y.D., LIU, M., GARCÍA, I.: Green infrastructure inequality in the context of COVID-19: Taking parks and trails as examples, U*rban Forestry & Urban Greening*, Vol. 86, 128027, pp. 1-10, 2023. https://doi.org/10.1016/j.ufug.2023.128027

[17] BOROWSKA-STEFAŃSKA, M., DULEBENETS, M.A., KOWALSKI, M., SAHEBGHARANI, A., TUROBOŚ, F., WIŚNIEWSKI, S., BEDNAREK, Z.: Analyzing mobility pattern and transport exclusion of older people in łódź province, Poland using statistical and clustering techniques, *Journal of Transport & Health*, Vol. 35, No. March, 101767, pp. 1-18, https://doi.org/10.1016/j.jth.2024.101767

[18] HAJDUK, S., JELONEK, D.: A Decision-Making Approach Based on TOPSIS Method for Ranking Smart Cities in the Context of Urban Energy, *Energies*, Vol. 14, No. 9, 2691, pp. 1-23, 2021. https://doi.org/10.3390/en14092691

[19] MŁODAK, A.: *Analiza taksonomiczna w statystyce regionalnej*, Publisher Wyd. Difin, Warszawa, 2006. (Original in Polish)

[20] WALESIAK, M.: Problemy selekcji i ważenia zmiennych w zagadnieniu klasyfikacji, *Prace Naukowe AE we Wroclawiu*, Taksonomia 12, pp. 106-118, 2005. (Original in Polish)
[21] KUKUŁA, K.: Zero unitarisation method as a tool in ranking research, *Economic Sciences for Rural Development*, Vol. 36, pp. 95-100, 2014.
[22] WYSOCKI, F., LIRA, J.: *Statystyka opisowa*, Publisher Wyd. AR, Poznań, 2005.
[23] SOMPOLSKA-RZECHUŁA, A.: Selection of the Optimal Way of Linear Ordering of Objects: Case of Sustainable Development in EU Countries, *Statistics & Economy Journal*, Vol. 101, pp. 24-36, 2021.
[24] VAVREK, R., PAPCUNOVÁ, V., TEJ, J.: Evaluation of Financial Management of Towns in relation to Political Cycles using CV-TOPSIS, *Lex Localis*, Vol. 18, No. 2, pp. 231-252, 2020.
[25] GODLEWSKA, J., SIDORCZUK-PIETRASZKO, E.: Taxonomic Assessment of Transition to the Green Economy in Polish Regions, *Sustainability*, Vol. 11, No. 18, 5098, pp. 1-25, 2019. https://doi.org/10.3390/su11185098
[26] PRUS, P., SIKORA, M.: The Impact of Transport Infrastructure on the Sustainable Development of the Region—Case Study, *Agriculture*, Vol. 11, No. 4, 279, pp. 1-15, 2021. https://doi.org/10.3390/agriculture11040279
[27] WASILEWSKA-MARSZAŁKOWSKA, I.: *Spedycja we współczesnych łańcuchach dostaw*, Publisher Wyd. CeDeWu, Warszawa, 2014. (Original in Polish)
[28] BALODIS, J., KOMAROVA, V., ČIŽO, E., RUZA, O., KOKAREVICA, A.: Assessing the transport development of the European Union countries, *Entrepreneurship and Sustainability Issues*, Vol. 10, No. 2, pp. 130-146, 2022. https://doi.org/10.9770/jesi.2022.10.2(8)
[29] KAROLEWSKI, M., ROMAN, M.: Przestrzenne zróżnicowanie rozwoju infrastruktury liniowej transportu drogowego w Polsce w latach 2004–2019, *Economics and Organization of Logistics*, Vol. 6, No. 1, pp. 39-49, 2021. https://doi.org/10.22630/EIOL.2021.6.1.4 (Original in Polish)
[30] KOS, B.: Kierunki poprawy efektywności zarządzania siecią drogową w Polsce, *Studia Ekonomiczne, Zeszyty Naukowe Uniwersytetu Ekonomicznego w Katowicach*, Vol. 136, pp. 149-164, 2013. (Original in Polish)
[31] KUZMINA-MERLINO, I., SKOROBOGATOVA, O., SCHMIDTKE, N., BEHRENDT, F.: *Mechanism for investment in the transport infrastructure development in Latvia*, In: Kabashkin, I., Yatskiv, I., Prentkovskis, O. (eds) Reliability and Statistics in Transportation and Communication, RelStat 2017, Lecture Notes in Networks and Systems, Vol. 36, Springer, Cham, pp. 507-518, 2018. https://doi.org/10.1007/978-3-319-74454-4_49
[32] DUDZIŃSKA, M., BACIOR, S., PRUS, B.: Considering the level of socio-economic development of rural areas in the context of infrastructural and traditional consolidations in Poland, *Land Use Policy*, Vol. 79, pp. 759-773, 2018. https://doi.org/10.1016/j.landusepol.2018.09.015
[33] RADZIMSKI, A.: Accessibility of social housing by sustainable transport modes: A study in Poznań, Poland, *Journal of Transport Geography*, Vol. 111, No. July, pp. 1-14, 103648, 2023. https://doi.org/10.1016/j.jtrangeo.2023.103648

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The impact of management systems and human resources on logistics performance: an empirical study
Giselle Rodriguez-Rudi, Diego Humberto Carreno-Benavides, Ana Julia Acevedo-Urquiaga, Neyfe Sablon-Cossio

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The impact of management systems and human resources on logistics performance: an empirical study

Giselle Rodriguez-Rudi
Anahuac University Xalapa, Economic and Administrative Department Xalapa, Arco Sur s/n, Lomas Verdes, Xalapa, Veracruz, Veracruz, 91098, Mexico, https://orcid.org/0000-0002-0555-1376, giselleрod1019@yahoo.es
Diego Humberto Carreno-Benavides
Technical University of Manabí, Faculty of Graduate Studies, Av. José María Urbina y Che Guevara, Portoviejo, Manabí, 130105, Ecuador, https://orcid.org/0000-0002-9174-988X, dcarreno0572@utm.edu.ec
Ana Julia Acevedo-Urquiaga
San Mateo University Foundation, Transversal 17 #25-25, Bogotá, 110111, Colombia, https://orcid.org/0000-0001-7867-1590, anajacevedo@sanmateo.edu.co
Neyfe Sablon-Cossio
Technical University of Manabí, Faculty of Graduate Studies, Av. José María Urbina y Che Guevara, Portoviejo, Manabí, 130105, Ecuador, https://orcid.org/0000-0002-6691-0037, nsabloncossio@gmail.com (corresponding author)

Keywords: administrative management, human resources, logistics performance, supply chain, SEM.
Abstract: The performance of logistics represents an essential dimension of supply chain management, incorporating a range of strategies and indicators to assess the proficiency and efficacy of logistics flows. This study empirically analyzes the relationships between management systems, human resources, and logistics performance in the province of Manabí, Ecuador. Using structural equation modeling (SEM), data was collected from a questionnaire of 144 questions evaluated in a Likert scale of five (5) points and applied to 117 managers across various industries. The results indicate that integration and personnel competency development significantly impact logistics performance. Likewise, the research highlights that to enhance logistics performance, companies should focus on improving their management systems, fostering integration with suppliers and customers, and providing effective training to enhance employee competencies. Additionally, the study emphasizes the importance of logistics infrastructure and human capital development as crucial factors for achieving efficient logistics performance. This paper contributes to understanding how management systems and human resources affect logistics performance in a developing region, providing a foundation for future strategies aimed at continuous improvement in local supply chains.

1 Introduction

Logistics performance is key to success at both the organizational and national levels. It affects supply chain efficiency and global trade competitiveness. It includes the effectiveness and efficiency of logistics activities, which include transportation, warehousing, inventory management, and order processing. The importance of logistics performance lies in its ability to reduce costs, improve service levels, and enhance the supply chain. This leads to a competitive edge and economic growth.

They are strategic, operational, and technological factors that affect a company's ability to manage its logistics. The promotion and development of human resources are currently as important as the creation of a logistics infrastructure in a country. Recent studies carried out in developing countries show that companies confront significant difficulties as regards hiring personnel with the skills and knowledge necessary to manage the integration of logistics processes, making this a frequently recognized problem.

In this respect, the studies carried out by Ahmad employ structural equations to analyze the influence of personnel on logistics performance in various environments. The first [1] is based on business systems and their influence on logistics performance, and future aspects of logistics are also defined simultaneously. The second [2], meanwhile, focuses on electronic reverse logistics and its development, and identifies the most critical factors and their relationship with electronic commerce. It specifies that an organization's culture has a direct influence I on electronic reverse logistics. The third [3] shows that logistics efficiency is positively correlated with electronic logistics, information technology capacity, information exchange, and the quality of service personnel. This work also emphasizes that electronic logistics favorably influences logistics performance.

Other research analyzes organizational management and logistics performance through the application of structural equations [2,4-6]. De Carvalho, et al. [4] also evaluate the performance of a city's logistics and the relationship between the actors involved, along with the efficiency and response capacity factors on the basis of urban parameters. In the case of Kankaew, et al. [5],the management and practices in an agri-food chain are mentioned, and as a result, the policies to be implemented as a consequence of a study carried out by managers.

Furthermore, in other research, integration and logistics performance are correlated by means of structural equations [7-12]. With regard to integration, the relationship between customers and suppliers and the interrelationship with performance is defined. The studies by Lai, et al. [9] also analyze information as part of integration and the relationship with collaboration in transportation. These elements are significant owing to the development of information and communications technologies and the globalization of supply chains. The work of Yingfei et al. (2022) [12], meanwhile, addresses logistics performance using a green approach. This interrelates the aforementioned concept with the service offered and the environment. This is owing to the need to implement the circular economy and the fact that logistics is a limiting factor.

Although several authors mention the variables and relationships that are analyzed in this study, this topic has not been explored in depth and there is consequently an information gap: that of validating the relationship between human resources, management systems and logistics performance.

The impact of personnel on logistics performance is mentioned in the studies cited above, although they do not, in general, analyze management as a factor that influences it. This signifies that there are not many studies that analyze the relationship between logistics performance, management systems and the work skills of logistics professionals. These elements make it possible to pose the following research questions:

Q1: What is the relationship between the organization's management systems and the logistics performance of a company?

Q2: What is the relationship as regards the integration of companies and logistics performance?

Q3: What is the relationship between human resources competencies and logistics performance?

In this respect, the objective of the research is to empirically analyze the current relationships between management systems, human resources, integration and logistics performance in the province of Manabí, Ecuador. This document is structured as follows: Section 2 presents an analysis of the application of structural models related to logistics performance and integration in the supply chain, while Section 3 shows an analysis of the training and knowledge management of logistics in Manabí, Ecuador. The materials and methods employed are provided in Section 4, and the results and analysis are shown in Section 5. Finally, Section 6 presents the conclusions, future lines and limitations of the present research.

1.1 Logistic performance

Logistics performance is like the engine of supply chain management. It is essential for everything to run smoothly. It measures how well your products are moving from the suppliers to the customer [13]. There are tools that help you evaluate efficiency (how fast you do it) and effectiveness (how well you do it). Logistics managers face challenges in achieving optimal performance, which are influenced by factors such as globalization, technological advancements, and regulatory changes [3]. These contests can significantly impact the efficiency and effectiveness of logistics operations.

In the literature there are studies that cover the estimation of logistics performance and the relationship between its corresponding activities. Within these, there is a tendency to use structural equation models to solve this type of problems. For example, Azevedo and Ferreira [14], analyze the performance measurement systems in logistics, the selection criteria for evaluation, define the variables and indicators. Based on the logistics activities and the indicators, they propose a model and hypothesis of the interaction between the previous elements. This includes integration as one of the research variables.

Other researchers, [5,9,15-17], propose a performance evaluation model in supply chains. The first researchers refer to the processes of the supply chains and associate indicators [15]. The second ones include the chain strategy as a variable [16]. Along these lines, other researchers analyze the relationships of supply chain practices, logistics indicators and competitiveness [5]. Kalubanga and Namagembe also take into account the organization (commitment, competence, reliability) and integration [13].

Ahmad and Mehmood, define logistics performance indicators and their relationship with the information system for the construction of cities of the future [1]. In this case, the study is directed at the business system, but takes into account logistics performance and organizational management. Other authors, De Carvalho and collaborators, study the same object [4]. In this case, they evaluate the performance of logistics in a city.

Bag and authors investigate how Industry 4.0 resources impact smart logistics along with the sustainability of business logistics [16]. This research takes into account integration through interconnection.

On the other hand, [3,9,18], include in the equation a variable related to human resource competencies. The approach is framed in the role of human resource competencies in improving logistics performance [18], and based on this they frame their hypotheses. Mai and coauthors demonstrated the evaluation with logistics performance, technology capacity and information sharing, and the quality of service personnel [3]. These studies demonstrate how the quality of employee service personnel positively affects logistics performance, part of our research.

Based on this background, the hypotheses of this research are defined and the applications of Table 1 are analyzed.

1.2 Application of structural models related to logistics performance

The number of publications that use quantitative multivariate analysis tools such as structural equation modeling (SEM) to test hypotheses and relationships between constructs that include latent variables and observed variables has increased in recent years. In order to begin the process of creating the model, a search was carried out in updated databases so as to verify the theoretical constructs and variables used in the current literature on this subject (Table 1):

Table 1 Studies that define variables that influence logistics performance and employ SEM/ PLS

Author/year	Reference	Logistics performance	Organization management	Integration	Human resources competence	SEM	PLS
(Azevedo and Ferreira, 2007)	[14]			X			X
(Jakhar and Barua 2014)	[15]	X				X	
(Ahmad and Mehmood 2016)	[1]	X	X			X	
(De Carvalho et al. 2019)	[4]	X				X	
(Bag, et al. 2020)	[16]			X			
(Chandak et al. 2020)	[17]	X				X	
(Masudin et al. 2020)	[19]	X				X	
(Prasetya and Wibawa 2020)	[20]	X				X	X
(Davidavičienė and Al Majzoub 2021)	[2]	X				X	
(Mesra 2021)	[18]	X			X	X	
(Sénquiz-Díaz 2021)	[21]	X				X	
(Falasca et al. 2022)	[22]	X					X
(Kalubanga and Namagembe 2022)	[13]	X	X	X		X	
(Kerdpitak 2022)	[8]	X	X			X	
(Lai, et al. 2022)	[9]	X			X	X	
(Mai et al. 2022)	[3]	X			X	X	
(Mokkhamakkul, 2022)	[23]	X	X			X	
(Moroni et al. 2022)	[10]	X		X		X	
(Thilakarathne et al. 2022)	[6]	X					X
(Wang et al. 2022)	[11]	X				X	
(Yingfei et al. 2022)	[12]	X					X
(Kovalenko 2023)	[24]	X				X	
(Chen and Hasan 2023)	[25]	X				X	X
(Ewuzie et al. 2023)	[26]	X				X	X
(Getele and Ruoliu 2023)	[27]	X		X		X	
(Maemunah and Nekrasov, 2023)	[28]	X				X	
(Sitisara et al., 2023)	[29]	X				X	

As clearly shown in the table above, few studies relate logistics performance and human resource competencies, despite the fact that this is, in our opinion, a limiting element in logistics. Using this concept as a basis, in this research the four variables are interrelated and the hypotheses used are justified. Moreover, the SEM method is simultaneously employed in order to solve these types of problems.

2 Training and knowledge management of logistics and supply chains in Manabí

The province of Manabí covers an area of 18,958 km^2 and is located within the coastal region of Ecuador. It has 22 cantons with a population of 1,369,780. The fundamental activities in the province are agriculture and fishing, and shrimp and tuna are two of the export rubles typical of the area. This demonstrates the need for logistics training in order to achieve competitiveness in the market.

With regard to professional, undergraduate and technological education in the province of Manabí, there are two training proposals. These proposals are developed in the technological field, and comprise the following courses: Higher Technology in Multimodal Logistics and Higher Technology in Port Logistics. They are studied at the Luis Arboleda Martínez Higher Technological Institute in the city of Manta.

With regard to postgraduate training in Logistics and supply chains in Manabí, one postgraduate course was identified: a Master's Degree in Industrial Engineering, which mentions logistics and supply chains. This is offered by the Technical University of Manabí in Portoviejo.

In the case of the research process at the universities of the province under study, there is a research group which states that logistics and supply chains are at the center of this area of science. This is called the UTM Production and Services Group (PROSERV). The above reaffirms the little interest that exists in the topic for research and application in this area of the country.

With regard to the lines of research, the classification of the UNESCO International Nomenclature for the fields of Science and Technology is followed by universities in Ecuador [30]. This infers that logistics is located in the area of mathematics and that supply chains are not shown in the first selection line (Table 2). This sometimes limits the focus of science.

Table 2 Six-digit level of classification of UNESCO fields

Specific field	**Detailed field**
Math	Operational Research (Distribution and transportation, inventories, queuing theory)
	Statistics (time series)
	Computer Science (Inventory Control)
Technological sciences	Environmental engineering and technology (industrial waste, recycling processes
	Regional and urban planning (transport and urban-rural relations)
	Industrial technology (Process engineering)
	Space technology (vehicle control)
	Oil and Coal Technology (Oil and Gas Storage)
	Railway Technology (Railway Services)
	Transportation systems technology (Urban traffic systems and Combination of systems)
Economic sciences	Economic activity (foreign trade, production
	General Economics (Consumer Behavior,
	International Economy (International Business,
	Business organization and management (Industrial studies, Marketing, Market studies, Operational research, Optimal production levels, Production organization and Sales management)

Source: The authors based on [30].

3 Methodology

The research was carried out from 2023 to 2024 on a total of 117 companies located in the province of Manabí, Ecuador. The sample consisted mainly of micro-enterprises located in the towns with the highest industrial activity in the province, as shown in Table 3.

Table 3 Characteristics of sample (n=117)

Company size	**Frequency**	**Percentage (%)**
Micro company (1 to 9 employees)	80	68.97
Small company (10 to 49 employees)	19	16.38
Medium company A (50 to 99 employees)	4	3.45
Medium company B (100 to 199 employees)	4	3.45
Large company (More than 200 employees)	10	8.62

The study was explanatory-correlational-causal because it analyzes the relationships between the variables of the logistics system. The decision was, therefore, made to use the SEM methodology recommended by [29], which is executed by following a series of steps, such as factor structure, exploratory factor analysis and confirmatory factor analysis. The structure and definition of the SEM methodology are followed simultaneously in order to obtain the data required for the construction of the model. With this objective in mind, a checklist evaluating the logistics system was applied [31]. This tool has 13 variables, and 144 questions evaluated in a Likert scale of five (5) points. The variables are defined as logistics concepts in the company (D1), organization and management (D2), information technology (D3), software system (D4), storage technology (D5), internal

transportation technology (D6), external transportation technology (D7), handling technology (D8), supply chain integration (D9), personnel (D10), logistics performance (D11), barriers (D12) and reverse logistics (D13).

The Competitive Logistics Reference Model (MRLC) questionnaire was then refined for the SEM model [31] and only the items concerning the variables under study were left in order to determine the extent to which the factors analyzed affect logistics performance. The independent variables selected were: organizational management systems (X1), integration (X2) and human resources competence (X3). One dependent variable was also selected: the performance of the logistics system (Y).

Management systems (X1) refer to planned actions and the updating of technologies to achieve demand forecasts and customer studies. The management systems scale therefore includes 5 items. The integration variable (X2) analyzes how the company incorporates the relationships and viewpoints of customers and suppliers to establish alliances that improve the services offered. X2 contains 12 items; some examples include: Level of use of alliances in the distribution channel and connection of the information system with customers. Human resources competence (X3) refers to the capacity of employees who perform logistics functions, encompassing aspects of knowledge, skills, and experience in the performance of their duties. X3 consists of 10 items. The dependent variable, the performance of the logistics system (Y), was defined as good practices aimed at meeting user needs through the use of a system of logistics indicators and contains 6 items. Some examples include: Frequent analysis of customer service level and Application of Benchmarking. All the items studied come from previously validated scales studied in the Competitive Logistics Reference Model (MRLC).

4 Result and discussion

4.1 Construction of the structural model

The population that was the object of this study comprised the 117 organizations in the province of Manabí, Ecuador, and all members of the population were, therefore, used as convenience samples. This study uses primary data, that is, the data obtained refers to first-hand information obtained by the researchers and related to the variables of interest for the specific purposes of the study. This information was used in order to define the hypotheses to be demonstrated in the construction of the model, as shown in Figure 1:

H1: Management systems competences (X1) positively influences logistics performance (Y).

H2: Companies' integration competence (X2) positively influences logistics performance (Y).

H3: Human resources competence (X3) positively influences logistics performance (Y).

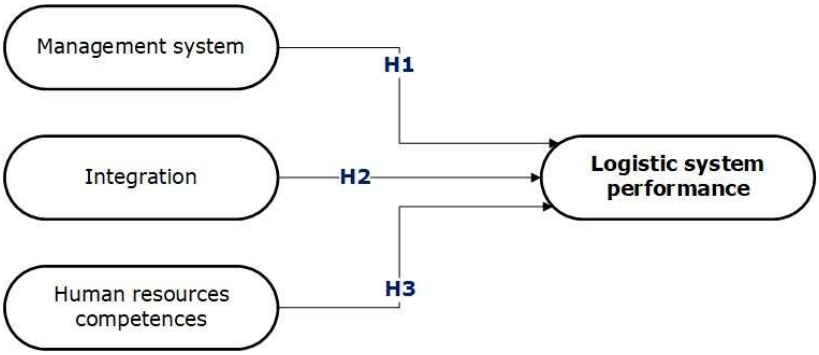

Figure 1 Theoretical model

Structural equation modeling using partial least squares (PLS-SEM) was employed to verify the proposed structural relationships and determine whether the model aligned with the hypotheses established in the research. The software used was Smart PLS version 4.1.0.

Structural equation modeling (SEM) was used to test the proposed relationships and meet the objectives set out in the research. In addition to coherently grouping the items, the exploratory factor analysis method of each scale was used to establish the items on the basis of their factor loadings. Items with factor loadings greater than 0.6 were retained as being optimal for further analysis, while items with low factor loadings were discarded [32], signifying that 14 articles were excluded. Once these elements had been eliminated, the correlations were recalculated. The items used to calculate the constructs are provided in Table 4.

The measures were validated using indices recommended in literature: Bartlett's test of sphericity, Cronbach's alpha, composite reliability (CR), and average variance extracted (AVE). A construct is considered to have good validity if the value of the average variance extracted is ≥ 0.50, while the reliability will be satisfactory if the value is ≥ 0.70 [14] (Table 5).

Table 4 Construct scales and descriptive statistics

Variables	Items	Loadings	Mean
Management systems	Level of skills and knowledge of logistics-related personnel	0.752	2.90
	Availability of personnel in logistics	0.637	2.67
	Degree of participation of logistics-related personnel in training programs	0.805	2.03
	Degree of decentralization of logistics services.	0.799	2.36
	Innovative management structures	0.731	2.72
Integration	Joint improvement programs with suppliers	0.721	2.66
	Assortment index for each supplier	0.632	3.38
	Level of use of alliances in the distribution channel	0.627	2.17
	Level of support with established alliance contracts	0.618	2.79
	Using alliances to improve customer service	0.805	3.08
	Connection of the information system with customers	0.722	2.98
	Level of customer access to information	0.652	2.07
	Coordination of improvement programs with customers	0.855	2.40
	The extent to which a supplier certification program is implemented	0.777	2.21
	Level of integration with suppliers regarding load unitizing means	0.761	2.61
	Level of integration with customers regarding load unitizing means	0.674	3.26
	Level of integration of logistics plans with participants in distribution channels	0.724	3.16
Human resources competence	Availability of administrative and operating personnel	0.615	2.70
	Level of experience of executive and technical staff	0.604	1.97
	Level of university training of executive and technical staff	0.730	2.77
	Operation of a logistics-related personnel training program	0.864	1.95
	Possibility of promotion and professional improvement and logistics personnel	0.747	2.48
	Operation of a performance evaluation system for logistics personnel	0.834	2.56
	Mastery and application of the objectives, policies, standards and procedures by logistics personnel	0.843	2.03
	Level of decentralization of logistics-related decision-making	0.778	2.25
	The ability of logistics staff to exercise decentralized decision-making	0.832	2.21
	Level of employment by logistics staff of delegated powers	0.799	2.51
Logistics system performance	Use of a system of indicators in logistics	0.868	2.36
	The existence of a permanent record of the indicator system	0.869	3.15
	Application of Benchmarking	0.679	2.76
	Frequent analysis of customer service level	0.614	2.19
	Existence of a record that allows perfect orders to be measured	0.656	1.97
	Systematic execution of surveys and other surveys with customers	0.894	2.49

Table 5 Validation measures employed in model

Construct	CA	Sig Barlett	CR (> 0.70)	AVE (> 0.50)
Management system (X1)	.863	.000	.863	.631
Integration (X2)	.928	.000	.930	.558
Human resources competence (X3)	.935	.000	.940	.588
Logistics system performance (Y)	.899	.000	.910	.664

Note: CA = Cronbach's alpha; CR = Composite reliability; AVE = Average variance extracted
*p-value < 0.05; **p-value < 0.01; ***p-value < 0.001
Source: Table compiled by the authors from PLS.

For the validation of the measurement scale, discriminant validity analysis was applied. For this purpose, the Heterotrait-Monotrait (HTMT) relationship criterion was selected. This criterion indicates that the confidence intervals should not exceed 0.9, thus validating the first-order model (Table 6).

Table 6 Discriminant validity

Heterotrait-Monotrait ratio	1	2	3
1. X1			
2. X2	0.726		
3. X3	0.756	0.726	
4. Y	0.802	0.739	0.775

Source: Table compiled by the authors from PLS.

4.2 Structural model

The overall quality of the model was assessed with the square root mean residual (SRMR) normalization index, where values below 0.05 are considered acceptable. In this case, the value reached was 0.076, which shows the overall validity of the model. Regarding multicollinearity and common method bias, the variance inflation factor (VIF) analysis was used, which reflects values below 3.3 and is therefore considered valid [14] (Table 7).

Figure 2 shows the research model and the path coefficients considered. The results show a consistent relationship of average R squared (R^2) that amounts to 0.777 between the independent and dependent variables [33]. This implies that the variables X1, X2, and X3 explain 77.7% of the logistics performance. Table 7 provides a summary of the final results of the hypothesis test.

Table 7 Variables and relationships in model

Dependent variables	Independent variables	Ratio coefficient	T (Bootstrap)	VIF	Relationship
Y	X1	.322	2.287	1.30	Accepted
	X2	.330	2.165	1.39	Accepted
	X3	.303	2.082	1.26	Accepted

Source: Table compiled by the authors from PLS.

These elements confirm that the three independent variables directly affect the dependent variable (logistics performance, Figure 2).

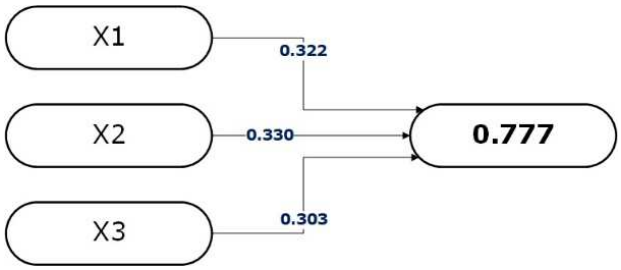

Figure 2 Structural model

Each independent variable in the model has relevance indicators. For example, with regard to the Control variable (X1), the most relevant indicators were the degree of staff participation (0.805) and the degree of decentralization of services (0.799). In the case of the Integration variable (X2), the most representative indicators were the coordination of improvement programs with customers (0.855) and the use of alliances to improve services (0.805), while in that of the Human resource variable (X3), the most relevant was the operation of a training program for personnel related to logistics (0.864) and the mastery and application by logistics personnel of the objectives, policies, standards and procedures (0.843).

Several relationships between the variables are investigated in the literature analyzed (management systems, integration, human resources competence, and the performance of the logistics system), such as the concept that logistics performance affects the management of the organization [34], and vice versa: that the management of the organization influences logistics performance [2,4-6]. Other studies state that logistics performance influences integration [13], and vice versa: that integration affects logistics performance [7-12]. There is also evidence that logistics performance directly affects job skills [19], and that job skills affect logistics performance [1-3].

These relationships were verified in the hypotheses formulated in the research in a particular way, although they demonstrate that no other previous study takes into account all the factors investigated as regards the performance of logistics in general. The correlations and results concerning human resource practices likewise demonstrated that training and compliance with policies, standards and procedures impact on the development of logistics performance.

5 Conclusions

5.1 Practical and managerial implications

This study identifies human resource management and development practices that lead to continuous improvement in logistics flows. The study shows that if a manager wishes to improve logistics performance, the improvements must include: management, the integration of suppliers and customers, and the training of personnel in order for them to achieve their work competencies. Government and local entities could, therefore, use these initial results as a basis on which to outline strategies and adaptations for the development of local supply chains.

In this context, universities and technological institutes in the region should offer training and capacity building programs in the field of logistics and supply chains. In addition, they should promote technology transfer to companies, entities and ventures through their research and linkage processes, focused on logistics and supply chains. These actions would contribute to the logistics development of the region and the country and promote business competitiveness and the reduction between academia and the productive sector.

5.2 Final remarks

This study contributes to logistics management literature by empirically analyzing the influence of the variables of management systems, business integration and human resources competencies on the logistics performance of 117 companies in a developing country in which these aspects have not yet been widely explored. A quantitative approach was used in order to test 3 study hypotheses. The results show that all 3 could be tested by means of significant positive relationships, evidencing that these factors are precursors to satisfactory logistics performance. Managers and decision-makers should, therefore, plan, organize and commit the necessary resources to these 3 factors in order to promote a positive outcome.

At the same time, this research provides guidance on the gap between the academic offering and the needs of the business sector in terms of logistics and supply chains in the region. This need is evidenced by the low growth of the logistics performance index estimated by the World Bank for Ecuador [35], with a value of 0.11 from 2007 to 2018 (no data are subsequently provided). This is exacerbated when nearby countries such as Colombia and Peru present higher values of the logistics performance index, and show better logistics services and costs.

5.3 Limitations and future work

With regard to the limitations of this research, it is necessary to consider that the sample was intentional and not probabilistic, and originated from companies based in Manabí, Ecuador, which have their own particularities, giving rise to a contextual bias that may pose problems as regards the generalization of the results. Secondly, the findings detected are conditioned by the use of 4 latent variables, which makes it necessary for future research to incorporate other valuable attributes into the analysis so as to provide a more complete understanding of the contrasted empirical model.

A further limitation of this research is the non-inclusion of reverse logistics as an analysis variable. This is owing to the need to strengthen compliance with the sustainable development goals of the 2030 agenda. Future research could develop variables such as green logistics and collect primary data in different geographical locations of the country in order to test a new model. In addition, research will continue with the analysis of possible solutions for companies and their logistics.

References

[1] AHMAD, N., MEHMOOD, R.: Enterprise systems and performance of future city logistics, *Production Planning and Control*, Vol. 27, No. 6, pp. 500-513, 2016. https://doi.org/10.1080/09537287.2016.1147098

[2] DAVIDAVIČIENĖ, V., AL MAJZOUB, M.: Performance of reverse logistics in electronic commerce: a case study from Lebanon and Syria, *Transport*, Vol. 36, No. 3, pp. 260-282, 2021. https://doi.org/10.3846/transport.2021.14956

[3] MAI, V.N., NGUYEN, Q.N., NGUYEN, Q.D.: Factors impacting logistics performance, *Uncertain Supply Chain Management*, Vol. 10, No. 4, pp. 1413-1420, 2022. https://doi.org/10.5267/j.uscm.2022.6.015

[4] DE CARVALHO, P.P.S., DE ARAÚJO KALID, R., RODRÍGUEZ, J.L.M.: Evaluation of the city logistics performance through structural equations model, *IEEE Access*, Vol. 7, 2934647, pp. 121081-121094, 2019. https://doi.org/10.1109/ACCESS.2019.2934647

[5] KANKAEW, K., YAPANTO, L.M., WARAMONTRI, R., ARIEF, S., SASTRAWATI, N., ESPINOZA-MAGUIÑA, M.R.: Supply chain management and logistic presentation: Mediation effect of competitive advantage, *Uncertain Supply Chain Management*, Vol. 9, No. 2, pp. 255-264, 2021. https://doi.org/10.5267/j.uscm.2021.3.007

[6] THILAKARATHNE, H.G.K.L.S., WIJAYANAYAKE, A.N., PETER, S.: *Evaluating the Factors that Affect the Reverse Logistics Performance in Plastic Supply Chain*, International Research Conference on Smart Computing and Systems Engineering SCSE, Sri Lanka, pp. 254-261, 2022. https://doi.org/10.1109/SCSE56529.2022.9905120

[7] SIRISAWAT, P., KIATCHAROENPOL, T.: *Correlation of barriers to reverse logistics performance using structural equation modeling*, IEEE International Conference on Industrial Engineering and Engineering Management, Bali, Indonesia, pp. 144-148, 2016. https://doi.org/10.1109/IEEM.2016.7797853

[8] KERDPITAK, C.: Business performance model of herbal community enterprise in Thailand, *Uncertain Supply Chain Management*, Vol. 10, No. 2, pp. 345-352, 2022. https://doi.org/10.5267/j.uscm.2022.1.004

[9] LAI, P.L., KAO, J.C., YANG, C.C., ZHU, X.: Evaluating the guanxi and supply chain collaborative transportation management in manufacturing industries, *International Journal of Shipping and Transport Logistics*, Vol. 15, No. 3-4, pp. 435-458, 2022. https://doi.org/10.1504/ijstl.2022.126945

[10] MORONI, I.T., ROMAN PAIS SELES, B.M., LIZARELLI, F.L., GUZZO, D., MASCARENHAS HORNOS DA COSTA, J.: Remanufacturing and its impact on dynamic capabilities, stakeholder

engagement, eco-innovation and business performance, *Journal of Cleaner Production*, Vol. 371, No. October, 133274, 2022. https://doi.org/10.1016/j.jclepro.2022.133274

[11] WANG, M., WOOD, L.C., WANG, B.: Transportation capacity shortage influence on logistics performance: evidence from the driver shortage, *Heliyon*, Vol. 8, No. 5, e09423, pp. 1-9, 2022. https://doi.org/10.1016/j.heliyon.2022.e09423

[12] YINGFEI, Y., MENGZE, Z., ZEYU, L., KI-HYUNG, B., ANDRIANDAFIARISOA RALISON NY AVOTRA, A., NAWAZ, A.: Green logistics performance and infrastructure on service trade and environment-Measuring firm's performance and service quality, *Journal of King Saud University - Science*, Vol. 34, No. 1, 101683, pp. 1-10, 2022. https://doi.org/10.1016/j.jksus.2021.101683

[13] KALUBANGA, M., NAMAGEMBE, S.: Trust, commitment, logistics outsourcing relationship quality, relationship satisfaction, strategy alignment and logistics performance – a case of selected manufacturing firms in Uganda, *International Journal of Logistics Management*, Vol. 33, No. 1, pp. 102-140, 2022. https://doi.org/10.1108/IJLM-05-2020-0215

[14] AZEVEDO, S.G., FERREIRA, J.: A model of logistics performance measurement: A structural equation modelling approach, *International Journal of Operations and Quantitative Management*, Vol. 13, No. 3, pp. 149-171, 2007.

[15] JAKHAR, S.K., BARUA, M.K.: An integrated model of supply chain performance evaluation and decision-making using structural equation modelling and fuzzy AHP, *Production Planning and Control*, Vol. 25, No. 11, pp. 938-957, 2014. https://doi.org/10.1080/09537287.2013.782616

[16] BAG, S., YADAV, G., WOOD, L.C., DHAMIJA, P., JOSHI, S.: Industry 4.0 and the circular economy: Resource melioration in logistics, *Resources Policy*, Vol. 68, No. October, 101776, 2020. https://doi.org/10.1016/j.resourpol.2020.101776

[17] CHANDAK, A., KUMAR, N., DALPATI, A.: Impact of supply chain strategy on supply chain performance: A structural equation modeling in the context of small scale Indian automobile industries, *International Journal of Scientific and Technology Research*, Vol. 9, No. 1, pp. 1071-1073, 2020.

[18] MESRA, T.: *The Role of Human Resource Competency in Improving Logistic Performance*, IOP Conference Series: Earth and Environmental Science, 2021, Vol. 709, pp. 1-6, 2021. https://doi.org/10.1088/1755-1315/709/1/012047

[19] MASUDIN, I., FERNANDA, F.W., ZULFIKARIJAH, F., RESTUPUTRI, D.P.: Customercase studyloyaltyof Indonesianon halal meatlogisticsproduct: A performance perspective, *International Journal of Business and Society*, Vol. 21, No. 1, pp. 433-453, 2020.

[20] PRASETYA, P., WIBAWA, B.M.: The empirical study of personal value and business performance in supply chain collaboration, *Uncertain Supply Chain Management*, Vol. 8, No. 4, pp. 729-738, 2020. https://doi.org/10.5267/j.uscm.2020.7.008

[21] SÉNQUIZ-DÍAZ, C.: Effect Size of Logistics: Evidence from Selected Countries, *Scientific Journal on Transport and Logistics*, Vol. 12, No. 1, pp. 123-134, 2021. https://doi.org/10.2478/logi-2021-0012

[22] FALASCA, M., DELLANA, S., ROWE, W.J., KROS, J.F.: The impact of counterfeit risk management on healthcare supply chain performance: an empirical analysis, *International Journal of Productivity and Performance Management*, Vol. 71, No. 7, pp. 3078-3099, 2022. https://doi.org/10.1108/IJPPM-08-2020-0426

[23] MOKKHAMAKKUL, T.: Factors Affecting Behaviours of Returning E-Waste to Reverse Logistics System in Thailand, *Wireless Communications and Mobile Computing*, Vol. 2022, 5307662, pp. 1-11, 2022. https://doi.org/10.1155/2022/5307662

[24] KOVALENKO, A.: Modelling container ship transport flow: an application to alternative sea routes between Northeast Asia and Northwest Europe, *Maritime Policy and Management*, Vol. 51, No. 4, pp. 572-587, 2023. https://doi.org/10.1080/03088839.2023.2220703

[25] CHEN, Y.C., HASAN, M.K.: Impacts of liner shipping connectivity and global competitiveness on logistics performance: the mediating role of the quality of port and infrastructure, *Transport*, Vol. 38, No. 2, pp. 87-104, 2023. https://doi.org/10.3846/transport.2023.19372

[26] EWUZIE, C., UG, G., OKOLO, V., OKOCHA, E., AGU, A.O.: Stimulators of third-party logistics performance of supply chains in the Nigerian manufacturing industry, *Problems and Perspectives in Management*, Vol. 21, No. 3, pp. 176-188, 2023. https://doi.org/10.21511/ppm.21(3).2023.14

[27] GETELE, G.K., RUOLIU, X.: Service supply chain risk management in the public healthcare sector, *International Journal of Emerging Markets*, Vol. ahead-of-print, No. ahead-of-print, 2023. https://doi.org/10.1108/IJOEM-04-2022-0627

[28] MAEMUNAH, S., NEKRASOV, K.: *Competitiveness based on logistics and supply chain in medical device industry during the Covid-19 period in Indonesia*, AIP Conference Proceedings, 2023, Vol. 2624, No. 1, 2023. https://doi.org/10.1063/5.0132304

[29] SITISARA, S., RATTANAWONG, W., VONGMANEE, V.: *Revolutionized Customs Declaration Documents Preparation Process*, 27th

International Computer Science and Engineering Conference 2023, ICSEC 2023, pp. 444-452, 2023. https://doi.org/10.1109/ICSEC59635.2023.10329700

[30] UNESCO: Nomenclatura Internacional de la Unesco para los campos de Ciencia y Tecnología, [Online], Available: https://www.um.es/documents/1235915/3330673/codigosUNESCO-ciencia-tecnologia.pdf/85d6ff59-e7bf-46a1-9619-fc33859e87c3 [12 Sep 2023], 2023.

[31] GÓMEZ-ACOSTA, M.I., ACEVEDO-SUÁREZ, J.A., PARDILLO-BAEZ, Y., LÓPEZ-JOY, T., LOPES-MARTÍNEZ, I.: Caracterización de la Logística y las Redes de Valor en empresas cubanas en Perfeccionamiento Empresarial, *Ingeniería Industrial*, Vol. 34, pp. 212-226, 2013. (Original in Spain)

[32] LLORET-SEGURA, S., FERRERES-TRAVER, A., HERNÁNDEZ-BAEZA, A., TOMÁS-MARCO, I.: El análisis factorial exploratorio de los ítems: una guía práctica, revisada y actualizada, *Anales de psicología/annals of psychology*, Vol. 30, No. 3, pp. 1151-1169, 2014. (Original in Spain)

[33] ROLDÁN, J.L., SÁNCHEZ-FRANCO, M.J.: *Variance-based structural equation modeling: Guidelines for using partial least squares in information systems research*, Research methodologies, innovations and philosophies in software systems engineering and information systems, IGI Global, pp. 193-221, 2012.

[34] SIRISAWAT, P., KIATCHAROENPOL, T.: Correlation of Reverse Logistics Performance to Solutions Using Structural Equation Modeling, *Journal of Advanced Manufacturing Systems*, Vol. 18, No. 4, pp. 511-525, 2019. https://doi.org/10.1142/S0219686719500276

[35] Grupo Banco Mundial: Índice de desempeño logístico, [Online], Available: https://datos.bancomundial.org/indicador/LP.LPI.OVRL.XQ [09 Apr 2024], 2022. (Original in Spain)

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The impact of outsourcing cold chain logistics services on the financial performance of agricultural enterprises in the southeast region of Vietnam
Minh Huong Tang, Doan Trang Do, Thu Hoa Ho Thi

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The impact of outsourcing cold chain logistics services on the financial performance of agricultural enterprises in the southeast region of Vietnam

Minh Huong Tang
Binh Duong University, No 504 Binh Duong avenue, Hiep Thanh ward, Thu Dau Mot city, Binh Duong province, Vietnam, tmhuong.21900006@bdu.edu.vn
Doan Trang Do
Binh Duong University, No 504 Binh Duong avenue, Hiep Thanh ward, Thu Dau Mot city, Binh Duong province, Vietnam, doantrang.bolt@bdu.edu.vn
Thu Hoa Ho Thi
International University, Quarter 6, Linh Trung Ward, Thu Duc District, Ho Chi Minh City, Vietnam, htthoa@hcmiu.edu.vn (corresponding author)

Keywords: financial performance, cold chain logistics, agricultural enterprise, Vietnam.
Abstract: This study delves into the agricultural industry and the cold chain logistics market, focusing on the impact of outsourcing cold chain logistics services on the financial performance of agricultural enterprises in the Southeast region of Vietnam. It assesses various factors influencing businesses' decisions to use cold chain logistics services, including electronic word-of-mouth, corporate image, outsourcing mindset, advantages, hazards, strategic considerations, functional features, supplier variables, interparty relationships, and environmental factors. The study's findings demonstrate high reliability, with Cronbach's Alpha coefficients ranging from 0.811 to 0.877. The observed variables in this Exploratory Factor Analysis (EFA) had factor loadings ranging from 0.535 to 0.882 (all exceeding 0.5), indicating that no variables were removed and that the observed variables met the EFA analysis requirements. The EFA categorized 56 observed variables into 12 distinct factors, clarifying the variable structure. Confirmatory Factor Analysis (CFA) validated the research model's appropriateness, confirming its effectiveness in describing relationships between variables. Overall, the study provides robust evidence supporting the reliability and validity of the research model in assessing the impact of outsourcing cold chain logistics services on enterprises' financial performance.

1 Introduction

The Southeast Region is one of the most developed agricultural production areas in Vietnam, featuring a wide variety of crops and aquaculture spread over large areas. However, maintaining the quality and value of agricultural products necessitates the use of cold chains. In the Southeast Region, cold chains are extensively used to preserve products such as vegetables, fruits, seafood, and animal products like beef, pork, and chicken [1].

Transportation companies and businesses can utilize vehicles such as trucks, container trucks, and air transport to move goods maintained within cold chains. Additionally, cold storage facilities are used to protect products from insects and bacteria. The use of cold chains in the production and transportation of agricultural products in the Southeast Region is crucial for enhancing product quality, increasing the commercial value of agricultural products, providing additional income for farmers, and reducing goods wastage [2].

Organizational behavior in the decision-making process regarding the use or outsourcing of services is a complex and significant research area that has attracted considerable attention from the economic and management research community. Various theories have been proposed to explain this organizational behavior, including notable theories such as Transaction Cost Economics (TCE) by Coase (1937), Core Competency Theory (CCT) by Prahalad and Hamel (1990), and Relationship Theories (RT) proposed by Klepper (1995). A review of related studies indicates significant differences in demonstrating the impact of factors on outsourcing decisions. This variance is due to each author using different foundational theories or drawing from empirical studies. However, most research is based on three main theories: TCE, RBV, and CCT. Thus, each study typically explains only one or a few factors influencing the extent of outsourcing by businesses and does not fully generalize the factors affecting outsourcing, such as follows:

First, studies using the TCE theory emphasize two important factors influencing outsourcing: benefit and risk factors. According to TCE, these studies highlight the role of cost savings for businesses [3-8]. Additionally, the TCE theory suggests that outsourcing also depends on the considerations and attitudes of business managers toward this activity [6,7]. However, TCE-focused studies often overlook the role of organizational functional characteristics, the compatibility of outsourcing activities with strategic orientations, and the ability of service providers to meet requirements.

Second, studies using the RBV and CCT theories also emphasize the benefits of leveraging resources from external organizations/individuals [7,12]. Additionally, the RBV and CCT theories discuss the influence of organizational functional characteristics, outsourcing

strategies, and the ability of service providers to meet requirements on the use of services [7,13,14]. However, studies based on RBV and CCT are limited by a lack of attention to the influence of managers' attitudes on outsourcing services and the risk factors when businesses outsource.

Previous global research has shown that earlier studies mainly focused on assessing factors influencing decisions to outsource logistics services in specific countries, cities, or sectors such as pharmaceuticals, construction, etc. Due to cultural and economic differences and income levels, these studies show that the factors influencing the use of logistics services in these countries are different and cannot be used to analyze the use of logistics services in developing countries like Vietnam.

Given the theoretical and practical urgency, the author decided to choose the topic " The Impact of Outsourcing Cold Chain Logistics Services on the Financial Performance of Agricultural Enterprises in the Southeast Region of Vietnam". The study will provide a comprehensive understanding of the cold chain logistics market and the agricultural sector in the Southeast Region, including the factors influencing the decision to use cold chain logistics services by agricultural businesses there.

2 Literature review

As of right now, there's no one cohesive explanation explaining the beginnings and development of outsourcing [14]. When attempting to understand outsourcing operations in the context of their research, researchers frequently turn to a variety of pertinent ideas. The paper uses particular theories as follows, which are based on the results of empirical investigations and the applicability of theories for the outsourcing in the Southeast Region.

2.1 Transaction Cost Economics - TCE

According to the TCE theory proposed by Coase (1937), saving transaction costs in business operations plays a crucial role for enterprises. This can affect their competitiveness and survival. TCE emphasizes that to save costs, enterprises can take advantage of opportunities by utilizing the resources of external organizations and units. Therefore, the TCE theory can explain the question "Why do businesses need to use outsourcing services?". This decision depends on comparing internal transaction costs and external transaction costs. If internal costs are higher than external costs, enterprises tend to outsource more and vice versa [15].

From this argument, according to TCE, the decision to outsource depends on the cost-saving benefits. Expanding from Coase's (1937) TCE theory, Williamson (1975) emphasized that TCE theory, widely studied in relation to outsourcing, provides an essential tool for enterprises in deciding to use Outsourcing Services (OS). However, TCE primarily focuses on the benefits to enterprises and may not account for the risks of encountering increased transaction costs, opportunism, or the risk of service providers shirking responsibilities. This can negatively affect the effectiveness of the enterprises' operations, particularly for SMEs when using OS [7].

Therefore, according to TCE, the decision to use outsourced resources depends on perceptions of benefits, risk assessments, and the attitude of the manager towards outsourcing activities in the enterprise, especially in SMEs in the Southeast Region.

2.2 Resource Based Views and Core Competency Theory

The Resource-Based View (RBV), proposed by Barney (1991), emphasizes the uneven distribution of resources among enterprises. Smaller enterprises often struggle with competition and become more vulnerable than larger enterprises due to competitive pressures and internal resource shortages. To address this issue, many enterprises have expanded outsourcing to utilize external resources to reduce competitive pressure [16]

Developed the Core Competency Theory (CCT) based on the Resource-Based View (RBV). According to CCT, in a volatile business environment, enterprises must identify their core competencies to develop and enhance their competitive advantages. Each organization typically possesses unique internal strengths that need to be leveraged to maximize benefits and capitalize on business opportunities. To achieve this, enterprises implement strategies that utilize their capabilities to attain sustainable competitive advantages. Fundamental resources of enterprises include manpower, knowledge, information technology, capital, and assets [15]

Although the CCT is often applied to analyze competitive advantages in the business operations of international corporations, CCT also plays a significant role in studies on the use of outsourcing services [9,12,13]. According to Dominguez (2005), outsourcing non-core activities is the most effective method for leveraging resources within an enterprise. Research on outsourcing, especially in SMEs, often applies CCT to analyze factors affecting the decision to use Outsourcing Services (OS) [10,11,14]. Based on CCT, the decision to use external resources depends on the nature of the jobs within the organization. Kamyabi and Devi (2011) indicate that SMEs mainly outsource non-core functions, focusing on core activities to optimize performance. However, there are cases where enterprises with sufficient internal resources still choose to outsource, even core activities, as the decision to outsource also depends on the enterprise's operational strategy [14].

To further explain CCT, Hale (2006) noted that enterprises often choose outsourcing when managers and employees do not have enough time to perform internal business tasks. Enterprises cannot perform these tasks as effectively as outsourcing can. Therefore, to ensure the effectiveness of outsourcing activities, enterprises need to: assess internal capabilities to choose outsourcing activities; evaluate the selection of service supply partners; assess the

effectiveness of outsourcing activities within the organization [17].

From these arguments, it is clear that combining the Resource-Based View and Core Competency Theory helps to identify and explain factors influencing the extent to which SMEs in the Southeast Region use external resources. The decision to outsource can depend on several factors, including: assessing the benefits that outsourcing activities bring to the enterprise; the enterprise's outsourcing strategy; the ability of the service supply partner to meet requirements; and the functional characteristics of the enterprise.

2.3 Relationship Theory – RT and Social Capital Theory – SCT

The topic also builds upon Relationship Theory (RT), RT theory emphasizes the significant role of cooperative relationships and economic exchanges between organizations. The result of these relationships is efficiency and benefits for all parties involved. This theory can explain why organizations, especially small and medium-sized enterprises (SMEs), often have closer business relationships.RT focuses on building agreements where each party considers the motivations to maintain the relationship to achieve efficiency for themselves from it. Therefore, RT can be applied to explain the intensity or extent of outsourcing by businesses, with the significant role of relationships between parties contributing to the decision to use outsourcing services and the operational efficiency of the business [18].

Additionally, the research is based on Social Capital Theory (SCT) developed by Bourdieu (1986). SCT emphasizes the existence of linked relationships and acquaintances among individuals, organizations, and groups within social networks. These relationships are considered the basis for building trust and mutual recognition. SCT also asserts that to create wealth, individuals, organizations, and groups need to connect with each other in society. Therefore, SCT can explain the cooperative relationship between a business and its service provider. It also refers to cases where SMEs outsource services to build relationships with supply partners, aiming to bring benefits to the business beyond just cost reduction and profit-seeking [17].

All things considered, it is clear from the above analyses that fundamental theories such as RT, TCE, RBV, CCT, and SCT can be used in conjunction to identify and explain factors influencing the choice of cold chain logistics services for Vietnamese businesses in general, and SMEs in the Southeast Region in particular. These five theories suggest that there are seven fundamental variables that SMEs in the Southeast Region may consider when deciding whether to use external resources: (1) the perceived benefits that outsourcing activities bring to the business [15,20] (2) the risks when the business outsources [20] (3) characteristics of internal resources of the business [16,17,20,21]; (4) the compatibility of outsourcing activities with the business's operational strategy [17], [20]; (5) the ability of the service provider to meet requirements [17,20]; (6) the attitude of business managers towards outsourcing activities [19]; (7) the relationship factor between the parties [14,18,22]. Accordingly, any decision related to the use of Outsourcing Services can impact the operational efficiency of the business [17-22].

3 Research model

3.1 Peer review process

The author's research model references typical elements from Transaction Cost Economics (TCE), Resource-Based View (RBV), and Core Competency Theory (CCT) as follows: (1) perceived benefits from outsourcing activities to businesses [15-17,19,20]; (2) risks when businesses outsource [19,20]; (3) characteristics of internal resources of businesses[16,17,20,21]; (4) alignment of outsourcing activities with business operational strategies [17,20]; (5) capability to meet the requirements of service providers [17,20]; (6) attitudes of business managers towards outsourcing activities [19]; and (7) relationship factors among parties [14,18,22]. Thus, any decision related to the use of services can impact the operational effectiveness of businesses [11,17-22].

Alongside recent studies related to decisions on choosing logistics services in general. The study includes factors such as electronic word-of-mouth [23,24], corporate image [23,24], and environment [25-30].

Based on previous studies, the author proposes the following hypotheses and research models (Figure 1):

H1: Perceiving benefits will positively impact attitudes towards outsourcing cold chain logistics services by businesses

H2: Perceiving benefits will positively impact the decision to use cold chain logistics services

H3: Risk control will positively impact attitudes towards outsourcing cold chain logistics services by businesses

H4: Risk control will positively impact the decision to use cold chain logistics services

H5: Attitudes towards outsourcing will positively impact the decision to use cold chain logistics services

H6: Outsourcing strategy will positively impact the decision to use cold chain logistics services

H7: The characteristic function factor will positively impact the extent of outsourcing in businesses.

H8: The standards factor for service providers will positively impact the extent of outsourcing in businesses.

H9: The relationship factor among parties will positively impact the decision to use cold chain logistics services by businesses

H10: The environmental factor will positively impact the decision to use cold chain logistics services by businesses

H11: The electronic word-of-mouth factor will positively impact the corporate image

H12: The corporate image factor will positively impact attitudes towards outsourcing cold chain logistics services

H13: The decision to use cold chain logistics services will positively impact the financial performance of the enterprise.

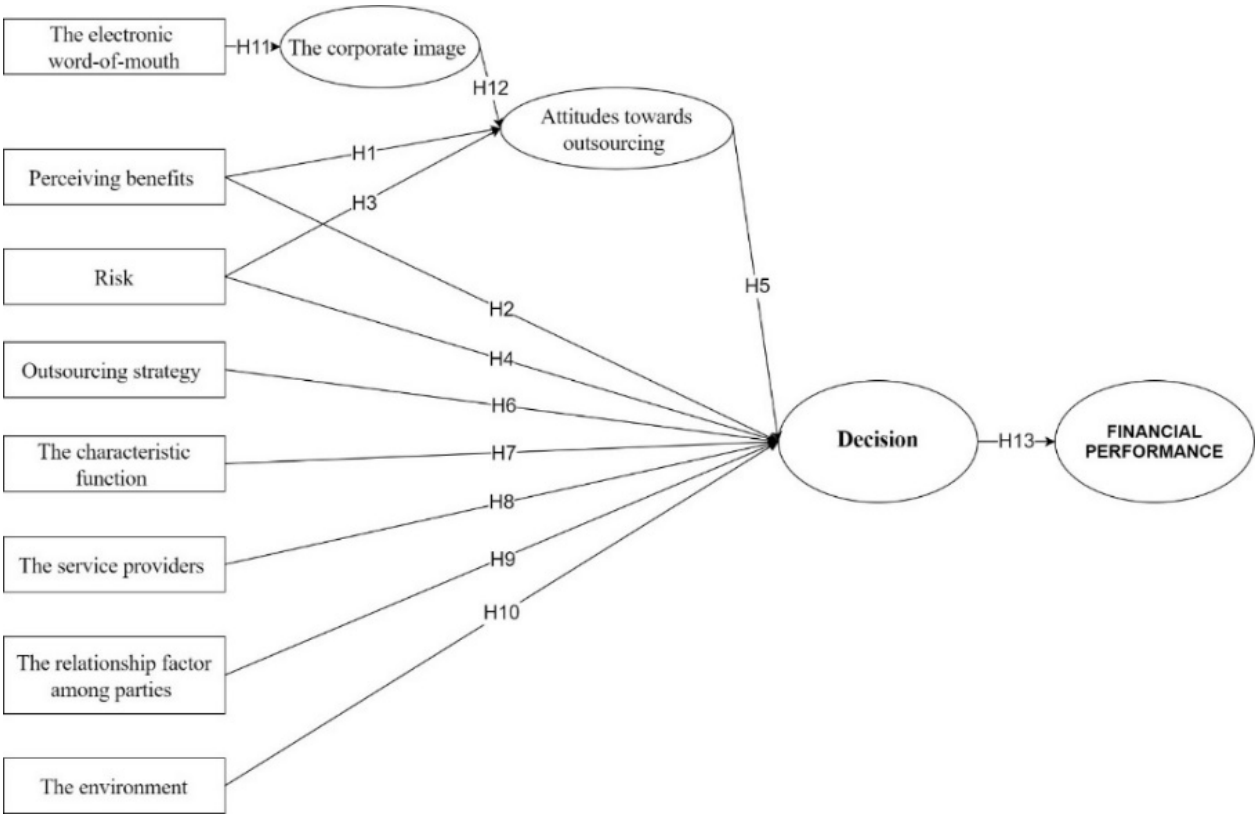


Figure 1 Research model

4 Result and discussion

The author analyzed the research results in detail, using AMOS software as the primary tool. Through this analysis, several important points were clarified:

Firstly, regarding Common Method Bias (CMB) analysis, the results do not indicate any serious issues related to Common Method Bias. This confirms that the relationships between the research concepts are not significantly affected by methodological bias, thereby enhancing the accuracy and reliability of the research findings. In the formal study, data were processed using SPSS 26.0, through Exploratory Factor Analysis (EFA) by fixing one factor without rotation. Harman's single-factor test through EFA revealed that a single factor explained 24.268% of the total variance. In this case, CMB is not considered a serious issue.

Next, in terms of Scale Reliability, Cronbach's Alpha coefficients for the scales ranged from 0.811 to 0.877, indicating strong reliability. This shows that the data have a high degree of consistency and that the measurement questions accurately and consistently represent the topics that have been researched.

By cleanly classifying 56 observed variables into 12 distinct factors, the Exploratory Factor Analysis (EFA) helped to clarify the structure of the variables in the research model. Crucially, the validity of the scale and study model is further reinforced by the fact that no variables were taken into account for elimination.

The Bartlett's test got a Sig. = 0.000 (meaning it is less than the significance level of 0.05) suggesting that the variables are related to each other; the KMO test had a KMO coefficient of 0.903 (>0.5). This demonstrates how appropriate the EFA analysis was.

12 factors were extracted from 56 observable variables using EFA, with Eigenvalues = 1.174 (>1.0) and a total explained variance of 56.815% (>50%); no new factors were produced in comparison to the first study model that was suggested. The observed variables in this EFA instance had factor loadings ranging from 0.535 to 0.882 (all more than 0.5), indicating that no variables had yet been removed and that the observed variables matched the requirements of the EFA analysis.

Thanks to standard reaching fit indices, Confirmatory Factor Analysis (CFA) was able to further validate the excellent appropriateness of the research model with the gathered data. This offers strong proof that the research model was built successfully and is capable of effectively describing the relationships between the variables (Figure 2).

The impact of outsourcing cold chain logistics services on the financial performance of agricultural enterprises in the southeast region of Vietnam

Minh Huong Tang, Doan Trang Do, Thu Hoa Ho Thi

The research's normal distribution was verified by skewness and kurtosis analysis. The data is regularly distributed, according to Kline (2015), if the absolute value of skew is two or less and less than three. A different way to assess a normal distribution is to check if the kurtosis's absolute value is equal to or less than 10. According to the results, the model's measurement questions' normal distribution was confirmed by the absolute values of skewness, which peaked at 1.022 (<3) for all of the questions, and kurtosis, which peaked at 1.321 (<10) [31].

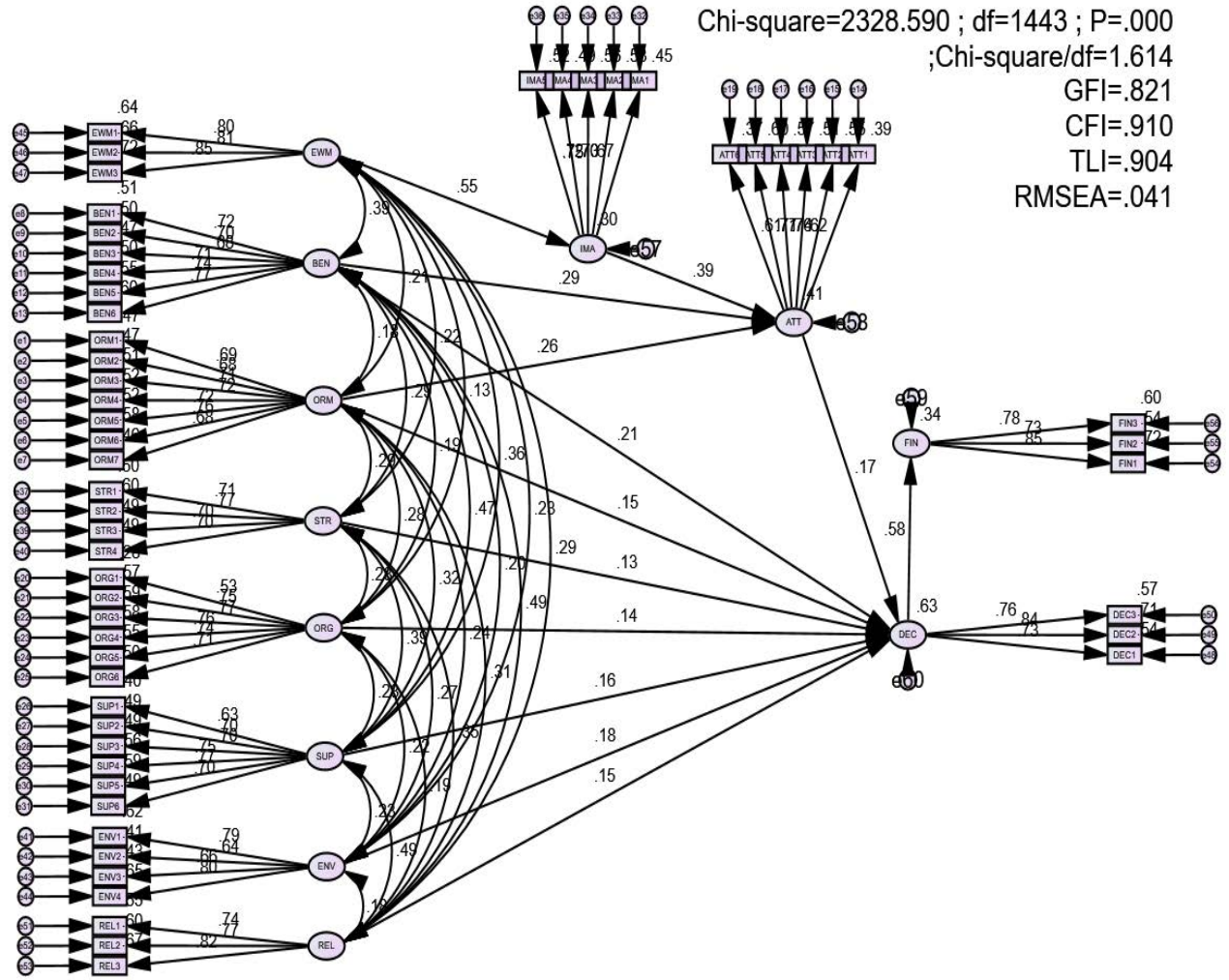
Following these guidelines, the associations within the model were tested:

P-values for statistical significance tests had to be less than 0.05.

A direct or inverse relationship between two factors is indicated by a positive or negative value of the calculated correlation coefficient.

The stronger the influence between the elements, the higher the computed correlation coefficient's absolute value.

The ML estimate method in conjunction with linear structural analysis revealed that the model had 1443 degrees of freedom. The Chi-square corrected for degrees of freedom, or CMIN/df, was 1.614, assuring it is less than 2.00, even though the Chi-square value was p =.000 (Chi-square = 2328.590). Apart from that, other indices also satisfied the requirements: RMSEA = 0.041 (meeting the criteria <.080); CFI =.910; TLI =.904; GFI =.821 (all matching the condition >.90). Hair et al. (2011) state that a GFI > 0.8 is still regarded as acceptable. We can therefore draw the conclusion that this model is appropriate for the market data that has been gathered.



Source: author's complication

Figure 2 Standardized SEM results of the research model

With p-values less than 0.05, Table 1 demonstrates that all of the hypotheses were accepted and that these factors significantly influence the decision to engage cold chain logistics services. The values of the standardized

regression coefficients, a metric that illustrates the degree to which independent variables affect the dependent variable in a regression model, are also shown in Table 1. Here's a more thorough examination of these coefficients for every hypothesis under study:

H1 and H2 (Perception of Benefits): With coefficients of 0.292 and 0.206, respectively, the standardized regression coefficients show that the perception of benefits has a considerable impact on attitudes toward and decisions to use cold chain logistics services. This suggests that a favorable opinion of the advantages of the service can encourage a favorable attitude as well as a favorable choice to utilize it.

H3 and H4 (Risk Control): Regression coefficients of 0.262 and 0.145 suggest that risk control not only improves the outsourcing attitude but also positively impacts the decision to use the service, although the effect is stronger on attitude than on the direct decision.

H5 (Outsourcing Attitude): The outsourcing attitude has a moderate impact on the decision to employ the service, as indicated by its coefficient of 0.174. This indicates that adopting a good attitude towards outsourcing is crucial in order to influence real decisions.

H6 to H10 (Other factors such as outsourcing strategy, functional characteristics, supplier standards, relationships among parties, environmental factors): These coefficients range from 0.129 to 0.184, indicating that each factor significantly impacts the decision to use the service, but not as strongly as perception of benefits or risk control.

H11 and H12 (Electronic Word of Mouth and Corporate Image): With coefficients of 0.55 and 0.393, respectively, high regression coefficients show the significant impact of corporate image and electronic word of mouth on the outsourcing attitude and the choice to employ the service. This illustrates how crucial it is to create and preserve a favourable company reputation in the eyes of the public.

Table 1 Results of testing the research hypotheses

Hypotheses	Unstandardized Regression Coefficient	P value (p < 0.05)	Standardized Regression Coefficient	Hypothesis Testing
H1: Perceiving benefits will positively impact attitudes towards outsourcing cold chain logistics services by businesses	0.255	0.000	0.292	Accept
H2: Perceiving benefits will positively impact the decision to use cold chain logistics services	0.206	0.000	0.206	Accept
H3: Risk control will positively impact attitudes towards outsourcing cold chain logistics services by businesses	0.245	0.000	0.262	Accept
H4: Risk control will positively impact the decision to use cold chain logistics services	0.155	0.005	0.145	Accept
H5: Attitudes towards outsourcing will positively impact the decision to use cold chain logistics services	0.2	0.001	0.174	Accept
H6: Outsourcing strategy will positively impact the decision to use cold chain logistics services	0.12	0.015	0.129	Accept
H7: The characteristic function factor will positively impact the extent of outsourcing in businesses.	0.126	0.003	0.145	Accept
H8: The standards factor for service providers will positively impact the extent of outsourcing in businesses.	0.173	0.006	0.162	Accept
H9: The relationship factor among parties will positively impact the decision to use cold chain logistics services by businesses	0.142	0.01	0.153	Accept
H10: The environmental factor will positively impact the decision to use cold chain logistics services by businesses	0.169	0.000	0.184	Accept
H11: The electronic word-of-mouth factor will positively impact the corporate image	0.491	0.000	0.55	Accept
H12: The corporate image factor will positively impact attitudes towards outsourcing cold chain logistics services	0.338	0.000	0.393	Accept
H13: The decision to use cold chain logistics services will positively impact the financial performance of the enterprise	0.737	0.000	0.581	Accept

Source: author's complication

5 Conclusions

In conclusion, this study developed an effective evaluation model to explore the factors influencing the decision to utilize cold chain logistics services in the Southeast region of Vietnam. The research confirms that various factors, including the perception of benefits, risk control, outsourcing strategy, functional characteristics, service provider standards, relationships among parties, environmental conditions, and electronic word-of-mouth, significantly impact the attitudes and decisions of businesses regarding the use of these services.

The findings, with p-values less than 0.05, indicate that all hypotheses (H1 to H13) were accepted, demonstrating the significant influence of these factors. Notably, the perception of benefits (H1 and H2) and risk control (H3 and H4) showed strong effects on attitudes and decisions, while electronic word-of-mouth and corporate image (H11 and H12) had substantial impacts on attitudes toward outsourcing.

To improve cold chain logistics services and positively influence businesses' decisions to outsource these services, the following suggestions can be made based on the proposed hypotheses:

Clearly articulate the benefits of cold chain logistics services, such as cost savings, improved product quality, and extended shelf life. Use case studies and success stories to demonstrate real-world advantages (H1, H2).

Implement and promote robust risk control measures, including real-time tracking, temperature monitoring, and contingency plans for potential disruptions. Communicate these measures effectively to build trust and confidence among businesses (H3, H4).

Work with businesses to develop tailored outsourcing strategies that align with their specific needs and goals. Provide consultation services to help them understand the strategic benefits of outsourcing cold chain logistics (H6).

Continuously improve the functional characteristics of logistics services, such as speed, reliability, and flexibility. Ensure that the services are adaptable to different types of products and varying business requirements (H7).

Adhere to high standards in service provision, including certification and compliance with industry regulations. Regularly audit and update service protocols to meet or exceed industry benchmarks (H8).

Build strong, collaborative relationships with businesses. Regular communication, transparency, and responsiveness to client needs will enhance trust and cooperation (H9).

Adopt environmentally friendly practices, such as using energy-efficient refrigeration units and reducing carbon footprints. Highlight these practices in marketing efforts to appeal to environmentally conscious businesses (H10).

Encourage satisfied customers to share positive feedback online. Utilize social media, review platforms, and testimonials to build a positive online reputation, which will, in turn, enhance corporate image (H11).

Invest in branding and public relations to strengthen the corporate image. A strong, positive corporate image will improve businesses' attitudes towards outsourcing (H12).

Provide clear evidence of the financial benefits of using cold chain logistics services. Use financial projections, ROI analysis, and performance metrics to show how outsourcing can lead to cost savings and increased profitability (H13).

By implementing these suggestions, cold chain logistics service providers can improve their offerings, build stronger relationships with businesses, and encourage more companies to adopt their services, ultimately leading to better financial performance for both parties

The study emphasizes the importance of understanding regional and economic contexts when analyzing service utilization decisions in developing economies. It provides a foundation for tailoring service offerings and adjusting legal frameworks to support the growth of the cold chain logistics sector in Vietnam and other emerging countries. Practical implications for service providers and government regulators include enhancing the business environment to allow stakeholders to evolve and adapt within specific market dynamics.

However, the study's focus on the Southeast region limits its generalizability to the entire country and broader market dynamics. Additionally, due to limited resources, not all potential influencing factors and financial outcomes were analyzed. Future research should consider a more comprehensive approach, including additional variables and wider geographical coverage, to better understand the decision-making processes regarding cold chain logistics services in Vietnam.

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References

[1] EMMERS, R., THU, L.H.: Vietnam and the search for security leadership in ASEAN, *Asian Security*, Vol. 17, No. 1, pp. 64-78, 2021. https://doi.org/10.1080/14799855.2020.1769068

[2] NONG, D., WANG, C., AL-AMIN, A.Q.: A critical review of energy resources, policies and scientific studies towards a cleaner and more sustainable economy in Vietnam, *Renewable and Sustainable Energy Reviews*, Vol. 134, No. December, 110117, 2020. https://doi.org/10.1016/j.rser.2020.110117

[3] KROES, J.R., GHOSH, S.: Outsourcing congruence with competitive priorities: Impact on supply chain and firm performance, *Journal of Operations Management*, Vol. 28, pp. 124-143, 2010.

[4] BHAGAT, P., BYRAMJEE, F., TAIANI, V.: A framework of total value orientation for strategic outsourcing decisions, *Competitiveness Review: An International Business Journal*, Vol. 20, No. 4, pp. 305-321, 2010.

[5] YANG, D.H., KIM, S., NAM, C., MIN, J.W.: Developing a decision model for business process outsourcing, *Computers and Operations Research*, Vol. 34, pp. 3769-3778, 2007.
[6] JAIN, R.K., NATARAJAN, R.: Factors influencing the outsourcing decisions: a study of the banking sector in India, *Strategic Outsourcing: An International Journal*, Vol. 4, No. 3, pp. 294-322, 2011.
[7] HAFEEZ, A., ANDERSEN, O.: Factors Influencing Accounting Outsourcing Practices among SMEs in Pakistan Context: Transaction Cost Economics (TCE) and Resource-Based Views (RBV) Prospective, *International Journal of Business and Management*, Vol. 9, No. 7, pp. 19-32, 2014.
[8] BUSTINZA, O., ARIAS-ARANDA, D., GUTIERREZ-GUTIERREZ, L.: Outsourcing, competitive capabilities and performance: an empirical study in service firms, *International Journal of Production Economics*, Vol. 126, No. 2, pp. 276-288, 2010. https://doi.org/10.1016/j.ijpe.2010.03.023
[9] JIANG, B., FRAZIER, G.V., PRATER, E.L.: Outsourcing effects on firms' operational performance: An empirical study, *International Journal of Operations & Production Management*, Vol. 26, No. 12, pp. 1280-1300, 2006. https://doi.org/10.1108/01443570610710551
[10] HSIAO, H.I., VAN DER VORST, J.G.A.J, KEMP, R.G.M, OMTA, S.W.F.: Developing a decision-making framework for levels of logistics outsourcing in food supply chain networks, *International Journal of Physical Distribution & Logistics Management*, Vol. 40, No. 5, pp. 395-414, 2010.
[11] KAMYABI, Y., DEVI, S.: Accounting Outsourcing and Firm Performance in Iranian SMEs, *International Journal of Economics and Finance*, Vol. 3, No. 4, pp. 181-192, 2011.
[12] AUSTIN-EGOLE, I.S., IHERIOANMA, E.B.J.: Outsourcing and organizational performance: A comparative analysis of Nigeria Bottling Company Plant and Camela Vegetable Oil Company, Owerri, Imo State, Nigeria, *Research on Humanities and Social Sciences*, Vol. 10, No. 12, pp. 64-83, 2020.
[13] DOMINGUEZ, L.: *The manager's step-by-step guide to outsourcing*, McGraw Hill Professional, 2005.
[14] AGBURU, J.I., ANZA, N.C., IYORTSUUN, A.S.: Effect of outsourcing strategies on the performance of small and medium scale enterprises (SMEs), *Journal of Global Entrepreneurship Research*, Vol. 7, No. 26, pp. 1-34, 2017. https://doi.org/10.1186/s40497-017-0084-0
[15] COASE, R.H.: The Nature of the Firm, *Economica*, Vol. 6, No. 16, pp. 331-351, 1937.
[16] BARNEY, J.: Firm resources and sustained competitive advantage, *Journal of Management*, Vol. 17, No. 1, pp. 99-120, 1991.
[17] HALE, C.R.: Activist Research v. Cultural Critique: Indigenous Land Rights and the Contradictions of Politically Engaged Anthropology, *Cultural Anthropology*, Vol. 21, No. 1, pp. 96-120, 2006.
[18] KLEPPER, R.: The Management of Partnering Development in IS Outsourcing, *Journal of Information Technology*, Vol. 10, No. 4, pp. 248-258, 1995.
[19] WILLIAMSON, O.E.: *Markets and Hierarchies: Analysis and Antitrust Implications*, New York, 1975.
[20] ARON, R., SINGH, J.: Getting offshoring right, *Harvard Business Review*, Vol. 83, No. 12, pp. 135-143, 2005.
[21] PRAHALAD, C.K., HAMEL, G.: The core competence of the corporation, *Harvard Business Review*, Vol. 1990, No. May-June, pp. 2-15, 1990.
[22] BOURDIEU, P.: *The Forms of Capital*, pp. 15-29, In: Richardson, J. (Ed.), Handbook of Theory and Research for the Sociology of Education, *New York, Greenwood*, 1986.
[23] ERKAN, I., EVANS, C.: The influence of eWOM in social media on consumers' purchase intentions: An extended approach to information adoption, *Computers in Human Behavior*, Vol. 61, pp. 47-55, 2016. https://doi.org/10.1016/j.chb.2016.03.003
[24] FORTES, N., RITA, P.: Privacy concerns and online purchasing behaviour: Towards an integrated model, *European Research on Management and Business Economics*, Vol. 22, No. 3, pp. 167-176, 2016. https://doi.org/10.1016/j.iedeen.2016.04.002
[25] FALSINI, D., FONDI, F., SCHIRALDI, M.M.: A logistics provider evaluation and selection methodology based on AHP, DEA and linear programming integration, *International Journal of Production Research*, Vol. 50, No. 17, pp. 4822-4829, 2012. https://doi.org/10.1080/00207543.2012.657969
[26] GUARNIERI, P., SOBREIRO, V.A., NAGANO, M.S., MARQUES SERRANO, A.L.: The challenge of selecting and evaluating third-party reverse logistics providers in a multicriteria perspective: a Brazilian case, *Journal of Cleaner Production*, Vol. 96, pp. 209-219, 2015. https://doi.org/10.1016/j.jclepro.2014.05.040
[27] BASK, A., RAJAHONKA, M., LAARI, S., SOLAKIVI, T., TÖYLI, J., OJALA, L.: Environmental sustainability in shipper-LSP relationships, *Journal of Cleaner Production*, Vol. 172, No. January, pp. 2986-2998, 2018. https://doi.org/10.1016/j.jclepro.2017.11.112
[28] GOVINDAN, K., KHODAVERDI, R., VAFADARNIKJOO, A.: A grey DEMATEL approach to develop third-party logistics provider selection criteria, *Industrial Management & Data Systems*, Vol. 116, No. 4, pp. 690-722, 2016. https://doi.org/10.1108/IMDS-05-2015-0180
[29] ROY, J., PAMUČAR, D., KAR, S.: Evaluation and selection of third party logistics provider under sustainability perspectives: an interval valued fuzzy-

rough approach, *Annals of Operations Research*, Vol. 293, No. 2, pp. 669-714, 2020. https://doi.org/10.1007/s10479-019-03501-x

[30] GARG, C.P., SHARMA, A.: Sustainable outsourcing partner selection and evaluation using an integrated BWM–VIKOR framework, *Environment, Development and Sustainability*, Vol. 22, No. 2, pp. 1529-1557, 2020. https://doi.org/10.1007/s10668-018-0261-5

[31] KLINE, P.: *A Handbook of Test Construction (Psychology Revivals)*, Routledge, 2015. https://doi.org/10.4324/9781315695990

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