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DIGITAL TRANSFORMATION OF LOGISTICS SERVICE PROVIDERS IN THE CONTEXT OF MATERIAL FLOW COORDINATION

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The paper explores logistics service providers (LSPs) in the context of material flow coordination and examines the correlation between digitalization and the implementation of selected coordination features. It includes a literature review and interviews with 18 experts in LSP operations to assess how digitalization influences the adoption of key material flow coordination elements. The study aims to determine the impact of technologies used by LSPs on the implementation of these elements, thereby expanding the logistics coordination concept by integrating the role of digitalization. Findings indicate that while LSPs seek to implement basic material flow coordination elements, they lack sufficient knowledge about advanced technologies like AI bots and Digital Twins. A strong positive correlation was observed between the number of technological solutions implemented and experts' perceptions of coordination capabilities. Different coordination elements require varying levels of technological adoption, with greater implementation leading to improved coordination possibilities. The study provides practical insights for LSP managers regarding the necessary technologies for easier integration of fundamental coordination elements. Additionally, it examines international LSPs to evaluate their potential for digital transformation. The paper highlights the significance of digital solutions in material flow coordination as a crucial mechanism for managing contemporary distribution networks.

Key words: Logistics service providers, material flows, coordination, digital transformation, distribution network

1. Introduction

The logistics industry has undergone significant transformations due to technological advancements, particularly digitalization and automation. Logistics Service Providers (LSPs), essential to supply chains, offer services such as transportation, warehousing, inventory management, and packaging while acting as intermediaries between shippers and carriers. Their role enhances supply chain efficiency through value-added services like order fulfillment, consolidation, and customs clearance (Mangan and Lalwani, 2016; Ajakaive, 2012; Griffis *et al.,* 2007; Herold *et al.,* 2021). This paper examines LSPs as third-party logistics providers, emphasizing the impact of Value Added Services (VAS) on service recipients. LSPs leverage digitalization to optimize operations, improve efficiency, and enhance customer experiences. Automating processes such as order processing and inventory management reduces human error and increases speed, driving cost efficiency. The integration of advanced software enhances shipment tracking, inventory control, and real-time data exchange, improving visibility and transparency. Additionally, data analytics and predictive modeling enable LSPs to optimize routes and refine operations for better service levels and cost savings (Sanchez-Rodrigues and Kumar, 2019). The rise of e-commerce and growing consumer demand for timely deliveries have accelerated innovations in last-mile logistics. Technologies like route optimization software, mobile apps, and real-time tracking enhance delivery accuracy. Emerging technologies such as IoT, blockchain, and AI further revolutionize logistics by improving traceability, automation, and visibility. LSPs harness digital transformation to maintain efficiency, elevate customer service, and stay competitive. This paper explores LSPs' digital evolution, highlighting benefits, challenges, and insights from contemporary literature.

2. Theoretical background

2.1. Digital transformation and digitalization of LSP

The fusion of physical and digital domains defines digital transformation (DT), where reality is virtualized within Service Oriented Architectures (SOA), integrating technical and business dimensions (Borangiu *et al.,* 2019). The rapid expansion of internet platforms drives this shift, with internet-based services at its core (Shah *et al*., 2021). DT represents a strategic evolution in business operations, leveraging digital opportunities and societal shifts (Benavides *et al.*, 2022). In sectors like catering micro and small enterprises, DT involves adopting digital technologies to enhance operations, reduce costs, and boost revenue (Tang and Fang, 2022). A key aspect is resource virtualization, notably virtual machines (VM), ensuring sustainability and operational flexibility (Borangiu *et al*., 2019). DT is not a singular technological shift but a convergence of information, computing, communication, and connectivity (Cichosz *et al.*, 2020). Emerging technologies such as e-commerce, IoT, AI, blockchain, and augmented reality further reshape the economic landscape (Naclerio and Giovanni, 2022). Closely linked to DT, digitalization remains a focal point for researchers (Lagorio *et al*., 2020). Ultimately, digital transformation stands as a progressive endeavor, primarily aiming to cultivate value in this digitally-dominated era. Chosen definitions of digitalization are presented in Table 1.

Table 1. Chosen definitions of digitalization

Definition	**Selected enthusiasts of the approach**
Digitalization as a process of converting analog information into digital form and organizing it in computer-readable formats for easier storage, retrieval, and manipulation	(Babu and Ramesh, 2011; Cichosz *et al*., 2020)
Digitalization as the adoption and integration of digital technologies into various aspects of an organization or society, leading to fundamental changes in how business is conducted and services are delivered	(Kraus *et al.*, 2021; Mathauer and Hofmann, 2019)
Digitalization as the transformation of physical processes, activities, and information into digital formats, enabled by advancements in technology, to enhance efficiency, productivity, and decision-making	(Paschek *et al.*, 2019; Romero *et al.*, 2018)

(Babu and Ramesh, 2011; Kraus *et al.,* 2021; Romero *et al.,* 2018; Mathauer and Hofmann, 2019)

Digitalization is a multifaceted concept, encompassing data conversion, operational transformation, and process enhancement. At its core, it involves converting analog data into digital formats, facilitating preservation, retrieval, and analysis. Beyond this, digitalization reshapes industries by integrating digital technologies, driving operational shifts, and redefining service delivery. It enhances efficiency, productivity, and decision-making by transitioning physical operations into digital processes. This article examines digitalization within LSP companies and their environments. The past decade, dubbed "the digital age," has redefined industry dynamics, with logistics acutely impacted (Cichosz *et al.,* 2020). Scholars have explored digital transformation (DT), developing frameworks and maturity models (Benavides *et al*., 2022). For LSPs, digital adoption fosters innovation (Cichosz *et al.,* 2020). The COVID-19 pandemic accelerated supply chain shifts, emphasizing domestic production and reassessing lean manufacturing (Butt, 2021). Digital logistics optimizes data flow, route planning, and supply chain management, reducing inefficiencies (Banzekulivaho, 2021). A dichotomy exists between established logistics firms and tech-driven startups (Agatic *et al.,* 2020). However, digital transformation presents challenges, including high costs, upskilling needs, cybersecurity, and regulatory complexities. LSPs must also navigate the evolution from Logistics 1.0 to 4.0, aligning with industrial revolutions and digital advancements (Shah *et al*., 2021). LSPs play a crucial role in logistics networks, offering contract logistics services such as transport negotiation, consolidation, and storage (Murphy and Wood, 2011). Some extend their services to assembly and installation. Rooted in third-party logistics theory, LSPs act as intermediaries between producers and consumers, coordinating procurement, transportation, and distribution (Thakkar *et al.,* 2005). Data access is central to material flow coordination, and LSPs add value by enhancing logistics processes. While LSP partnerships boost efficiency and productivity, challenges arise from unrealistic expectations and limited flexibility (Murphy and Wood, 2011). Nonetheless, LSPs are key architects of modern distribution networks, shaping contemporary markets and supply chains.

2.2. Coordination of material flows

Scholars increasingly view competitive collaborations through the lens of supply chain versus supply chain rather than individual firms (Akbari, 2018). This holistic strategy optimizes outcomes by leveraging synergies across the entire distribution network. However, a paradox arises as companies acknowledge the importance of coordination but often prioritize individual objectives over collective benefits (Chan *et al.,* 2020). The logistics service industry thrives on networked relationships, with LSPs relying on robust communication structures supported by relational infrastructure (Czakon *et al.,* 2020). Kmiecik (2022) highlights the evolving role of third-party logistics (3PL) in distribution networks, extending LSP functions to include advanced inventory and transport management, resource planning, and demand forecasting, supported by modern information technologies. Demand management is crucial for aligning business activities, aiding suppliers and customers alike (Croxton *et al.,* 2002; Szozda, 2015). Christopher and Rylas (2014) stress the shift from supply chains to demand chains, highlighting the need to address demand-side challenges. As distribution networks grow in complexity, logistics operators take on greater coordination roles, especially in omnichannel systems (Briel, 2018; Kramarz and Kmiecik, 2022). Inventory management remains vital for handling demand fluctuations and optimizing customer service, facing challenges such as stockouts and reverse logistics (Paril and Divekar, 2014). With one-day delivery becoming standard, logistics operators are judged by sustainability efforts, CO2 emissions, and urban logistics solutions. Resource planning is equally critical for cost optimization and value creation in logistics (Kayakutlu and Buyukozkan, 2011). Efficient operations rely on structured information exchange, enhanced by digital technologies and electronic data exchange (Karaenko *et al.*, 2019). The integration of cyber-physical systems and IoT is crucial for coordinating multi-, cross-, and omnichannel logistics (Rai *et al.*, 2018). Emerging technologies such as blockchain improve information exchange (Casino *et al*., 2019; Tan *et al.*, 2020), while Digital Twins offer digital modeling for enhanced demand forecasting (dos Santos *et al.*, 2020; Wright and Davidson, 2020). These advancements lay the foundation for the digital transformation of logistics operators.

3. Research framework and methods

The research examines 18 expert interviews on logistics outsourcing and a case study analysis. The selected experts are LSP managers overseeing warehousing or transportation flows, each with at least five years of experience. The choice of 18 experts ensured diverse perspectives while maintaining practical feasibility, balancing time, financial, and logistical constraints. This number allowed for a representative and specialized sample, providing valuable insights into logistics outsourcing. The experts' experience enabled a broad understanding of outsourcing challenges, making their input essential for a comprehensive analysis. The study followed the procedure outlined in Figure 1, incorporating multiple methods such as survey analysis, correlation analysis, and case studies. The combination of these approaches, as discussed in research by Clark *et al.* (2008), Bazeley (2004), and Pole (2007), broadened the analytical perspective, enriching the study's findings. Research procedure is presented in the figure 1.

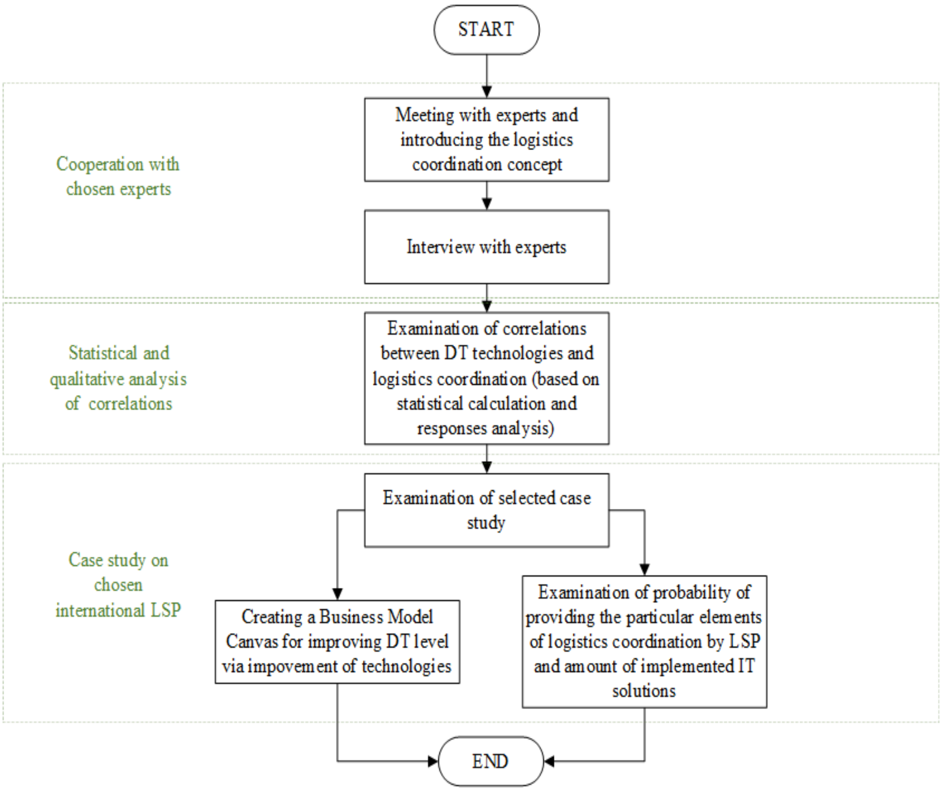

Figure 1. Research procedure

Before the interview, an introductory lecture familiarized experts with Kmiecik's (2022) concept of material flow coordination by LSPs. The interview assessed digitalization aspects, distinguishing between existing technologies and those feasible for near-future implementation. It evaluated how well LSPs adapt to digital transformation, emphasizing its benefits, such as streamlined logistics operations, improved speed and accuracy, reduced costs, optimized routes, and enhanced customer satisfaction. Digitalization enables real-time shipment visibility, data-driven decision-making, and competitive advantages. The interview also explored willingness to adopt digital solutions in material flow coordination. Experts provided insights on AI-based systems, IoT, EDI, forecasting tools, Digital Twins, simulation models, WMS, cloud data replication, and logistics automation technologies like AS/RS and RPA. Additionally, responses covered material flow coordination mechanisms, including stock management, demand forecasting, transportation planning, logistics information management, and infrastructure management within distribution networks. The case study examined an international LSP operating in multiple European countries, offering warehousing, transportation, and inventory management. The company prioritizes technology, innovation, sustainability, and employee development. The study highlighted key LSP features relevant to material flow coordination and concluded with the Canvas Model (Osterwalder and Pigneur, 2010), providing a structured framework for analyzing business models. This approach supported the research hypotheses, demonstrating the significance of digitalization in material flow coordination from an LSP perspective. The research was aimed to answer the following research questions:

RQ.1: Is the LSP would like to implement the particular elements of material flow coordination in their future activity?

RQ.2: Is there a correlation between the number of contemporary solutions which support digitalization and the innovation level of LSP and elements of material flow coordination?

RQ.3: What are the main factors for the successful implementation of solutions connected with digitalization in LSP from the perspective of material flow coordination?

4. Results

During the interview research, 18 experts were examined. They answered the interview questions concerning the technology usage in LSP. LSP's willingness to implement material flow coordination (Figure 2) was elaborated based on the interview results in which experts answered for the question in their opinion the LSP would like to implement particular elements of material flow coordination in the future.

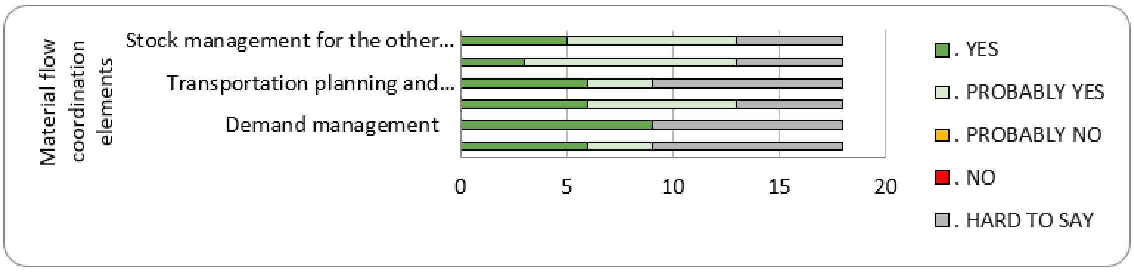

Figure 2. Would the LSP like to implement the following elements of material flow coordination in the future?

According to the majority of experts' opinions, the LSP would like to implement the basic elements. Most of them strongly agree or think that LSP probably wants to implement the particular features in the future. Some of the experts did not give their confirmation, but also, did not disagree with the mentioned issue. The next issue which was examined in the following paper is the usage of particular basic technologies which supports the material flow coordination ideology (Figure 3).

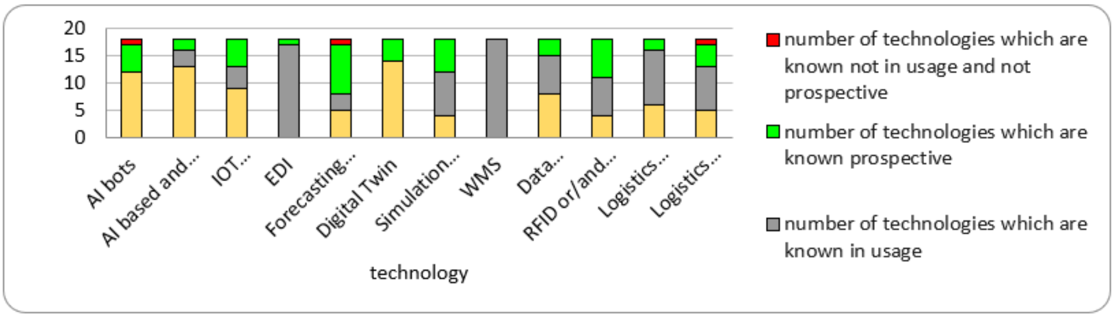

Figure 3. The experts' knowledge about the technologies which support material flow coordination and the level of their implementation at LSP

What is interesting about this situation is that the experts seem to possess a limited understanding of the latest technologies, particularly those related to AI bots and Digital Twins. This lack of knowledge is most likely attributed to the low innovation level within the LSP (presumably the organization or industry in question). The implications of this narrow expertise can be significant, as it may hinder the organization's ability to fully leverage the potential benefits of cutting-edge technologies. In today's rapidly advancing technological landscape, AI bots and Digital Twins are emerging as transformative tools with vast potential across various industries. AI bots, for instance, can automate processes, enhance customer service, and streamline operations, leading to increased efficiency and cost savings. Digital Twins, on the other hand, enable real-time simulations and analysis of physical assets, optimizing maintenance, and improving overall performance. Given the importance of staying competitive and adaptive in the modern business world, organizations are encouraged to embrace innovation and invest in research and development to keep up with the latest technological trends. By fostering a culture of curiosity and continuous learning, the experts within the LSP can expand their knowledge base and explore the possibilities offered by AI bots and Digital Twins. Collaborations with technology experts, universities, or research institutions can be beneficial in gaining insights and expertise in cutting-edge technologies. Embracing innovation not only empowers the experts to make well-informed decisions but also enhances the organization's overall growth and competitiveness in the market. However, the fact of the willingness of LSP to implement the particular elements of material flow coordination and the small level of innovation confirmed some research about the increasing level of innovation of LSP in the last years (Cimini *et al.*, 2019; Marhauer and Hofman, 2019). Currently the most of examined LSPs use the most common IT support like WMS or EDI. Next figure (Figure 4) shows the structure of the percentage value of implemented technologies and the experts' opinions about the possibility of implementation of particular material flow coordination elements, where in the figure there is only the number of possible and impossible technologies to implement.

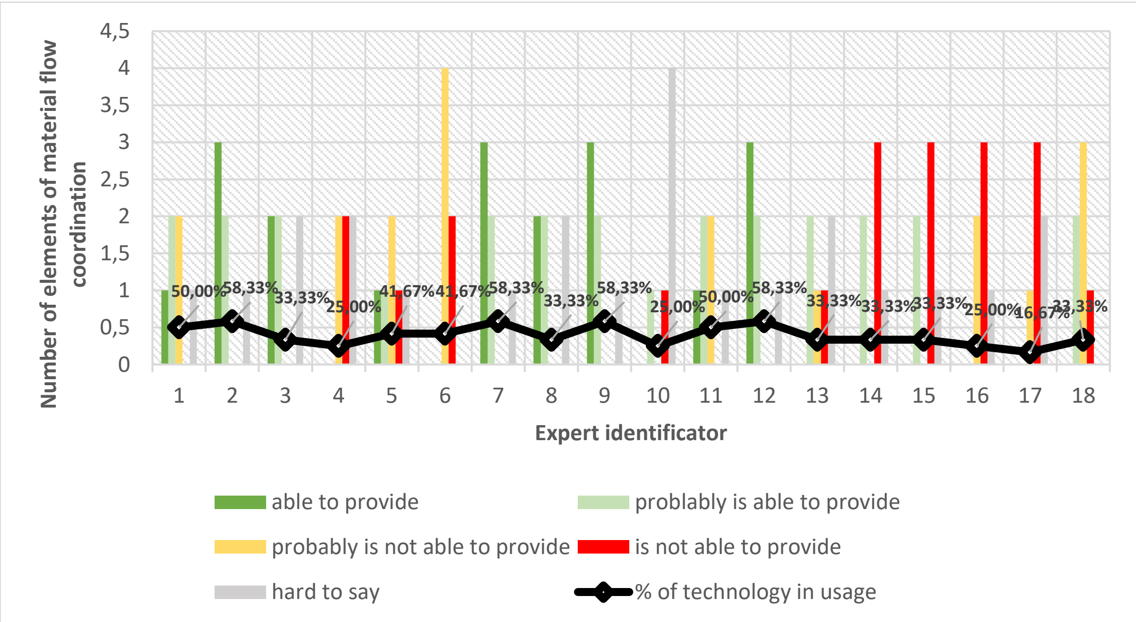

Figure 4. The experts' knowledge about the technologies that support material flow coordination and the level of their implementation at LSP

Looking at the interview results, one can see certain correlations related to the number of implemented technological solutions and the opinions of experts regarding the possibility of implementing individual solutions that support material flow coordination. Because of this reason, the correlation between these two variables was tested. To correlation, the Pearson correlation index (r) was used in the following ranges (Cohen, 1988):

- $|r| < 0,3$ means weak correlation;
- $0,3 \leq |r| < 0,5$ means moderate correlation;
- $0,5 \leq |r| < 0,7$ means strong correlation;
- $|r| \geq 0,7$ means very strong correlation.

The author acknowledges that a quantitative study with only 18 experts may raise concerns about result reliability. To address this, statistical significance (p-value) was assessed for each correlation. A p-value threshold of 0.05 ($p<0.05$) was used to determine statistical significance, following Wasserstein and Lazar (2016). Additionally, a mixed-methods approach combining qualitative and quantitative analysis enhanced the study's comprehensiveness. Quantitative analysis revealed a strong correlation ($r = 0.7957$, $p = 0.00008$) between the number of implemented technologies and experts' perceptions of material flow coordination. Another correlation ($r = 0.5675$, $p = 0.0140$) was found between the number of technologies and achieving coordination functions, though its statistical significance was less conclusive. This suggests potential external factors influencing the results. To deepen the analysis, expert interviews provided qualitative insights into the relationship between technology adoption and material flow coordination. No strong correlation was observed between the percentage of implemented technologies and the belief that material flow coordination is currently unfeasible ($r = -0.1668$, $p = 0.5082$). However, a significant negative correlation ($r = -0.6992$, $p = 0.0012$) indicated that as technology adoption increases, experts are less likely to perceive logistics coordination as unachievable. Qualitative interviews supported this finding by identifying specific factors influencing experts' views on digitalization's role in coordination. The study also examined the correlation between experts' assumptions about coordination feasibility and the number of implemented technologies. A strong positive correlation ($r = 0.8017$, $p = 0.0006$) confirmed that increased technology adoption increases experts' belief in the possibility of logistics coordination. Expert interviews provided contextual depth, highlighting challenges and benefits associated with technology implementation. The combination of quantitative data and qualitative insights strengthened the study's validity, offering both numerical evidence and expert perspectives to support the findings.

Table 2. Elements of material flow coordination with the comparison of experts answers

Elements of material flow coordination	**Does the LSP is able to provide such an element in the current state?**				**Number of implemented solutions**
	YES	**PROBABLY YES**	**PROBABLY NO**	**NO**	
Stock management for the other entities in the distribution network	1	8	2	1	6
Demand forecasting for particular distribution network nodes	2	7	4	4	7
Transportation planning and management in the whole distribution network	0	6	2	4	4
Logistics information management	6	1	4	4	3
Demand management	4	0	3	5	5
Resources and infrastructure management in the distribution network	6	4	4	2	5

Different elements of material flow coordination require varying levels of digitalization. A higher number of implemented solutions positively influences the feasibility of material flow coordination. Some elements, such as stock management and demand forecasting, demand extensive digitalization, while others, like logistics information management, can be developed with fewer technologies. In the next research phase, an international LSP was analyzed for its digitalization potential in material flow coordination. The company, a global logistics and supply chain provider, offers transportation, warehousing, and distribution services, specializing in customized solutions across industries. Its operations are supported by advanced technology systems enabling real-time tracking and monitoring. Committed to sustainability, the company integrates eco-friendly practices and employs a skilled workforce to optimize logistics operations. The Model Canvas was applied as an innovation tool, serving as a bridge between business models and innovation (Teece, 2010). Recognized for its adaptability across various industries (Szromek, 2021), the author posits that it is also applicable in the LSP context, facilitating digital transformation and strategic planning. The general structure of Business Model Canvas for improving the digitalization level of LSP and reaching the possibility of implement the general elements of material flow coordination is showed in Figure 5.

<table>
<tr><th colspan="5">BUSINESS MODEL CANVAS</th></tr>
<tr>
<td rowspan="2">KEY PARTNERS
2PL (second-party logistics)
3PL (third-party logistics)
Software and hardware developers
Logistics infrastructure developers</td>
<td>KEY ACTIVITIES
Implementation of new technologies
Providing the key elements of logistics coordination</td>
<td rowspan="2">VALUE PROPOSITION
Better adjusting to current logistical needs
Reducing the disruptions and negative effects in distribution networks
Improving the final customer service</td>
<td>LSP SERVICES RECIPIENT'S RELATIONSHIPS
Fully integration with data flow
Developing trust and transparency</td>
<td rowspan="2">LSP SERVICES RECIPIENT'S SEGMENTS
Manufacturers and distribution networks in traditional and omnichannel distribution systems</td>
</tr>
<tr>
<td>KEY RESOURCES
Software and hardware to develop nowadays technological
Workforce responsible for the implementation and maintenance of new solutions</td>
<td>CHANNELS
Developing the partnership with the current internal customers
Reaching new customers by offering the new services</td>
</tr>
<tr>
<td colspan="2">COST STRUCTURE
Licenses for new technologies
Workforce salaries
Changes in the LSP structure</td>
<td colspan="3">REVENUE STREAMS
Revenue for new service as an offer</td>
</tr>
</table>

Figure 5. General Business Model Canvas for the digital transformation of LSP to achieve the material flow coordination

Enhancing LSP digitization relies heavily on key partners, particularly technology providers specializing in advanced software and hardware integration. These partners drive digital transformation by implementing innovative tools that optimize operations and streamline processes. Additionally, infrastructure providers play a vital role in supporting material flow coordination, ensuring the seamless movement of goods and information across distribution networks. Collaborations with 2PL and 3PL companies further strengthen LSP capabilities by providing specialized expertise and resources. Such partnerships enable LSPs to align their services more effectively with client needs, enhancing customer satisfaction and loyalty. Data sharing and transparency are crucial for synchronized activities, facilitating informed decision-making and process optimization. Trust and cooperation among partners ensure smooth collaboration and efficient logistics operations. By embracing digitalization and strategic partnerships, LSPs can improve operational efficiency and gain a competitive edge. Expanding service offerings through innovative logistics solutions attracts new customers and creates additional revenue streams. Financial benefits from these advancements position LSPs as market leaders. Adopting digital technologies and fostering symbiotic partnerships with technology providers, infrastructure firms, and LSPs enables superior service delivery, operational excellence, and sustained competitiveness.

5. Discussion

5.1. Findings

Digital transformation is crucial for LSPs, offering opportunities to optimize operations, improve efficiency, and enhance customer experiences. However, challenges such as high costs, data security, and employee training must be navigated to remain competitive. Despite research limitations, several conclusions and further questions emerged. One key issue is why LSP experts have limited knowledge of innovations. While they possess deep logistics expertise, they may struggle to stay updated with rapid technological advancements. Implementing new technologies also requires significant investments in time, resources, and infrastructure, creating barriers for adoption. Similar challenges have been noted in green logistics (Mollenkopf and Stolze, 2013). To address this, Kmiecik (2023a) suggests a platform for innovation knowledge sharing within LSP activities, enabling companies to exchange insights on modern solutions for managing material and information flows. Evangelista and Durst (2015) propose a similar approach focused on sustainability, while Karia (2018) discusses knowledge-sharing beyond material flow coordination. Expanding expert knowledge on implementing and benefiting from new technologies is vital. This enables informed decision-making, enhances coordination capabilities, improves efficiency, reduces costs, and drives overall performance. The article addresses the research gap on the impact of technological solutions in material flow coordination, highlighting LSPs' challenges in keeping up with advancements. A knowledge-sharing platform is proposed as a solution to bridge this gap, empowering LSPs to manage material and information flows more effectively. The next issue is about how the digitalization level of LSP influence on material flow coordination? In Figure 6 there is a chart which shows the amount of technologies which are used in LSP and the probability of providing the particular elements of material flow coordination by LSP in the current state according to the experts' opinions.

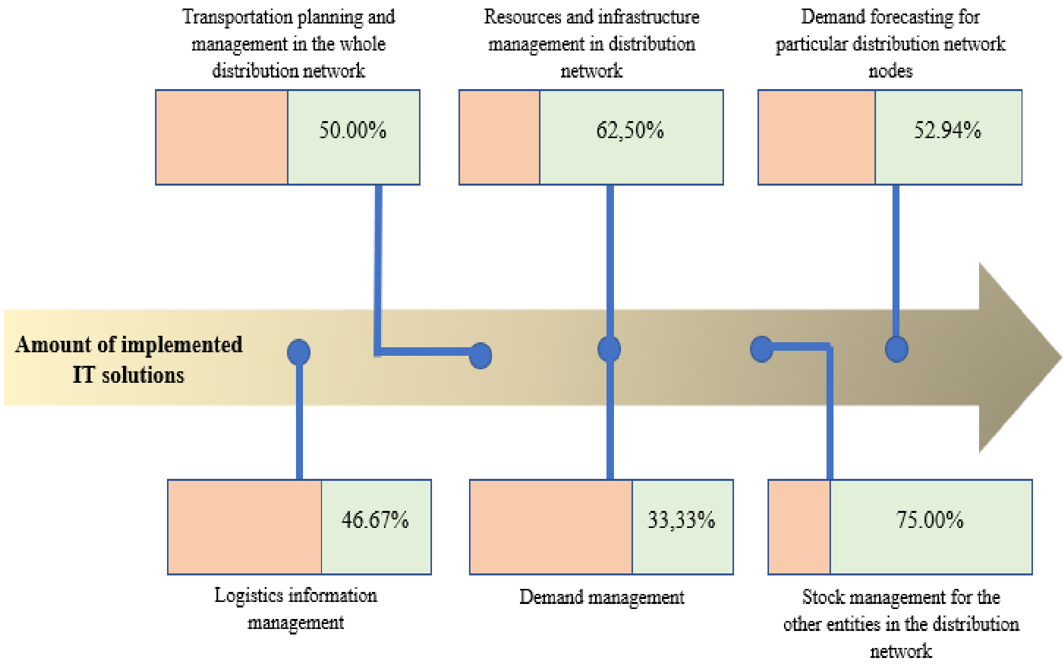

Figure 6. Probability of providing the particular elements of material flow coordination by LSP and amount of implemented IT solutions

The research indicates that approximately half of the experts believe companies with high technological involvement could implement demand forecasting for individual distribution links. However, demand forecasting and broader demand management remain unfamiliar to many LSPs. Despite this knowledge gap, LSPs have the potential to adopt these solutions, supporting manufacturers' demand planning in distribution networks (Kmiecik, 2023b). Successful implementation requires not only technological investments but also centralization and specific attributes within the distribution network (Kmiecik, 2021). In contrast, inventory management can be implemented with the current level of LSP innovation, as many LSPs already engage in internal warehouse management (Akbari, 2018). About half of the experts also viewed other material flow coordination elements as feasible for current LSP operations. The weakest IT infrastructure development was observed in logistics information management, likely because LSPs manage partner-acquired data but lack broader network-wide access. However, this is evolving, as LSPs seek to collect and utilize more extensive information (Herold *et al.*, 2021). A key question is how LSPs can implement digital solutions and their impact on business operations. Digitization enhances material flow coordination, and achieving optimal innovation levels is a well-researched topic (Fulconis *et al.*, 2016; Majid *et al.*, 2019). The logistics industry is projected to invest $10 billion in digital transformation by 2025 (DHL, 2020). The Business Model Canvas is introduced as a tool for illustrating LSP business model expansion to integrate these solutions. While previously applied in humanitarian logistics (Kucukaltan *et al.*, 2022) and smart city solutions (Parados *et al.*, 2022), this study presents its first use in material flow coordination. The findings offer valuable insights into the future of LSP operations.

5.2. Limitations and further research

Despite its contributions, this study has limitations that present opportunities for further research. The small sample of 18 LSP experts, while insightful, limits generalizability. A larger, more diverse sample could provide a broader perspective. Additionally, the study focused on international LSPs, which may not fully represent material flow coordination across different industries and regions. Future research could include a wider range of LSPs to gain a more comprehensive understanding of coordination practices. The findings revealed that experts had limited knowledge of advanced technologies such as AI bots and Digital Twins. Investigating the reasons behind this gap and identifying barriers to adoption could provide valuable insights for overcoming these challenges. While expert interviews provided qualitative depth, ensuring data reliability is crucial. Future research could use additional triangulation methods to strengthen the validity of qualitative findings. The study examined the correlation between digitalization and material flow coordination but did not explore long-term impacts. Further research could assess how digital transformation influences LSP operational efficiency and competitiveness over time. Additionally, developing a comprehensive framework integrating various coordination mechanisms in distribution networks could enhance understanding of material flow coordination and its relationship with digitalization. Acknowledging these limitations, this study offers valuable insights into the role of digitalization in LSPs. Future research addressing these gaps could further advance material flow coordination theory and improve digital transformation strategies for LSPs in dynamic distribution systems.

6. Conclusions

This research makes a significant contribution to management sciences, particularly in material flow coordination and LSP studies. The study examines LSPs' willingness to implement coordination features and their use of basic technologies supporting material flow coordination. Through in-depth interviews with 18 experts, valuable insights were gathered on technology adoption and the challenges and opportunities in coordination practices. A key finding is that most experts recognize LSPs' interest in adopting fundamental coordination elements, demonstrating openness to coordinated logistics. However, a knowledge gap was identified regarding advanced technologies like AI bots and Digital Twins, highlighting the need for continuous learning. The study also found a strong positive correlation between the number of implemented technological solutions and experts' opinions on material flow coordination. LSPs with higher technological adoption were more likely to integrate coordination elements, emphasizing technology's role as a facilitator. The research further analyzed the varying technological requirements for different coordination elements, confirming that a higher number of implemented technologies increases the likelihood of successful coordination. Additionally, an assessment of selected international LSPs' digitalization potential provided insights into the growing role of innovation in material flow coordination. By emphasizing the importance of technological advancements, this study contributes to theories of network coordination and material flow management, offering insights into LSP operations in the modern market. It underscores the need for deeper digitization within LSPs to enhance coordination capabilities. However, future research should expand the sample size and employ more extensive quantitative methods to strengthen the findings, providing a broader and more robust understanding of material flow coordination in logistics management.

Declaration of Generative AI and AI-assisted technologies in the writing process:

- During the preparation of this manuscript the author(s) used ChatGPT in order to support the translation of selected parts of the text into English. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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