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DIRECTIONS OF TECHNOLOGICAL CHANGE AMONG LOGISTICS OPERATORS IN POLAND: THE RESULTS OF A PILOT STUDY

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Abstract.
Industry 4.0 technology (I4.0T) is transforming the economic landscape by extending the physical world with the capabilities of the digital world. While this integration generates a range of development opportunities, it also carries certain risks. The research niche of this article is the small number of studies and publications focusing on the implementation of I4.0T among logistics operators. The purpose of this article is to organise I4.0T in the context of its application in logistics and to analyse the use of I4.0T among a selected group of logistics operators in Poland, based on responses provided by individual respondents. The present pilot study will inform the main study. As part of a literature review, twenty-one I4.0T were identified, grouped, and categorised according to the authors' methodology, thereby providing a basis for interpreting the empirical research results. The pilot survey involved twenty-three respondents (representing different logistics operators) and focused on their knowledge of I4.0T, their partial use or full adoption, and their strategic importance to the organisation. The results show that the use of I4.0T concentrates on digitalisation in the broadest sense, the application of big data analytics, and the use of mobile applications and sensor networks—in other words, solutions that have been available on the technology market for at least two decades. The results highlight the untapped potential of I4.0T, which the surveyed logistics operators should exploit to improve operational efficiency and even transform their business models.

Keywords:
Industry 4.0 technologies; logistics operators; technology adoption; digitalisation; pilot study

Introduction

Several key factors are driving the dynamic changes in the economic environment of companies operating in the market. They include implementing the assumptions of Industry 4.0 (I4.0), pursuing sustainable development and circular economy goals, and adapting to turbulent geopolitical changes. Industry 4.0 technologies (I4.0T) are particularly significant in this context, as their unique characteristics may transform existing logistics paradigms.

The I4.0 concept was introduced in 2011 at the Hannover Messe trade fair and was finally set out in a report prepared for the German government in 2013 (Kagermann et al. 2013). I4.0 is underpinned by technologies that form cyber-physical systems (CPS) in smart factories. The most prevalent I4.0T include the Internet of Things (IoT), the Internet of Services (IoS), and the Industrial Internet of Things (IIoT); big data and big data analytics; cloud computing; blockchain; additive manufacturing (AM), which incorporates 3D printing; augmented reality (AR) and virtual reality (VR); and artificial intelligence (AI), along with the supporting algorithms of machine learning and deep learning (Nascimento et al. 2019).

The I4.0T presented here apply not only to the manufacturing sector but also to logistics. Traditional logistics processes can incorporate I4.0T at every stage. This is particularly important for companies providing logistics services, as it is a key factor in improving operational efficiency and the resilience, preparedness, business continuity, and security of logistics systems.

Although studies on the digital transformation of logistics operators exist, the available literature remains limited (Nicoletti and Appolloni 2025) and focuses, for example, on issues related to the relationships and interactions between people and machines (Cimini et al. 2020). On this basis, a research gap can be identified regarding the use of I4.0T among logistics operators.

The rapid evolution of I4.0 requires a clear understanding of its impact on logistics operators. In this context, it is appropriate to identify the directions of technological change among logistics operators in Poland (LOP), to provide answers to the following research questions:

RQ1: What types of I4.0T exist, and how can these technologies be categorised in the context of logistics operators?

RQ2: Which I4.0T are used by the surveyed LOP, and to what extent?

RQ3: What is the scope of I4.0T adoption, and what technological changes might this imply for the surveyed LOP?

This theoretical and empirical article is structured as follows. The first section presents a review of the literature on I4.0T, how these technologies are categorised, and the specific characteristics of logistics operators. The following section describes the research methodology, empirical results, and a discussion. The article concludes

with a summary that highlights the research's limitations, managerial implications, and suggestions for future research directions.

Literature Review

Logistics operators are companies that provide logistics services. These companies use various technologies to increase operational speed (in response to emerging market demands), while simultaneously enhancing operational transparency; this directly impacts the quality of their cooperation with clients and partners (Baglio et al. 2025). In this respect, I4.0T are very important, as they can serve as powerful tools for creating a competitive advantage.

Bai et al. (2020) identified seventeen I4.0T, which they classified as follows: AM, AI, AR, autonomous robots, big data and big data analytics, blockchain, cloud computing, cobotics systems, cybersecurity, unmanned aerial vehicles (UAVs), commonly referred to as drones, global positioning systems (GPS), IoT and IIoT, mobile technologies, nanotechnologies, radio frequency identification (RFID), sensors, sensor networks and actuators, and simulations.

Zheng et al. (2021) indicated that CPS, IoT, big data and big data analytics, cloud computing, AI, blockchain, simulations and modelling, visualisation technologies, automation, industrial robots, and AM are among the dominant forms of I4.0T.

A significant proportion of this group consists of specific technological tools. By contrast, terms such as cybersecurity (Kshetri 2017) or simulations (Dai and Ke 2022) represent areas of I4.0 development rather than technologies in their own right.

To systematise I4.0T, this study identifies twenty-one core I4.0T, including the broadly defined term 'smart,' as it relates to materials, systems, processes, and goods. The alphabetical list of I4.0T—presented in Table 1—requires further systematisation, particularly regarding the relationships between individual technologies. Therefore, classification I4.0T requires an examination of existing classifications in the literature.

Table 1. Identified Industry 4.0 Technologies

5G	Cobots and Cobotics Systems	Modern Identification Systems (RFID) / Near Field Communication (NFC) / Quick Response (QR)
Additive Manufacturing	Cyber-Physical Systems	Nanotechnology
Artificial Intelligence / Machine Learning (Computational Algorithms)	Digital Twins (DT), Digital Assistants (DA)	Robotics

Table 1 (continued)

5G	Cobots and Cobotics Systems	Modern Identification Systems (RFID) / Near Field Communication (NFC) / Quick Response (QR)
Augmented Reality / Virtual Reality / Mixed Reality	Internet of Things / Industrial Internet of Things	Sensors and Actuators
Big Data / Big Data Analytics	Machine Autonomy	Smart
Blockchain	Machine-to-Machine (M2M) Communication	Unmanned Aerial Vehicles UAVs (Drones)
Cloud Technologies	Mobile applications	Vision Systems

Source: own study

Chiarello et al. (2018) proposed a classification of I4.0 that reflects Porter's value chain for I4.0. They identified five distinct groups:

- Resources, comprising sensors, microprocessors, microcontrollers, and actuators.
- Connectivity, including Wi-Fi, Bluetooth, 3G, 4G, 5G, RFID/NFC, low-power wide-area network (LPWAN), and Zigbee (a data transmission protocol).
- Cybersecurity, encompassing firewalls, cryptography systems, and Blockchain.
- Data sets and analytics, including fog computing, cloud computing, data mining, and AI.
- Simulations, involving agent systems, system dynamics, and discrete events.

By contrast, Frank et al. (2019) categorised these technologies into smart supply chains, smart working, smart manufacturing, and smart products, which are underpinned by the IoT, cloud computing, big data, and big data analysis. Similarly, Dachs et al. (2019) identified three main areas of I4.0T: digital management systems, wireless human-machine communication, and CPS. While both Frank et al. (2019) and Dachs et al. (2019) presented a broad scope for I4.0T, their focus remains primarily on management-related issues. This broad approach may hinder the accurate classification of a specific I4.0T, as potential applications frequently vary across contexts.

Di Maria et al. (2022) divided I4.0T into two categories: data processing technologies and smart manufacturing technologies. The first group includes big data, cloud computing, simulation, automated analysis and data visualisation, AI, and IoT technologies. The second group comprises advanced robotics, CPS, 3D printing and scanning, and AR.

The I4.0T categorisation process can also be examined from the perspective of technology adoption models. Using the Technology-Organisation-Environment (TOE) framework as a starting point, the presented I4.0T can be analysed and grouped in other contexts. For example, based on the technological context, they can be examined in terms of a given technology's characteristics, compatibility, complexity, or availability. In the Technology Acceptance Model (TAM), they can be examined in terms of perceived usefulness and ease of use. In the case of the Diffusion of Innovations (DOI) model, technologies can be considered in terms of the relative advantage of the new technology over the currently used technology, similar to the TOE model's focus on compatibility and complexity, but also in terms of testing and observation opportunities (Prakash 2025). It should be clearly noted that the proposed models categorise technologies based on their organisational implementation, which may be useful for future research aimed at identifying potential barriers to I4.0T implementation and developing a framework for implementing these technologies.

The technologies and classifications reviewed here allow us to propose a slightly different approach to I4.0T issues within LOP. Given that these technologies originate in information and communication technologies, data processing and digital communication are paramount. Furthermore, emerging manufacturing technologies can be distinguished by whether they alter the manufacturing process itself (AM) or its operational environment—the workplace (robotics, cobotics, CPS). Moving beyond theoretical grouping, I4.0T are integrated into cohesive systems and processes to achieve specific operational objectives. Consequently, the grouped technologies can be considered components of systems and processes critical to I4.0, such as cybersecurity, business analytics (including optimisation and simulation), and smart objects (including smart machines, smart materials, and smart products). On this basis, the following I4.0T groups are proposed to support specific I4.0 processes and systems - Table 2.

The I4.0T presented in Table 1, along with the proposed grouping of these technologies in Table 2, address the first research question. According to the authors, the classification proposed in Table 2—excluding the manufacturing group—allows for the evaluation of each of the logistics processes: transportation, warehousing, packaging, order fulfilment, and inventory management, which can, for example, be expanded to include issues such as security, resilience, and business continuity, in the I4.0T implementation context. Therefore, the division proposed in the Table 2 is important because it will serve as the basis for presenting the research results later in the paper

Table 2. Classification of Industry 4.0 technologies and identification of key processes and systems

Industry 4.0 Technology Groups	Industry 4.0 Technologies	Industry 4.0 Processes and Systems
Digitalisation (changing the physical world into a digital one)	General digitalisation, DT, DA	Cybersecurity Simulations Optimisation Business Analytics Intelligence of Things
Data processing and protection (computing)	Big Data, Cloud Computing, AI, ML, Blockchain	
Communications (new ways for people and machines to communicate)	IoT/IIoT, 5G, M2M, RFID, NFC, QR	
Manufacturing	AM, 3D printing, 3D scanning	
Process support	Robotics, cobots and cobotics systems, machine autonomy, UAV	
Supporting Tools	Sensors and actuators, vision systems, nanotechnologies, blockchain, AR/VR, mobile applications	

Source: own study

Methods

The research method used in this article combines a structured literature review with a computer-assisted web interview (CAWI) conducted via Google Forms.

The structured literature review was designed to identify and categorise the I4.0T concept. This enabled the identification and categorisation of each I4.0T according to the categories proposed in Table 2, thereby improving the clarity of the research findings presented in the next section of the paper.

In the pilot study, 50 companies based in central Poland (mainly in the Lodz Voivodeship and neighbouring regions) were deliberately selected because it was easy to contact staff at these companies. Twenty-three respondents (from 23 different companies) provided answers, resulting in a response rate of 46%. The survey was conducted in the fourth quarter of 2025.

The use of purposive (convenience) sampling is supported in the literature as an effective approach in exploratory research, where participant selection is guided by specific research objectives (Glinka and Czakon 2021). This choice stemmed from the authors' ability to establish contact with specific employees in the logistics sector, thereby increasing the likelihood of receiving responses. Furthermore, this sampling method ensured that participants could effectively test the research tool, thereby highlighting any ambiguities in the questionnaire.

As LOP form part of the transport, freight forwarding and logistics (TFL) sector, the target sample for the future survey will comprise the 150 companies with the highest turnover in these areas, identified in the "Ranking firm TSL 2025" published by Rzeczpospolita (Przybylski 2025).

The questionnaire presented the I4.0T identified in the structured literature review and asked respondents about their general familiarity with each one ("unfamiliar" or "familiar with the concept") and the extent to which they are used (ranging from "partial use" to "full integration into processes"). In addition, respondents indicated whether the I4.0T used by the companies is important. The questionnaire consisted of closed-ended questions regarding specific areas of I4.0T—structured as shown in Table 2—open-ended questions, and a metrics section. The latter was used to verify the length of service, position within the company, primary industry, type of clients served, logistics processes handled, and company size as measured by the number of employees.

The data collected through Google Forms was converted into an MS Excel spreadsheet, where they were aggregated and organised using standard functions. These data served as the basis for the charts presented in the results section.

While the sample selection constrains the generalisability of the research findings, it provides a valuable opportunity to validate the questionnaire. Therefore, these limitations should be taken into account when reviewing the results.

Results

As this CAWI survey is exploratory, it seeks to provide a deeper understanding of the subject matter. Consequently, the research findings are descriptive and do not reveal any correlations, relating solely to the study participants.

Large enterprises employing over 250 people accounted for the majority of respondents – around 70% of the surveyed companies; medium-sized enterprises (50–250) accounted for over 17%; and small enterprises accounted for 13%. Over 50% of respondents stated that the companies surveyed handle all logistics processes comprehensively, i.e., transport, warehousing, packing and packaging, order fulfilment, and stock management; therefore, it is difficult to identify specific types of transportation or warehousing companies. The respondents were predominantly managers (over 43%) and specialists (over 39%), with an average length of service of 8.5–15 years (around 32%) and 15.5–25 years (over 18%), respectively. The remaining respondents had shorter lengths of service. The dominant sectors served by the surveyed companies were transport, freight and logistics (TFL), electronics and computers, clothing and footwear, pharmaceuticals and food, which accounted for over 80% of all surveyed companies – Table 3.

Table 3. Sample characteristics

Position	Director	8.7%	Length of service in years	0.5 - 2	4.3%
	Manager	43.5%		2.5 - 5	30.4%
	Specialist	39.1%		5.5 - 8	17.4%
	Expert	4.3%		8.5 - 15	30.4%
	Trainee	4.3%		15.5 - 25	17.4%
Number of employees	Small	8.7%	Logistics processes handled – T–Transport/ S-Storage/ P–Packaging/ H-Handling/ SM-Stock Management	T/S/P/H/SM (only one of them)	17.4%
	Medium	21.7%		T/S	8.7%
				T/S/H	8.7%
	Big	69.6%		S/P/H/SM	13.0%
				T/S/P/H/SM(all of them)	52.2%
Sectors served					
TFL	34.8%	Pharma-ceuticals	8.7%	Electrical goods	4.3%
Electronics and computers	17.4%	Food	8.7%	Household appliances	4.3%
Clothing and footwear	13.0%	FMCG	4.3%	Tobacco	4.3%

Source: own study

The first area examined was digitalisation, which addressed three key elements: digitalisation as a general phenomenon, alongside two specific I4.0T items: DT and DA – Figure 1.

Analysis of Figure 1 reveals that while uptake of specific I4.0T — DT and DA — remains modest, general digitalisation, according to the respondents is firmly established within their LOP organisations, with more than 60% of respondents indicating its integration into their operational processes. The I4.0T items DT and DA are unfamiliar to a significant portion of the sample, representing 60.8% of responses (39.1% for DT and 21.7% for DA). A further 30.4% and 34.8%, respectively, are familiar with the concept but unaware of any internal implementation. Consequently, approximately 70% of respondents concerning DT and over 56% concerning DA lack practical engagement with these tools. Only 13.0% of respondents reported that these technologies had been adopted in processes within their companies, and none reported adoption in important processes. In contrast, according to the respondents, general digitalisation is implemented at their LOP.

Over 30% of responses indicated that it is used in key processes, and in total, over 60% of respondents stated that their LOP had implemented it across all its processes.

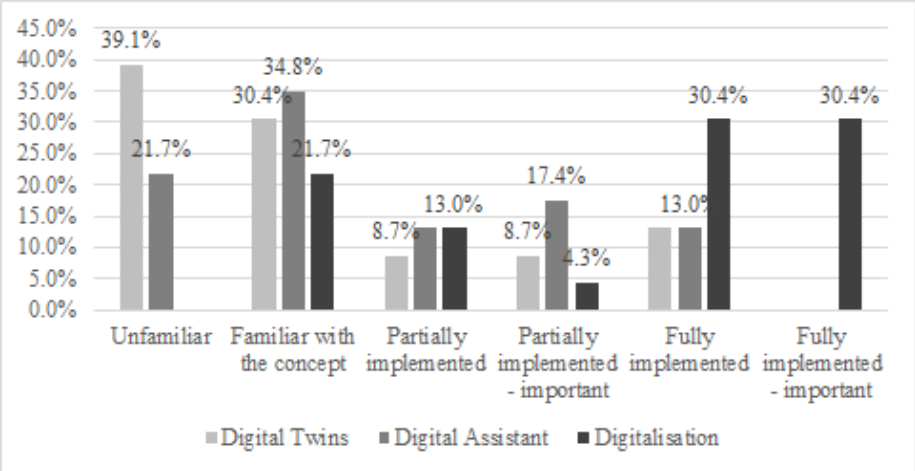


Figure 1. The use of digitalisation technologies
Source: own study

The second area of research concerned data processing technologies. The use of AI and machine learning, big data analytics, cloud computing, and blockchain technology was examined - Figure 2.

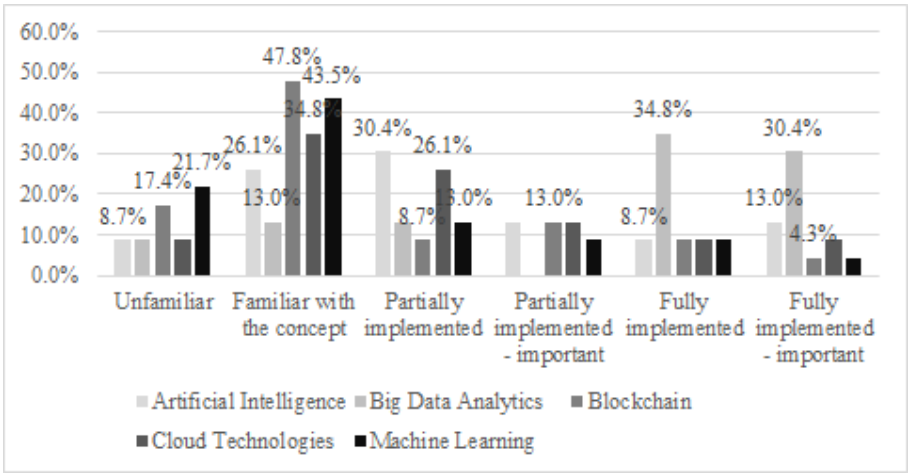


Figure 2. The use of data processing technologies
Source: own study

As the survey results show, respondents identified big data analysis as the technology most frequently used (either fully implemented or fully implemented and significant) in the processes surveyed at their LOP, accounting for over 65% of responses. A significant portion of respondents are familiar with blockchain, machine learning, and cloud computing technologies (ranging from 35% to over 47%), although cloud computing is partially used in over 25% of cases, and AI in over 30% of responses. The remaining data processing technologies do not have a clear dominance in any of the surveyed areas.

The respondents were also asked about communication technologies - Figure 3.

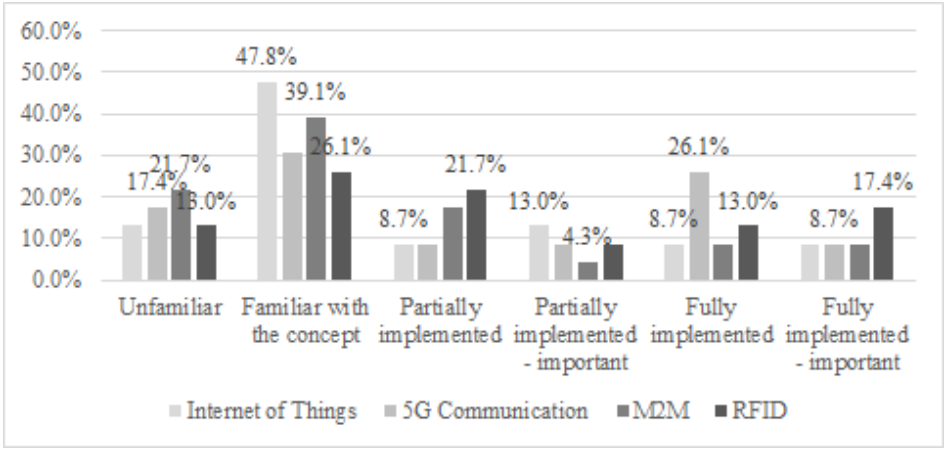


Figure 3. The use of communication technologies
Source: own study

According to the respondents, the most frequently used and most important technologies in their LOP logistics processes are RFID (or partially used) and 5G communication. Technologies such as IoT and M2M have the highest levels of conceptual awareness. They are conceptually known, but respondents say they are not implemented in the surveyed LOP.

The next I4.0T groups analysed supporting tool technologies included AR, VR, vision systems, mobile applications, sensor networks, and sensor technology - Figure 4.

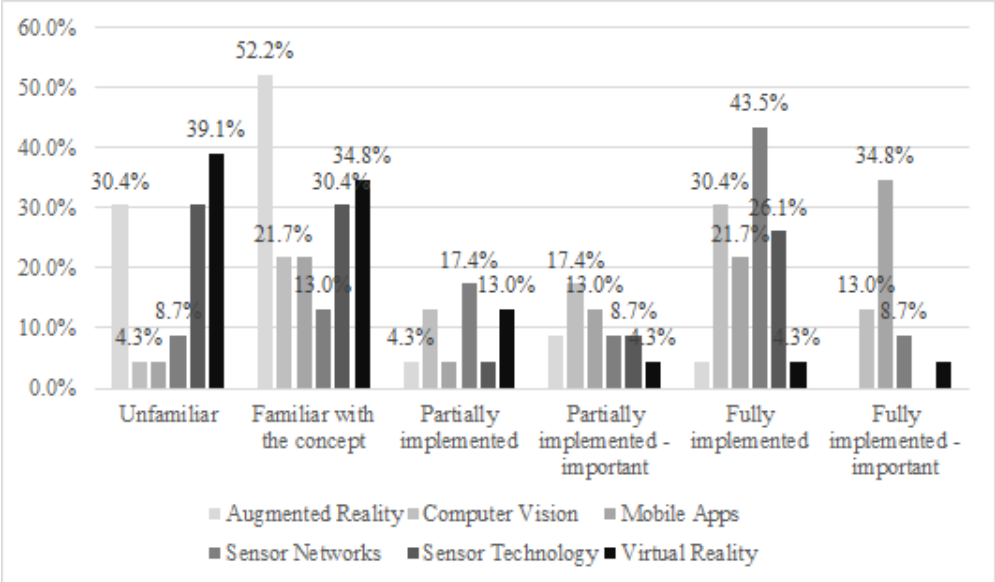


Figure 4. The use of supporting tool technologies
Source: own study

Figure 4 illustrates the varying scale of digital tool use. Sensor networks are fully implemented in over 43% of responses, while mobile applications are fully implemented and considered important in nearly 35% of responses. Some respondents are familiar with the concepts of AR and VR, but their practical use remains limited. The use of machine vision, also referred to as computer vision, is also worth noting, as it is used in approximately 30% of cases and partially used in more than 17% of cases.

Another area related to the use of I4.0T was process supported technologies, specifically robotics, CPS, and autonomous vehicles - Figure 5.

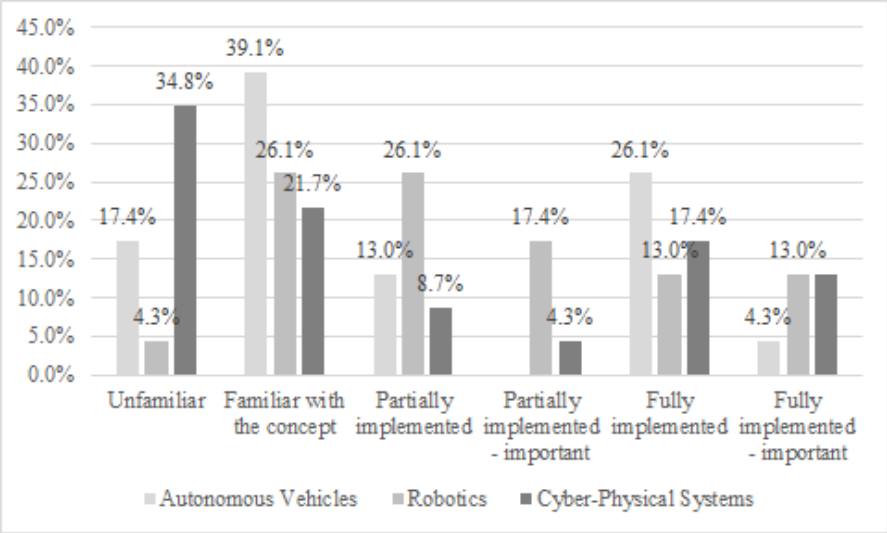


Figure 5. The use of process support technologies
Source: own study

Analysis of Figure 5 reveals that robotics is the most "transparent" technology in the set; nearly every respondent knows whether or not their company uses it. While autonomous vehicles have a higher rate of being "Adopted in processes" (26.1%), robotics is the clear leader in the "Important" categories. Robotics is the only technology with double-digit adoption in important processes (13.0%) and a strong presence in partial use for important processes (17.4%). CPS, if used, is fully implemented into processes (over 30%) or is completely unknown in about 35% of responses.

The next research area concerned processes related to cybersecurity, simulation, optimisation systems, and business analytics - Figure 6.

Respondents most frequently mentioned cybersecurity and business analytics. Optimisation systems also remain important. Simulations are the least frequently used tool.

Within the broadly defined concept of smart, three basic areas are referenced: machines, materials, and products - Figure 7.

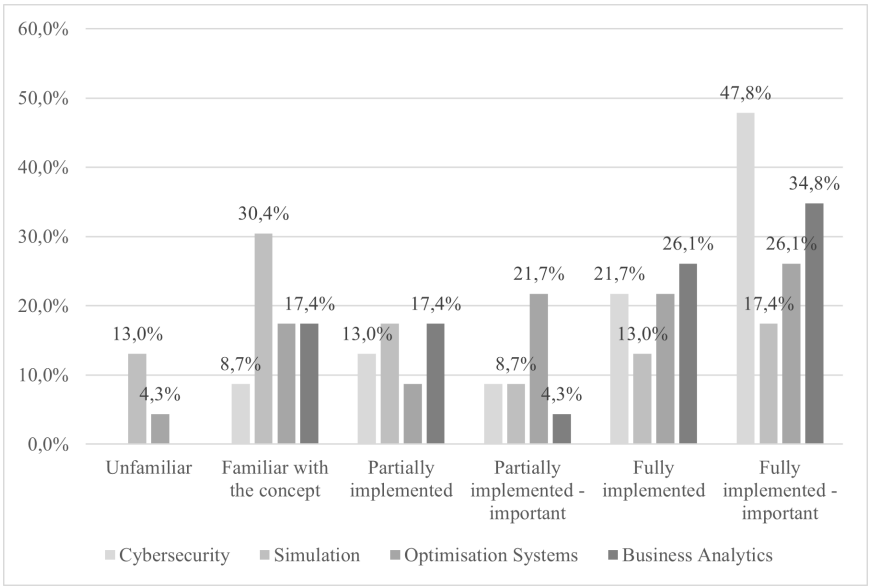


Figure 6. Industry 4.0 Processes and Systems
Source: own study

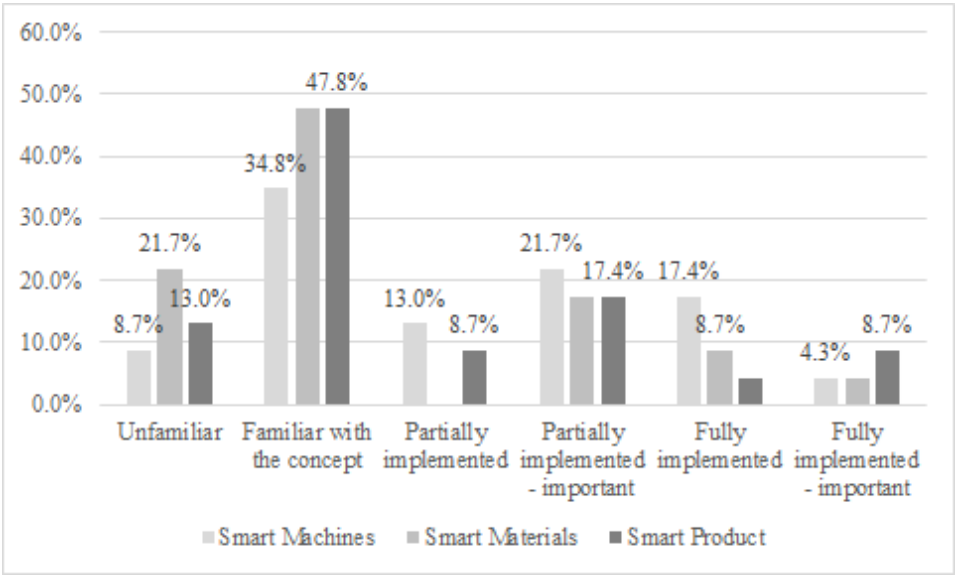


Figure 7. Intelligence of Things - Smart Machines, Product, and Materials implementation
Source: own study

Figure 7 shows that intelligent machines are partially used and considered important (over 20%) or are being integrated into processes (over 17%). Smart materials and products were identified as known technologies by over 47% of responses, while smart machines were identified by over 30%. These results suggest that while the concept of "smart" items is well recognised, practical application remains focused primarily on machinery rather than on materials or final products.

To facilitate analysis of the level of adoption of I4.0T — based on responses from LOP respondents in the pilot study — a summary table has been proposed that, in the authors' view, may help interpret the pilot study's results. The summary table presents four possible implementation variants, understood as utilisation rates for a given technology: "full use", "partial use", "no use" and "unable to determine". A description of how the utilisation rates were calculated on the basis of the responses received is set out in Table 4.

Table 4. A description of how the utilisation rates of I4.0T were calculated

Utilisation rate	Aggregated responses	Total percentage of responses
Full use	Fully implemented – important Fully implemented	More than 50%
Partial use	Partially implemented Partially implemented – important	More than 50%
	Fully implemented – important Fully implemented Partially implemented Partially implemented – important	More than 50%
No use	Familiar with the concept	More than 50%
	Fully implemented – important Fully implemented Partially implemented Partially implemented – important	Less than 25%
Unable to determine	Any case other than full use, partial use or no use	

Source: own study

The aggregated research results, together with their assigned usage classifications, are presented in Table 5.

Table 5. Scope of use of I4.0T, according to respondents, within their LOP organisations

I4.0T Groups	I4.0T	Utilisation rate
Digitalisation (changing the physical world into a digital one)	Digitalisation	Full use
	Digital Twins	Unable to determine
	Digital Assistants	Unable to determine
Data processing and protection (computing)	Artificial Intelligence	Partial use
	Big Data Analytics	Full use
	Blockchain	Unable to determine
	Cloud Computing	Partial use
	Machine Learning	Unable to determine
Communications (new ways for people and machines to communicate)	Internet of Things	Unable to determine
	5G Communication	Partial use
	M2M	Unable to determine
	RFID	Partial use
Process support	Autonomous Vehicle	Unable to determine
	Robotics	Partial use
	Cyber-Physical Systems	Unable to determine
Supporting Tools	Augmented Reality	No use
	Computer Vision	Partial use
	Mobile Apps	Full use
	Sensor Networks	Full use
	Sensor Technology	Unable to determine
	Virtual Reality	Unable to determine
Industry 4.0 Processes and Systems	Utilisation rate	
Cybersecurity	Full use	
Simulations	Partial use	
Optimisation	Partial use	
Business analytics	Full use	
Intelligence of Things	Smart Machines	Partial use
	Smart Materials	Unable to determine
	Smart Products	Unable to determine

Source: own study

These findings lead directly to a discussion of how, in the respondents' view, specific I4.0T technologies are used in the companies surveyed.

Discussion

The results of the pilot study presented here reveal certain trends in the direction of technological change, as perceived by respondents in the companies where they are employed. Neither does the sample selection itself allow generalisations to be drawn from these results. Similarly, failing to use tools in the analysis that enable the identification of correlations may lead the discussion section to contain conjectures or raise further research questions.

The results of the pilot studies show that, according to respondents, digital technologies are increasingly supporting and facilitating work. Big data technology has been fully implemented in the processes of over 50% of companies like business analytics, which, according to respondents, has also been fully implemented in over 50% of the companies surveyed. By analysing the theoretical framework of these technologies and the research findings, it is reasonable to hypothesise that the two technologies may be linked.

Data collection can take place via sensor networks and the widespread use of mobile devices, which may make data virtually unlimited, accessible anywhere and at any time. According to the respondents, both sensor networks and mobile applications have been fully implemented in over 50% of the companies surveyed. To protect the data they collect, the companies surveyed use cybersecurity technologies that logically complement their broader digitalisation.

The survey results also show that, despite respondents' familiarity with augmented reality technology, it is virtually unused: in their opinion, it has been partially implemented in 13% of the companies surveyed and fully implemented in just 4%. This finding is particularly interesting given that the use of augmented reality in warehouse operations could replace existing 'Pick by Voice' or 'Pick by Light' methods, enhancing the real-world view with additional digital elements (Stoltz et al. 2017).

It should be noted that for more than 47% of I4.0T initiatives, the extent of their implementation is difficult to determine. This may be due to several reasons. For example, the creation of DT or the use of DA is relatively rare, but there may be various reasons for this. The creation of DT (digital representations of real, physical objects) may, first and foremost, require specialised computer vision equipment (Tao et al. 2019). Furthermore, in logistics companies, DT may not be utilised to its full potential, unlike in manufacturing companies, where digital representations of products or machine layouts within the production environment can be used much more effectively.

Digital assistant applications, which are frequently used on mobile operating systems — such as Google Assistant and Apple's Siri — or via smart speakers, e.g., Alexa on Amazon Echo devices, may serve a similar purpose, making it easier to carry out everyday tasks (Brill et al. 2019). It may be assumed that the inability to assess the extent of DA adoption stems from their widespread use and the fact that the names mentioned above are not recognised by respondents as associated with DA technology, as is the case with blockchain technology, which forms the foundation of cybersecurity (Kshetri 2017). A similar discrepancy is evident with regard to sensors: although, according to the respondents, sensor networks are widely used in the companies surveyed, sensor technology is used only to a limited extent or not at all.

Other noteworthy findings relate to big data analytics and cloud computing. Respondents stated that their companies make full use of big data analytics, although cloud computing, which is often used for this purpose, is used only partly. It is unlikely that big data would be stored exclusively on physical rather than virtual drives, which is the domain of cloud computing (Yang et al. 2017).

When analysing processes that utilise I4.0T, big data analytics, and data security (i.e., cybersecurity), respondents report that these are being utilised to their full potential. The respondents also highlighted simulations and optimisation issues, namely processes that identify extremes in time, cost, and efficiency. Among the I4.0 processes and systems, simulations are used to a limited extent, which may confirm the limited use of DT technology that supports these processes (Boschert and Rosen 2016).

The discussion presented here serves as a good starting point, before the main research, for a thorough, systematic literature review that could confirm or highlight differences between the research findings and existing studies in this type of enterprise.

Conclusions

Although some scholars dispute the notion that a fourth industrial revolution has occurred (Moll 2021), technological and digital advancements have reached a stage at which changes to existing organisational practices and business models are now possible, including amongst logistics operators. The aim of the pilot study was to validate the developed questionnaire, with a view to identifying preliminary patterns observed among respondents in the surveyed companies, as well as any shortcomings in the questionnaire itself. The results of the study are purely descriptive and do not indicate any causal relationships.

The results of the pilot study highlight several key aspects of technological development trends that, according to the respondents, are evident among the

organisations surveyed in the LOP sector. Firstly, I4.0T are not widely used among these companies. This applies both to the extent to which these technologies have been implemented and to their general usage. Secondly, some of these technologies are completely unknown to respondents or may be known by different names, which may complicate analysis in future studies. Thirdly, the technologies most frequently used are those that originated at the beginning of the 21st century or earlier—namely, digitalisation in the broad sense, sensor networks, mobile applications, and big data. There is no clear trend towards the use of the latest technologies. Fourthly, based on the respondents' answers, these tools may not be applicable in the LOP organisations surveyed, and a lack of familiarity with the subject may hinder their implementation.

The study identifies the initial managerial implications for the surveyed companies. The most pressing issue is the educational aspect relating to the existence and potential applications of I4.0T. Lack of knowledge of I4.0T by respondents suggests a need for target research into these within companies, which may subsequently facilitate adoption. Another important factor supporting management processes is the systematisation and categorisation of I4.0T, which enabled the LOP surveyed to identify potential areas of application. Finally, these findings help to identify technological gaps (areas where these technologies are not currently being applied), thereby defining technological development directions for the LOP.

The research findings may also be of use to governments and customers. In the first instance, by pointing the way towards changes in secondary and higher education curricula that promote the use of I4.0T across various areas of activity. This, in turn, may be valuable for consumers who, by identifying opportunities presented by existing technologies, can communicate their needs to businesses and expect them to be met, whether in products or services.

The study has several limitations, most notably the sample size and selection; however, these are not considered critical factors in a pilot study. The potential for varied interpretations of I4.0T terms among respondents suggests that subsequent research should provide concise definitions or examples for each term. Further research should adopt a longitudinal approach to analysing the adoption of I4.0T by LOP. Furthermore, distinguishing between operational and managerial staff would enable an examination of how professional roles influence perceptions of I4.0T use. The small sample size also makes it impossible to demonstrate fundamental relationships, such as the impact of company size, business profile or number of employees on the level of I4.0T implementation, which is certainly a weakness of the presented results. An important limitation of the study is that more than 50% of the surveyed companies handled all logistics processes (transportation, warehousing, packaging, order fulfilment, and inventory management), which made it impossible to compare companies specialising in only individual processes. Finally, exploring

the relationship between I4.0T and sustainable development, particularly within circular economy frameworks, represents another important direction for the field.

Future, extended research based on the pilot study questionnaire should focus on several important aspects. First, it should consider the relationship between the responses provided and the respondents' data (age range, length of service, position held, etc.). It would also be valuable to capture the differences in the use of I4.0T and I4.0T groups across operational areas of logistics operators in Poland, e.g., transport, warehousing, information, security, and resilience. It is also worth considering framing the research and its analysis within the TOE (Technology, Organisation, Environment) business model, which supports companies in implementing and adapting new technologies. Future research should examine the relationship between business profiles of logistics operators in Poland (dominant processes) and the I4.0T they use, to reveal trends in technological change within the companies under study. It should also consider the sequence of I4.0T implementation from a logistics perspective, including transport, warehousing, safety, resilience, and efficiency. It might also be interesting to identify technological gaps in terms of their criticality for maintaining business continuity at LOP.

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Conceptualisation: M.B. and A.B.-P.; Data curation: M.B. and A.B.-P.; Formal analysis: M.B. and A.B.-P.; Investigation: M.B. and A.B.-P.; Methodology: M.B. and A.B.-P.; Resources: M.B. and A.B.-P.; Validation: M.B. and A.B.-P.; Visualisation: M.B.; Writing – original draft: M.B.; Writing – review and editing: M.B.

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The authors used Grammarly/v1.2.282.1933 only as auxiliary support for basic language, grammar, punctuation, style, and technical or formatting corrections, which do not require separate disclosure in the manuscript under SLW policy. All AI-assisted outputs were verified by the authors.

Ethics Approval / Consent
The survey was voluntary and anonymous. Respondents were informed about the purpose of the study and provided consent by completing the questionnaire. No sensitive personal data were collected. Formal ethics approval was not required.

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