“Mapping Industry 4.0 awareness and training priorities in logistics and transport”

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MAPPING INDUSTRY 4.0 AWARENESS AND TRAINING PRIORITIES IN LOGISTICS AND TRANSPORT

Abstract

The rapid digitalization of logistics and transport sectors under the Industry 4.0 paradigm has reshaped operational models, workforce requirements, and managerial decision-making. Understanding how professionals perceive these technological changes and what competencies they prioritize is vital for effective adaptation. This study aims to assess the level of Industry 4.0 awareness and identify key training needs among logistics and transport professionals. A quantitative survey was conducted in Vilnius, Lithuania, in January 2025 with 172 respondents from logistics (56%) and transport (44%) sectors. The survey covered four thematic areas: demographic profile, perception of Industry 4.0 components, perceived benefits and barriers, and training priorities. Descriptive and inferential statistics were used to analyze the data. Results show that 58.2% of respondents view Industry 4.0 as an integrated ecosystem of technologies, with software (13.9%) and Internet technologies (11.1%) most often cited as individual elements. Key training priorities include cybersecurity (80%), augmented/virtual reality (75%), and 3D printing (72.1%). High maintenance costs (26.4%) and implementation complexity (16.7%) were identified as the main obstacles to adoption. The findings show that although professionals recognize the transformative potential of Industry 4.0, significant skill and resource gaps persist. Closer collaboration between academia, policymakers, and industry is needed to address these gaps and prepare the workforce for a human-centered transition toward Industry 5.0.

Keywords Industry 4.0, logistics, transport, digital transformation, training, human capital

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INTRODUCTION

The ongoing digital transformation, often called Industry 4.0, marks one of the most significant changes in modern production and logistics systems. It combines technologies such as the Internet of Things (IoT), automation, artificial intelligence (AI), and data analytics to create intelligent, interconnected value chains. For logistics and transport companies, these changes reshape operational models, decision-making, and workforce skills. As global supply chains become more digitized, organizations' ability to adapt to new technological paradigms determines their competitiveness and resilience.

However, despite widespread recognition of Industry 4.0 as a strategic priority, many logistics and transport organizations encounter obstacles in understanding its components and turning them into tangible actions. Previous research has mainly concentrated on technological and managerial aspects of digital transformation (e.g., predictive maintenance, innovative warehousing, and data-driven routing). At the same time, comparatively less focus has been given to the human and educational dimensions of these changes. Specifically, the extent to which employees in the logistics and transport sectors comprehend Industry 4.0 and recognize their learning needs remains underexplored.

This gap is particularly evident in sectors characterized by high operational dynamics, fragmented supply chains, and diverse skill requirements. The shift to Industry 4.0 demands not only investments in infrastructure and technology but also the development of digital skills and ongoing training for employees at all levels. Without this human-focused adaptation, even advanced technological solutions may fail to achieve the expected performance gains.

The main scientific issue in this study is the limited understanding of how logistics and transport professionals view Industry 4.0 and which specific skills they prioritize for training and development. Recognizing this relationship is crucial for aligning educational programs and corporate training efforts with the real needs of the sector, ensuring a smoother and more inclusive shift toward digitalized logistics ecosystems.

1. LITERATURE REVIEW

The evolution of industrial revolutions provides a conceptual foundation for understanding how technological change has shaped manufacturing, logistics, and labor structures over time. Industry 1.0 emerged in the 18th century with the introduction of water and steam power, mechanized tools, and early factory systems (Sharma & Singh, 2020; Mohajan, 2019; Ilham & Apriliyanti, 2022). Mechanization significantly increased production capacity (A. George & H. George, 2020), while expanding transport networks improved the movement of raw materials and goods (Sutherland, 2008). Although the term logistics was not yet used in its modern sense, 19th-century military literature began to apply the concept to the coordination of supplies and troop movements (Sutherland, 2008). The Second Industrial Revolution (Industry 2.0) in the late nineteenth and early twentieth centuries brought electricity, conveyor-based manufacturing, and major improvements in transport and communication infrastructure (Hobsbawm, 1968; Ford, 1926; Landes, 2003). Electrification enabled mass production and shortened delivery times (Podgórska, 2022; Koc & Teker, 2019), while global trade expanded due to more efficient transport and communication systems (Chandler, 1977; Mokyr, 1992; O'Rourke & Williamson, 1999; Standage, 1998). Although logistics remained associated mainly with military operations (van Creveld, 1977; Black, 2006), the growing complexity of industrial distribution networks laid the groundwork for modern supply chain management (Mentzer et al., 2001; Christopher, 2016).

Industry 3.0 introduced electronics, information technologies, and automation into production and supply systems (Kaplinsky & Cooper, 1989; Kaplinsky, 2005). Barcodes and RFID technologies improved inventory tracking and decision-making (Sanders, 2014), while increasingly globalized supply chains demanded stronger analytical and adaptive capabilities (Wamba et al., 2017). Manufacturing shifted from standardized, centrally planned models to more flexible, computerized processes (Koc & Teker, 2019; Kumar et al., 2021; Podgórska, 2022). Taken together, these three revolutions increased automation, connectivity, and information intensity, creating the organizational and technological conditions that enabled the emergence of Industry 4.0.

Industry 4.0 is characterized by cyber–physical systems, smart sensors, the Internet of Things (IoT), big-data analytics, and artificial intelligence (AI). These technologies enhance traceability, forecasting, operational visibility, and real-time decision-making in logistics and supply chains (Pfohl et al., 2015). They also support decentralized control, continuous monitoring, and greater operational flexibility. In logistics, Industry 4.0 is reshaping transport network design, shortening production cycles, and improving efficiency and service quality (Sanders et al., 2024). However, the rising level of digitalization also brings challenges, including data-security risks, complex system integration, and an increasing need for specialized digital competencies (Wamba et al., 2017).

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Recent literature shows a transition from technology-centric automation to more human-oriented and sustainable industrial paradigms. Industry 5.0 emphasizes the reintegration of human creativity, problem-solving, and decision-making into a technologically advanced environment (A. George & H. George, 2020; Mattila et al., 2022; Adel, 2022). Collaborative robots, immersive interfaces, and human–machine co-creation reflect this shift, promoting a balanced interaction between people and intelligent systems (Akundi et al., 2022; Alojaiman, 2023). Industry 6.0 extends this trajectory by incorporating hyper-connectivity, anti-fragile systems, advanced AI, virtualization, and ethical decision-making frameworks (Chourasia et al., 2022; Duggal et al., 2022; Das & Pan, 2022). Key enabling technologies include artificial intelligence, the Internet of Things, virtual reality, cybersecurity solutions, digital twins, and ambient intelligence (Kuosmanen et al., 2021; Martini et al., 2024). Together, these concepts illustrate an evolution toward intelligent, human-centered, and sustainable industrial ecosystems.

Despite the extensive theoretical focus on technological capabilities in Industries 4.0, 5.0, and 6.0, considerably less is known about how logistics and transport professionals perceive Industry 4.0 and which skills they deem essential for its effective implementation. Existing research primarily focuses on technologies, organizational impacts, or barriers to adoption. However, empirical evidence regarding awareness, understanding, and training priorities remains scarce, especially in logistics and transport, where human capital is crucial for digital transformation. This highlights the necessity for empirical studies on Industry 4.0 awareness and competency needs among sector practitioners.

This study aims to assess the level of Industry 4.0 awareness and identify key training needs among logistics and transport professionals.

2. METHODOLOGY

The methodological framework of this study follows a sequential design integrating four main stages:

- Identification of research objectives and hypothesis formulation.
- Development and piloting of the survey instrument.
- Data collection through an online questionnaire.
- Statistical analysis and interpretation of results.

The empirical study was conducted in Vilnius, Lithuania, in January 2025 using a structured online questionnaire distributed to professionals working in the logistics (56%) and transport (44%) sectors. A total of 172 valid responses were gathered. The sampling method was non-probabilistic (convenience sampling), targeting employees and managers involved in logistics operations, transport management, and supply chain activities. Participation was voluntary and anonymous, with all respondents giving informed consent before completing the questionnaire. Demographic indicators included gender, age, and professional background: 73.8% of respondents were female, 26.2% male; 85% were between 25 and 50 years old. These proportions reflect the composition of the national workforce in the logistics and transport sector, thereby increasing the representativeness of the sample.

The data analysis focuses on four core aspects:

- Respondents' understanding of Industry 4.0.
- Perceived benefits and challenges of technological transformation.
- Training and skills development priorities.
- Cross-sectional insights that connect awareness with learning needs.

Quantitative indicators are expressed in percentages and counts to ensure comparability and clarity of interpretation.

The questionnaire was organized into four thematic sections:

- Demographic characteristics.
- Perception of Industry 4.0 components.
- Perceived benefits and barriers.
- Training and skill development priorities.

This ensured both theoretical validity and comparability with international studies. Respondents could select multiple options where appropriate, especially when identifying key technologies and challenges. The instrument was pre-tested with a pilot group of 10 participants to confirm its clarity and logical order. Minor linguistic adjustments were made before the full-scale distribution. Ethical considerations were observed throughout the study. The survey did not collect any personally identifiable data, and responses were used exclusively for academic research purposes. Participants were informed about the aims and confidentiality of the research before participation. The study design adhered to the ethical principles of the university's research ethics policy.

The collected data were analyzed using descriptive and inferential statistics. Frequency and percentage distributions were employed to summarize responses for categorical variables, while cross-tabulations were used to identify relationships between demographic groups and key indicators.

The chosen methodology combines theoretical grounding, validated measurement instruments, and transparent analytical procedures. The approach ensures reliability, replicability, and relevance of the findings to the logistics and transport sector. By focusing on both awareness and training needs, the methodological design enables a comprehensive assessment of the human dimension of Industry 4.0 implementation.

3. RESULTS

Respondents were asked what they believe Industry 4.0 encompasses. Table 1 presents a comparison of Industry 4.0. The vast majority (58%) indicated that all the elements listed in Table 1 were present. The Internet was mentioned by 11.1% of respondents, and software by 13.9%.

Respondents were asked, "Would you like to see the following Industry 4.0 themes explained in your institution?" Most respondents answered that they would like detailed explanations on topics such as IT security, assistive systems, augmented reality and virtual reality, change management in Industry 4.0, additive manufacturing, and 3D printing.

Respondents were also asked to define their understanding of Industry 4.0. As shown in Table 1, the majority (58.2%) associated it with an integrated combination of all technological components, while others emphasized individual elements such as software (13.9%) and the Internet (11.1%). This finding suggests that sector professionals tend to view Industry 4.0 holistically rather than as a set of isolated technologies.

Table 1. Composition of Industry 4.0

Answer options	Percent
Internet	11.1
Software	13.9
Big data and data analytics	4.2
Communication between equipment	2.8
Cloud solutions	1.4
Additive manufacturing (3D printing)	1.4
Cyber security	1.4
Remote control	1.4
All the above options	58.2
Other	1.4
Did not answer the question	2.8

Figure 1 illustrates how the research participants understand which technologies comprise Industry 4.0. It is shown that 58.2% of respondents selected "All listed elements," indicating that more than half of the participants perceive Industry 4.0 as an integrated set of technologies rather than isolated innovations. (Pfohl et al., 2015). The separate selections of "Software" (13.9%) and "Internet" (11.1%) suggest that some respondents still view these technologies as distinct and more familiar than, for instance, cloud computing or big data. Values such as "Cybersecurity" (4.2%), "Cloud Computing" (3.5%), "Big Data and Analytics" (2.1%), or "Remote Control" (1.4%) indicate that, although critically important, these technologies are not yet widely recognized among respondents as core components of Industry 4.0.

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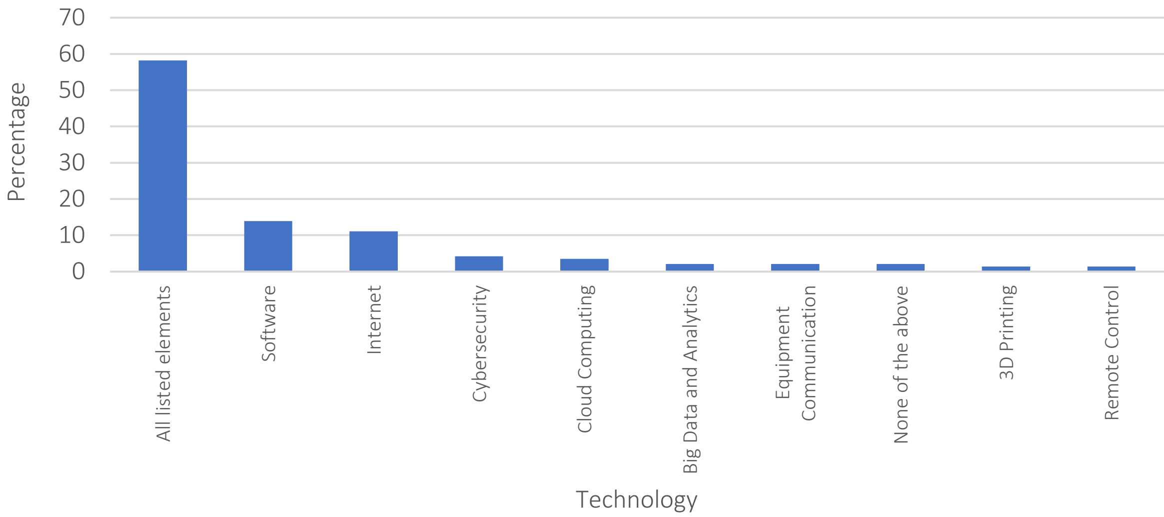

Figure 1. Areas covered by Industry 4.0

These findings are particularly relevant in the logistics sector, where a significant portion of Industry 4.0 technologies are applied within supply chains – from real-time tracking systems (IoT) to cloud-based ERP platforms and cybersecurity solutions.

Respondents were asked what the need is for Industry 4.0 topics to be taught in higher education (Table 2). The majority of respondents noted that it is assistive systems, augmented reality and virtual reality, additive manufacturing and 3D printing, and software systems environment.

Respondents were asked whether it is necessary to apply Industry 4.0 tools in the training process. Thus, 55% answered yes, 3% answered no, and 42% of respondents answered that they do not know. 28% of respondents indicated which Industry 4.0 tools could be applied in their institution's work process. Additionally, 27% invite experts in the field and organize guest lectures for companies working on Industry 4.0, while 15% share best practices from other countries in this area. When asked about the impact of the Industrial Revolution on education, 28% of respondents noted an increase in standardization, 42% responded that it has led to the training of more skilled and educated workers, 30% said that it has led to the creation of a new workforce, and 30% said that it has led to the creation of a new workforce with more skills and education.

The next part of the survey aimed to determine which characteristics of Industry 4.0 are considered most and least significant for logistics and transport activities. Table 3 summarizes the distribution of responses. The results indicate that efficiency improvement and better data integration remain central benefits, while respondents also highlight increased transparency and customer responsiveness as emerging values. These results

Table 2. The need for Industry 4.0 topics to be taught in higher education

Answer options	Yes	No
Human-equipment collaboration	68.6%	31.4%
Assistive systems, augmented reality, and virtual reality	75.0%	25.0%
Cloud and service orientation	63.8%	36.2%
Software systems environment	69.6%	30.4%
Change management for Industry 4.0	71.2%	28.8%
IT security	80.0%	20.0%
Continuous and digital engineering	46.3%	53.7%
Additive manufacturing and 3D printing	72.1%	27.9%
Implementation management of digital processes	62.9%	37.1%

Table 3. Benefits of Industry 4.0

Answer options	Percent
Greater productivity	10.1
Greater efficiency	10.9
Greater knowledge-sharing and collaboration	8.4
Flexibility and agility	8.2
Customer experience is improving	6.9
Costs are decreasing	5.3
Better use of resources	7.2
Production is accelerating	7.6
Downtime of equipment and production lines is reduced	5.1
Product quality problems are decreasing	4.8
Waste of resources, materials, and products is reduced	5.1
Total operating costs are reduced	4.6
Innovation opportunities are created	10.3
More revenue is generated	5.5

align with the theoretical framework, as technological integration was identified as a key driver of productivity and operational flexibility.

Figure 2 reveals which Industry 4.0 topics interest workers most and provides a foundation for planning educational programs, particularly those focused on the logistics sector. IT security (80%), assistive systems and AR/VR (75%), and 3D printing (72.1%) are the three most preferred topics among workers. Change management for Industry 4.0 (71.2%) stands out as a significant topic, emphasizing that technological transformation requires both technical and managerial competencies. Topics of moderate interest include Big Data and Analytics (51%), Artificial Intelligence (39.3%), and Cybersecurity (31%). The lowest levels of interest were recorded for machine-to-machine (M2M) communication at 21.2%, while just 1.4% selected "None of the above," indicating that most students are interested in Industry 4.0 topics to some degree.

In the logistics sector, these findings offer several important insights. The high interest in IT security and AR/VR demonstrates that students recognize the necessity of being prepared for work in modern, digitized supply chains, where both data protection and innovative training solutions, such as AR simulations in warehouses, are vital. Prioritizing 3D printing is connected to a rising trend in logistics: the decentralized production of spare parts.

Alongside the benefits, respondents were asked to identify the main barriers and disadvantages of implementing Industry 4.0. As presented in Table 4, the leading concern was the high cost of maintenance (26.4%), followed by the length and complexity of implementation (16.7%) and cyber-

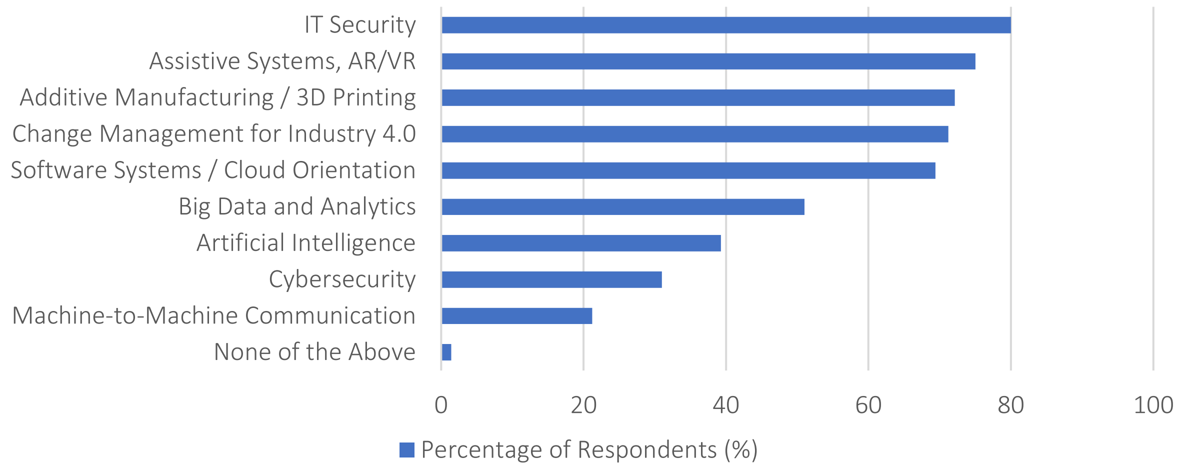

Figure 2. The need for Industry 4.0 teaching topics

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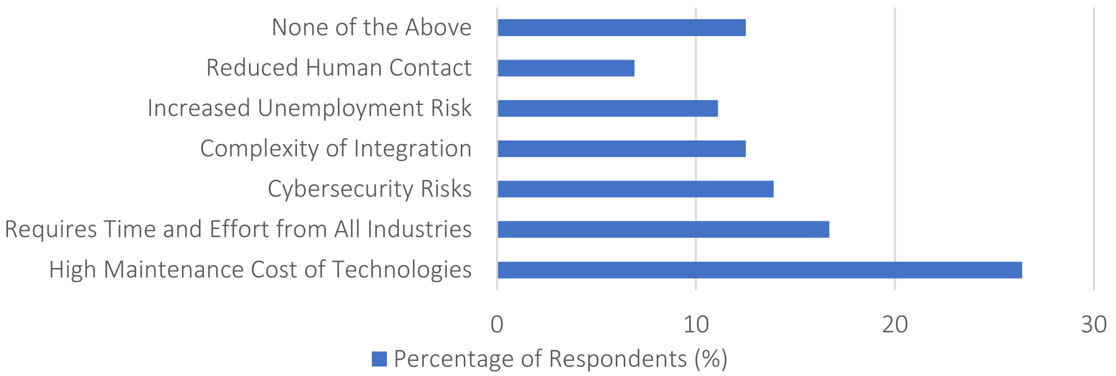

Figure 3. Perceived disadvantages of Industry 4.0

Table 4. Disadvantages of Industry 4.0

Answer options	Percent
Reduced cybersecurity	13.9
The skills and education of the employees working in "Industry 4.0" are not satisfactory	12.5
Expensive maintenance of Industry 4.0 tools	26.4
Maintenance of M2M communication (Machine to Machine) is expensive	6.9
The need for integrity in production processes is growing	13.9
Implementation takes time and effort from all industries	16.7
Other (enter)	4.2
Did not answer the question	5.6

security risks (13.9%). These findings indicate that financial and technological readiness remain key challenges, particularly for small and medium-sized enterprises (SMEs). The perceived cybersecurity risk also underscores the growing need for organizational awareness and employee training in digital resilience.

Figure 3 illustrates the most frequently identified Industry 4.0 disadvantages among the surveyed students. It highlights the primary concerns and obstacles related to implementing these technologies. The most significant portion of respondents (26.4%) identified the high maintenance cost of Industry 4.0 technologies as the most important drawback. 16.7% noted that implementing these technologies requires considerable time and effort across all industrial sectors, while 13.9% pointed out the risk of cybersecurity threats. Other frequently mentioned barriers included the complexity of technology integration (12.5%), increased unemployment risk (11.1%), and reduced human interaction (6.9%). 12.5% selected "None of the above," suggesting that some students do not perceive any significant disadvantages or are unaware of them.

The high maintenance cost is one of the most prevalent challenges encountered by smaller logistics companies, especially when integrating IoT sensors, autonomous systems, or ERP solutions. This underscores the importance of gradual implementation strategies, particularly in regional terminals and logistics hubs.

The concern regarding cybersecurity (13.9%) is highly relevant, as logistics chains increasingly rely on data exchange among various systems and suppliers. Such concerns should promote greater emphasis on information security in academic curricula and practical training materials.

Fears about unemployment and reduced human interaction highlight the necessity of fostering a positive narrative surrounding Industry 4.0, one in which technologies do not eliminate jobs but rather transform them (e.g., transitioning from a warehouse worker to a warehouse management system operator).

Table 5 presents the importance of Industry 4.0. 28.5% of respondents said that it increases the speed of innovation, 21.5% said that it is easier to

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respond to market changes, and 21% said that it helps manufacturers cope with current challenges.

Table 5. Importance of Industry 4.0

Answer options	Percent
Helps manufacturers to meet current challenges	21.0
Easier to respond to market changes	21.5
Increases the speed of innovation	28.5
More user-centric	10.8
Design processes are accelerated	17.2
Other	1.1

Figure 4 illustrates the key motivational factors that students identified for why Industry 4.0 is needed. Other important motivations included:

- Simplified response to market changes (21.5%)
- Support in solving current business challenges (21.0%)

Responses that were slightly less frequently mentioned but still relevant included improved customer satisfaction (11.1%), time savings (6.3%), ensured quality (5.6%), and increased productivity (4.9%).

Addressing business challenges (21%) in the logistics industry requires minimizing problems such as data gaps, planning errors, or delivery delays. Industry 4.0 solutions, such as AI-based forecasting systems, enable automated, timely responses to disruptions.

Customer satisfaction (11.1%) is crucial in e-commerce logistics, where delivery speed, accuracy, and information transparency are competitive advantages. Industry 4.0 technologies help ensure last-mile efficiency and improved service reliability.

Automated warehouses, robotic sorting systems, and intelligent packaging logistics are all components of Industry 4.0 reality (Table 6). Answering the question of whether they have heard about certain things, 68.7% have heard of 3D printing, 14.9% have heard of smart factories, and 10.3% have heard of augmented reality.

Table 6. Awareness of Industry 4.0

Variables	Yes, often	Yes rarely	Rarely	Never
"Virtual Real Estate"	4.4%	22.1%	25.0%	48.5%
Augmented reality	10.3%	23.5%	26.5%	39.7%
Mixed reality	4.5%	22.7%	27.3%	45.5%
Rapid prototyping	11.9%	38.8%	17.9%	31.3%
3D printing	68.7%	22.4%	1.5%	7.5%
FABLAB	6.2%	4.6%	20.0%	69.2%
Industry 4.0	7.5%	14.9%	41.8%	35.8%
Smart factories	14.9%	19.4%	32.8%	32.8%

The high awareness of 3D printing indicates that this subject is familiar to respondents. This is particularly significant for logistics, as 3D printing facilitates decentralized production, lowers warehousing costs, and accelerates the delivery of spare parts.

However, the very low awareness of technologies like digital twins, IoT, cloud computing, and big data is concerning, as these are the backbone of Industry 4.0 in logistics systems. They enable:

- Real-time tracking of shipments (IoT),
- Demand forecasting and route planning (big data),

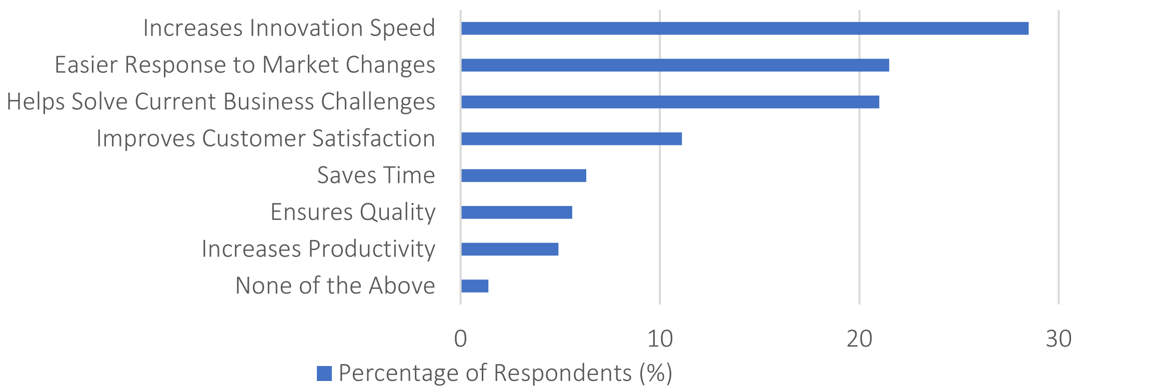

Figure 4. Reasons for the need for Industry 4.0

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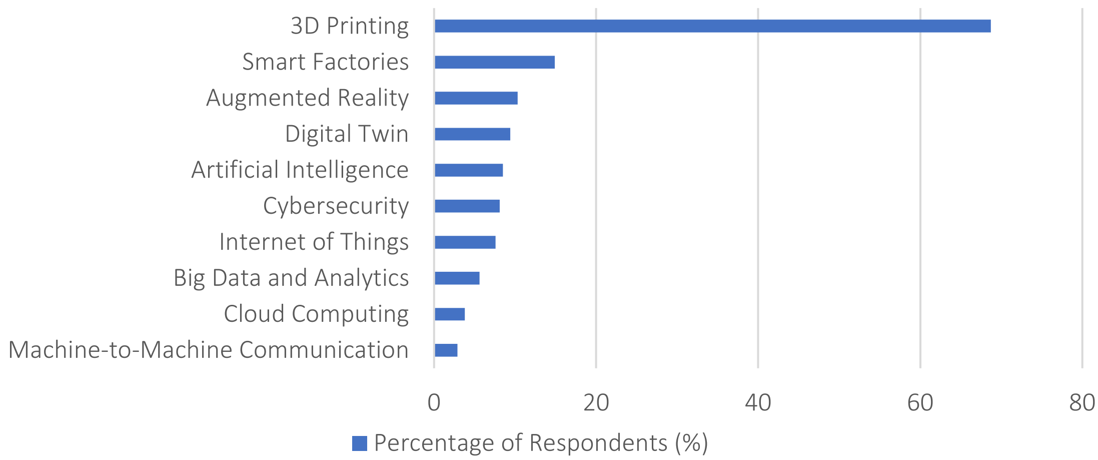

Figure 5. Awareness of specific Industry 4.0 technologies

- Centralized information management (cloud computing),
- Simulation of logistics processes (digital twin).

Figure 5 presents awareness of specific Industry 4.0 technologies. It visualizes respondents' familiarity with specific Industry 4.0 technologies. The results assess overall awareness levels and identify which topics need more attention in the educational process, particularly logistics and supply chain management. 3D printing (68.7%) is the dominant technology in terms of workers' awareness. Significantly fewer respondents know other technologies:

- Smart factories (14.9%),
- Augmented reality (10.3%),
- Digital twin (9.4%),
- Artificial intelligence (8.5%),
- Cybersecurity (8.1%),
- Internet of Things (IoT) (7.6%),
- Big data & analytics (5.6%),
- Cloud computing (3.8%),
- Machine-to-machine (M2M) communication (2.9%).

The analysis reveals that Industry 4.0 is widely perceived as an integrated technological ecosystem within the logistics and transport sectors. Respondents demonstrate a strong interest in developing competencies related to cybersecurity, automation, and immersive technologies, while simultaneously acknowledging financial and operational constraints that limit rapid implementation. The results provide a comprehensive quantitative picture of how logistics and transport professionals perceive Industry 4.0 technologies, evaluate their benefits and constraints, and identify training priorities essential for adaptation.

4. DISCUSSION

The results confirm that Industry 4.0 is understood by logistics and transport professionals primarily as an integrated system of interrelated technologies, rather than as a collection of isolated tools. This holistic understanding is consistent with technological-oriented definitions that foreground interoperability, cyber-physical integration, and end-to-end connectivity in value chains (Rupp et al., 2021; Vaidya et al., 2018). The finding that 58.2% of respondents selected "all technological components" aligns with a systems-thinking perspective, consistent with contemporary reviews that frame Industry 4.0 as a platform for the convergence of digital technologies across supply networks (Kohnová & Salajová, 2023; Pfohl et al., 2015).

At the same time, the emphasis on software (13.9%) and Internet technologies (11.1%) as salient identifiers highlights the centrality of information infrastructures in shaping day-to-day industrial practices. Prior profiling of the Internet of Things in industry underscores how connectivity and device-to-device communication enable real-time visibility and control, while simultaneously introducing integration challenges (Wójcicki et al., 2022). In logistics and transport contexts, such data-rich environments connect operational execution with planning and analytics, reinforcing the view that employees experience digitalization through tangible technological touchpoints, applications, interfaces, and connected equipment (Kohnová & Salajová, 2023; Rupp et al., 2021).

The strong prioritization of cybersecurity (80%), augmented/virtual reality (75%), and 3D printing (72.1%) in training preferences offers a clear window into the human dimension of digital transformation. Systematic reviews of Industry 4.0 impacts on human capital show that new skill profiles, such as data literacy, human–machine interaction, and digital safety, are prerequisites for realizing performance gains from technology (Sima et al., 2020; Tri et al., 2021). Similarly, value-chain analyses emphasize capability development and cross-functional coordination as foundations for technology adoption (Kohnová & Salajová, 2023). Hence, respondents' training priorities align with the literature's call for competency frameworks that blend technical proficiency with applied, scenario-based learning (Rupp et al., 2021; Vaidya et al., 2018).

Nevertheless, the study also reveals persistent barriers. The prominence of maintenance costs (26.4%) and implementation complexity (16.7%) mirrors evidence that capital intensity, integration risk, and organizational readiness frequently constrain adoption, especially in smaller firms and fragmented value chains (Podgórska, 2022; Kohnová & Salajová, 2023). Reviews of IoT in industry additionally highlight security and privacy as enduring concerns that demand both technical controls and awareness training (Wójcicki et al., 2022). Together, these obstacles explain why awareness may exceed actual rollout rates, as firms balance investments against uncertain returns and capability gaps (Pfohl et al., 2015; Rupp et al., 2021).

From an educational and managerial perspective, respondents' concurrent interest in technical (e.g., cybersecurity, AR/VR, additive manufacturing) and organizational (e.g., change management) topics points to a need for a socio-technical balance. Scholarship on Industry 5.0 and beyond places humans back at the center of industrial transformation, stressing collaboration, creativity, responsibility, and sustainability alongside efficiency (Adel, 2022; Akundi et al., 2022; Alojaiman, 2023; Maddikunta et al., 2022). The pattern observed here suggests that employees anticipate this trajectory: technology must be complemented by people-focused upskilling, ethical frameworks, and resilient operating models (Chourasia et al., 2022; Duggal et al., 2022).

Situating these findings in the broader supply chain literature further clarifies their implications. Classic definitions of supply chain management emphasize end-to-end integration and coordinated decision-making (Mentzer et al., 2001), while empirical work links data-driven capabilities with improved performance and agility (Wamba et al., 2017; Sanders, 2014). In practice, however, organizations face a trade-off between advanced analytics and interpretability, governance, and capability maturity issues that frequently surfaced during digital transitions (Baryannis et al., 2019; Pfohl et al., 2015). Our results, especially the salience of cybersecurity and implementation effort, echo these constraints and reinforce calls for staged adoption strategies and continuous learning paths (Kohnová & Salajová, 2023; Podgórska, 2022).

An important theoretical implication emerges when linking the present results to the historical evolution of industrial revolutions. Reviews tracing the path from mechanization to digital ecosystems show that technological shifts co-evolve with institutional arrangements and workforce skills (Sharma & Singh, 2020; Kumar et al., 2021). The transition toward more human-centric paradigms (Industry 5.0/6.0) reframes success as a function of human–machine cooperation and societal value creation, not technology alone (Adel, 2022; Maddikunta et al., 2022; Akundi et al., 2022). Our survey indicates that logistics and transport professionals perceive digitalization less as a threat and more as an opportunity, provided adequate training, security, and resource support mechanisms are in place (Sima et al., 2020; Wójcicki et al., 2022).

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Finally, the discussion highlights two practical implications. First, education providers such as universities, colleges, and vocational centers should align curricula with empirically identified skill needs, integrating foundational cyber-hygiene, immersive learning technologies, and applied analytics (Tri et al., 2021; Rupp et al., 2021). Second, policy and ecosystem coordination can reduce cost and complexity barriers through standards, incentives, and collaborative platforms, as reflected in longitudinal analyses of the Industry 4.0 agenda (Kagermann & Wahlster, 2022) and in supply-chain integration studies (Pfohl et al., 2015). Addressing these aspects together would support a more inclusive, resilient, and human-centered implementation of Industry 4.0 principles in logistics and transport, while laying foundations for Industry 5.0 readiness (Adel, 2022; Akundi et al., 2022).

The discussion confirms that the digital transformation of the logistics and transport sectors is simultaneously a technological, organizational, and human challenge. The survey results and their alignment with contemporary literature demonstrate both progress in Industry 4.0 awareness and persisting readiness gaps in cybersecurity, implementation costs, and competence development. These insights provide a solid foundation for deriving concrete conclusions and outlining future research and policy directions.

CONCLUSION

This study aims to assess the level of awareness of Industry 4.0 and identify key training needs among logistics and transport professionals. The empirical results suggest that employees tend to view Industry 4.0 not as separate tools but as a coherent technological ecosystem. At the same time, the strongest demand for learning appears in areas such as cybersecurity, augmented and virtual reality, and 3D printing. The findings also show that financial and technical barriers, particularly high maintenance costs and system integration challenges, continue to slow wider adoption.

Based on these insights, several conclusions can be drawn. Logistics and transport professionals already possess a reasonably solid grasp of Industry 4.0 technologies and how these elements interact within digitalized supply chains. The sector shows a clear need for continuous, structured training in digital skills, with particular emphasis on cybersecurity and immersive technologies that are becoming increasingly relevant. Digitalization efforts are still constrained by practical obstacles, especially the financial burden of implementation, the complexity of integrating new systems, and persistent data security concerns, which are particularly visible in small and medium-sized enterprises. Closer collaboration between industry actors, policymakers, and educational institutions is needed to align training initiatives with real operational needs and to support a more human-centered approach to digital transformation.

Future research could benefit from cross-country comparisons, longitudinal studies tracking changes in awareness over time, or more in-depth explorations of how emerging Industry 5.0 principles shape human–machine collaboration in logistics environments.

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