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Digital revolution in European enterprises: assessing the use of IoT in logistics and production processes

Rewolucja cyfrowa w przedsiębiorstwach europejskich: ocena wykorzystania IoT w procesach logistycznych i produkcjij

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Abstract. Nowadays, enterprises understand that the implementation and management of information technologies is a step towards improving not only the selected process (in the studied case in the area of production processes, logistics processes and auxiliary processes), but also the entire organization. Existing literature emphasizes the role of IoT in improving logistics efficiency, predictive maintenance and production automation. However, differences in IoT adoption in different countries and company sizes remain insufficiently researched. The research focused on countries that have not kept up with digital transformation trends in order to understand what are the main obstacles in their case. Addressing this research gap is essential for decision makers and business leaders who want to support digitalization strategies in the manufacturing sector. The following research problem was posed in the paper: What is the importance and impact of the use of IoT technology in selected processes on the development of enterprises in the economies of EU countries? The aim of the study was to determine the similarities in the development of EU member states in terms of the level of IoT technology use in logistics and production processes in small, medium and large enterprises of the manufacturing sector. The scope of the study includes the analysis of data on the use of IoT in production, logistics and auxiliary processes in small, medium and large enterprises in the EU. The results contribute to a better understanding of digital transformation trends and provide recommendations for increasing IoT implementation in industrial environments.
Keywords: Internet of Things (IoT), logistics processes, production processes, IT solutions/technologies, RFID

Abstrakt. Coraz więcej przedsiębiorstw rozumie, że implementacja i zarządzanie technologiami informatycznymi, to krok w kierunku doskonalenia nie tylko wybranego procesu (w badanym przypadku w obszarze procesów produkcji, procesów logistyki oraz procesów pomocniczych), ale również całej organizacji. Istniejąca literatura podkreśla rolę IoT w poprawie wydajności logistycznej, konserwacji predykcyjnej i automatyzacji produkcji. Jednak różnice w przyjęciu IoT w różnych krajach i wielkościach firm pozostają niedostatecznie zbadane. W badaniach skupiono się na krajach, które nie nadążają za trendami transformacji cyfrowej celem zrozumienia, co jest głównymi przeszkodami w ich przypadku. Badania mogą również dostarczyć rekomendacji i strategii dla tych krajów, aby mogły lepiej wykorzystać potencjał technologii IoT. Rozwiązanie tej luki badawczej jest niezbędne dla decydentów i liderów biznesowych, którzy chcą wspierać strategie cyfryzacji w sektorze produkcyjnym. W pracy postawiono następujący problem badawczy: Jakie jest znaczenie i wpływ wykorzystania technologii IoT w wyróżnionych procesach na rozwój przedsiębiorstw w gospodarkach krajów UE? Celem badania było określenie podobieństw rozwoju krajów członkowskich UE pod względem poziomu wykorzystania technologii IoT w procesach logistycznych i produkcyjnych w małych, średnich i dużych przedsiębiorstwach sektora produkcyjnego. Zakres badania obejmuje analizę danych dotyczących wykorzystania IoT w produkcji, logistyce i procesach pomocniczych w małych, średnich i dużych przedsiębiorstwach w UE. W części badawczej posłużono się metodami taksonomii numerycznej, a w szczególności metodami porządkowania liniowego obiektów. Wyniki przyczyniają się do lepszego zrozumienia trendów transformacji cyfrowej i dostarczają rekomendacji dotyczących zwiększenia wdrożenia IoT w środowiskach przemysłowych. Na podstawie przeprowadzonych badań wskazano kraje, które mogą być jeszcze we wczesnej fazie adaptacji technologii IoT lub wykazują mniejsze zaangażowanie w ten obszar oraz te, w których technologia IoT jest już znacznie rozwinięta i mogą być wzorem dla pozostałych.
Słowa kluczowe: Internet rzeczy (IoT), procesy logistyczne, procesy produkcyjne, rozwiązania/technologie informatyczne, RFID

Introduction

An essential element of the education of a modern organizational manager is the knowledge and practical ability to leverage the potential of modern technologies, which ensure the required efficiency of business operations. The continuous development of IT systems and the digitalization of management procedures in companies, newly emerging automation solutions, artificial intelligence, and high competition have led to a growing interest in utilizing IT support for improving business processes. The demand for this knowledge has also increased in recent years due to social, economic, and environmental changes - leading to an expanded use of modern technologies and rationalization of managerial decisions.

Among these technological advancements, such as AI, big data, autonomous vehicles, information systems, cloud solutions, machine learning, industrial robots, simulation programs, and digital twins, there is now the capability to introduce real-time tracking of shipments and inform customers about the current status of their orders, as well as to make improvements in customer service quality. The implementation of new technologies also presents an opportunity to accelerate certain production processes and deliver products faster to specific locations.

In the scientific literature, numerous examples of studies can be found in which authors present the characteristics of the latest technologies for better management of various processes within companies (Waśniewski et al., 2015, pp. 792-808; Ficoń, Krasnodębski, 2018, pp. 78-98). However, due to the subject of this paper, the focus is placed on those that relate to improving service delivery in industrial logistics. In this context, the selection and integration of modern technologies in industrial logistics can be seen as a primary opportunity to enhance the productivity and international competitiveness of macro- and microeconomic entities in the European Union, as well as on a global scale (Woschank et al., 2022, pp. 727-737). Both research and practice provide ample evidence that effectively combining a company's technological resources enables full utilization of their potential.

One such revolutionary technological combination in enterprises is the Internet of Things (IoT) and RFID, as the configuration of these two technologies can support human labor in areas of production and logistics processes such as identification, monitoring, tracking, transport, warehousing, order fulfillment, packaging, labeling, sorting, weighing, scanning, and more. These technologies allow for faster and more accurate identification, tracking, and monitoring of logistics objects, such as goods, pallets, containers, and vehicles. Their collaboration reduces the risk of delays, theft, errors, damage, and even losses throughout the supply chain. Furthermore, they contribute to improved communication and collaboration among the various entities involved in logistics processes, such as suppliers, manufacturers, distributors, customers, customs authorities, and transportation agencies, etc.Additionally, there is an improved ability to meet customer needs and expectations by offering greater flexibility, mobility, and personalization of services.

From a scientific perspective, the study of IoT adoption in enterprises is significant due to its implications for economic development, industrial competitiveness, and technological advancement. Understanding how IoT technologies are deployed across various EU member states can offer valuable insights into the digital maturity of different economies and their capacity for innovation-driven growth. Existing literature highlights the role of IoT in improving logistical efficiency, predictive maintenance, and production automation. However, disparities in IoT adoption across countries and company sizes remain underexplored. Addressing this research gap is essential for policymakers and business leaders aiming to foster digitalization strategies in the manufacturing sector.

The objective of the study was to determine the similarities in the development of EU member states concerning the level of IoT technology utilization in small, medium, and large enterprises in the manufacturing sector. To achieve this objective, numerical taxonomy methods are employed, particularly linear ordering methods, to systematically assess and compare the degree of IoT implementation among different economies.

The research addresses the following key questions:

- How does IoT adoption in logistics and production processes vary across EU member states?
- Which specific areas of manufacturing enterprises exhibit the highest levels of IoT integration?

– Is it possible to establish a metric for assessing the digital development of EU countries based on IoT adoption?

To further structure the analysis, the study formulates the following hypotheses:

H1: It is possible to identify differences in the level of IoT adoption in the studied processes across EU member states.

H2: The highest levels of IoT adoption in manufacturing enterprises of the analyzed EU countries are observed in their core processes.

H3: A development measure can be estimated for EU countries regarding their level of IoT adoption in the studied processes.

The study's scope includes an analysis of data on IoT utilization in production, logistics, and auxiliary processes across small, medium, and large enterprises within the EU. The findings contribute to a better understanding of digital transformation trends and provide recommendations for increasing IoT adoption in industrial settings.

Adoption of IoT Technology in Enterprises – A Literature Review

The competitiveness of a company is a fundamental feature of the modern market economy. Companies should strive to make business decisions that ensure long-term competitive advantage. In today's environment, those who respond faster to changes in their surroundings gain the advantage. In this context, the possibility of using smart devices and fast Internet networks (IoT) is gaining broader acceptance and popularity in both logistical and production processes (Pawlisiak M., Maslii O.,2024, pp. 165-180). Due to the complexity and diversity of production operations, the demand for real-time information and data quality is gradually increasing. The Internet of Things is a new generation of internet-connected embedded information and communication technologies (ICT) that work together to integrate the supply chain with logistical and production activities in a digital environment (De Vass et al., 2021, pp. 605-624). IoT is a set of technologies that enables the identification of essential objects and the execution of daily tasks using smartphones, computers, GPS, and networks (Lopes, Moori, 2021, pp. 1-27; Mostafa et al., 2019, pp. 84). Technologies used in IoT can be applied to improve the efficiency, productivity, safety, convenience, and response time of processes while addressing labor shortages in various logistical and warehousing operations, reducing costs, and having a positive impact on the environment. For example, the order picking procedure accounts for 50-55% of total warehouse operating costs (Jeble et al., 2017, pp. 36-44; Nagda et al., 2019, pp. 744-749) and largely determines its operational efficiency. The Internet of Things, along with the use of RFID (radio frequency identification) technology, where each participating object has a digital shadow with associated information stored in cyberspace (Liu et al., 2020, pp. 1429-1451), and QR codes for precise tracking of goods at every stage of the supply chain, enables better inventory management and faster product localization. It can make the order picking process more efficient, improving real-time visibility and traceability of goods in warehouses (Affia, Aamer, 2021, pp. 90-109; Waśniewski, Laskowski, 2016, pp. 350-368). The use of RFID technology combined with SAP Business Application Programming Interface improves both inbound and outbound processes to better manage, optimize, and automate activities in the ERP system (Majeed, Rupasinghe, 2017, pp. 25-40; Yetkin, 2021, pp. 1107-1126; Winkelhaus, Grosse, 2020, pp. 18-46). Numerous studies have been conducted on IoT technologies to understand and harness their potential in decision-making processes in various areas of organizations (Tu et.al., 2018, pp. 96-125; Tsang et al., 2018, pp. 1432-1462; Tang et al., 2018, pp. 102659; Tsang et al., 2021, pp. 1534-1556; Hopkins, Hawking, 2018, pp. 575-591). For instance, Russo et al. and Zhang et al. focused on smart IoT infrastructure in organizational management processes, primarily to solve problems using real-time data collected by IoT devices (Russo et al., 2015, pp. 1-13; Zhang et al., 2017, pp. 1890-1905). Tsang et al. proposed an IoT-based risk monitoring system in quality management for integrated supply chain and occupational safety (Tsang et al., 2018, pp. 1432-1462). Given that in every enterprise all actions should result from a specific goal, and only then should they be planned and coordinated, Hopkins and Hawking presented research on the impact and role of Big Data Analytics and IoT in supporting the goals of a large logistics company, which include improving workplace safety, minimizing operational costs, and reducing environmental impact (Hopkins, Hawking, 2018, pp. 575-591). Moreover, IoT technologies in warehouse management systems enable the implementation of smart logistics for Industry 4.0, combining advanced data analysis with computational intelligence approaches (Lee et al., 2018, pp. 20-23). Winkelhaus and Grosse developed a Logistics 4.0 framework that can be used to identify future strategies and technologies to accomplish specific logistics tasks and develop new technological solutions for current and future process requirements (Winkelhaus, Grosse, 2020, pp. 18-46). Despite the growing body of work on IoT, research on IoT technologies in the area of warehousing and production logistics is still lacking. The lack of research on the link between IoT and warehousing partly stems from the fact that IoT technology is multifaceted, time-consuming, and costly (Nagda et al., 2019, pp. 744-749). Moreover, there is still a lack of awareness of how organizations can leverage this potential and implement these technologies, which poses a significant challenge to their adoption (Chung, 2021, pp. 102455; Frank et al., 2019, pp. 15-26; Havard et al., 2021, pp. 2338-2349; Mann et al., 2018, pp. 108455).

Research methodology

The data used for the analysis was sourced from the publicly available Eurostat database. It pertains to the use of IoT-related technologies by enterprises in European Union countries, particularly devices or systems connected to the Internet that can be monitored or remotely controlled. The focus was on the following areas (referred to as variables X1, X2, and X3 in the subsequent analysis):

- the share of enterprises using IoT in production processes (including solutions such as sensors or RFID tags for monitoring or automating production processes);
- the share of enterprises using IoT for managing logistical processes (e.g., solutions including sensors for tracking products or vehicles within the warehouse);
- the share of enterprises using IoT for auxiliary production processes - maintenance based on technical condition (including sensors for monitoring the maintenance needs of machines or vehicles).

The data obtained concerned enterprises operating in sectors such as manufacturing, electricity, gas, steam, and air conditioning, water supply, sewage, and waste management. Therefore, the analysis will relate to these sectors of the economy. The presented data was expressed as a percentage (as a share of enterprises), and the analysis was conducted by company size:

- small (employing 10 to 49 employees);
- medium (employing 50 to 249 employees);
- large (employing 250 or more employees).

Micro-enterprises (employing up to 9 employees) were not included in the analysis, as the use of IoT in the studied areas among this group is negligible relative to their number, which could distort the results. The data selected for the analysis concerns the 27 EU member states (Austria - AT, Belgium - BE, Bulgaria - BG, Czechia - CZ, Denmark - DK, Germany - DE, Estonia - EE, Ireland - IE, Greece - EL, Spain - ES, France - FR, Croatia - HR, Italy - IT, Cyprus - CY, Latvia - LV, Lithuania - LT, Luxembourg - LU, Hungary - HU, Malta - MT, Netherlands - NL, Poland - PL, Portugal - PT, Romania - RO, Slovenia - SI, Slovakia - SK, Finland - FI, Sweden - SE) and refers to the year 2021.

The research method applied was multivariate analysis, specifically the method of statistical comparative analysis. Its advantage lies in the ability to assess the differences between the studied units—in this case, the economies of the EU countries—regarding a complex phenomenon, which is the use of IoT in production, logistics, and auxiliary processes in the broad manufacturing sector. This analysis also allows for the ranking of these units, thereby providing a better understanding of the economic phenomena affecting the operation of enterprises. Linear ordering methods, which form the basis of multivariate comparative analysis, are widely used, especially in assessing the diversity of objects in terms of their level of economic development (M. Górska and M. Daroń 2023, Li 2022).

The vector of variables was examined::

$$X = \left[X_1 \ldots X_m \right] \tag{1}$$

where m – number of variables. When using multidimensional comparative analysis methods, due to the condition of separating variables expressed in the same units of measurement with similar orders of magnitude, it is recommended to normalize variables, which aims to unify both the units of measurement of variables and the orders of magnitude of variables. Therefore, standardization was performed, which is a frequently used method of normalization. Standardization was carried out using the following formula:

$$z_{ij} = \frac{x_{ij} - \overline{x}_j}{S_j}, \left(i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, m \right) \tag{2}$$

where the individual symbols represent:
n – number of objects,
zij – standardized value of variable Xj for the i-th object,
$\overline{x}_j$ – arithmetic mean of variable Xj,
Sj – standard deviation of variable Xj. [Dziechciarz 2003]

In the next step, the similarity of objects was determined. It is noted that the closer the values of the variables describing a given complex phenomenon, the more similar the objects are to each other. Using Euclidean distances [Mesjasz-Lech 2018] between individual objects and the reference object, the similarity of objects was determined:

$$d_{i0} = \sqrt{\sum_{j=1}^{m} \left(z_{ij} - z_{0j} \right)^2} \qquad \text{(i=1, …, n)} \tag{3}$$

whereas:

$$z_{0j} = \begin{cases} \max\limits_i z_{ij} \textit{ for stimulants} \\ \min\limits_i z_{ij} \textit{ for destimulants} \end{cases} \tag{4}$$

The distance between the development pattern and the anti-pattern (d0) was determined using the following formula (Mesjasz-Lech 2018):

$$d_0 = \sqrt{\sum_{j=1}^{m} \left(z_{ij} - z_{\_0j}\right)^2} \qquad (i = 1, \dots, n) \tag{5}$$

Assuming that the level of influence of all variables on the analyzed phenomenon is the same, the development measure for each object was estimated using the following formula:

$$m_i = 1 - \frac{d_{i0}}{d_0} \quad (\mathrm{i}=1, \dots, \mathrm{n}), \tag{6}$$

whereas:

$$z_{\_0j} = \begin{cases} \min\limits_i z_{ij}\, \textit{for stimulants} \\ \max\limits_i z_{ij}\, \textit{for destimulants} \end{cases} \tag{7}$$

For the development measure defined in this way, with values ranging between [0,1], an interpretation can be made. It is assumed that the higher the value of the development measure, the higher the level of the analyzed phenomenon.

Digital Transformation in Logistical, Production, and Auxiliary Processes of Enterprises in EU Countries –IoT Technology Implementation

Table 1 presents a summary of the percentage share of enterprises using IoT in various processes.

Table 1. Percentage share of enterprises using IoT in the analyzed processes in 2021, broken down by company size

Country	Enterprises using IoT in production processes			Enterprises using IoT in logistical processes			Enterprises using IoT in auxiliary production processes		
	small	medium	large	small	medium	large	small	medium	large
Austria	4.0	10.0	20.9	4.4	9.3	18.0	8.1	14.8	20.5
Belgium	6.8	11.8	23.8	9.2	14.7	23.6	7.0	15.3	27.5
Bulgaria	1.8	5.1	10.4	3.5	7.0	9.6	2.2	5.8	10.5
Croatia	2.1	5.5	11.1	1.3	3.5	7.2	4.3	12.5	19.3
Cyprus	1.8	3.4	8.5	3.3	11.3	15.3	3.0	9.6	18.5
Czechia	4.2	12.6	26.7	3.3	6.0	14.1	**9.7**	16.8	30.0
Denmark	1.7	4.8	13.3	4.9	8.3	17.3	5.9	10.7	20.4
Estonia	2.3	8.0	14.4	4.8	4.2	9.6	3.6	8.4	15.8

cd. tab. 1

Finland	6.1	10.9	27.8	10.6	13.1	28.1	8.6	13.3	**31.8**
France	1.7	7.0	13.7	2.9	8.0	11.7	3.6	8.8	17.3
Germany	4.4	8.3	15.9	4.9	8.9	13.2	7.2	13.2	23.2
Greece	3.3	6.3	9.3	6.9	9.7	13.2	4.8	12.6	11.2
Hungary	2.6	7.7	16.2	7.2	13.5	19.7	3.3	6.0	13.2
Ireland	3.5	7.5	14.2	5.9	9.4	15.9	3.6	9.4	12.6
Italy	7.1	15.3	26.8	6.3	11.0	20.4	8.4	16.8	29.4
Latvia	4.4	12.4	26.2	6.6	14.3	29.2	5.3	11.2	23.3
Lithuania	3.8	12.1	18.6	7.2	12.5	23.8	5.4	14.1	27.4
Luxembourg	2.1	6.8	18.5	4.5	11.1	18.1	4.1	8.7	18.4
Malta	3.8	13.1	12.5	7.9	17.8	22.5	7.8	**17.7**	27.5
Netherlands	2.5	6.7	15.3	2.5	6.1	14.6	4.6	9.7	19.5
Poland	1.5	6.6	19.5	9.5	18.9	27.8	4.1	11.5	25.7
Portugal	3.4	8.7	14.8	3.8	9.0	11.8	3.0	8.0	16.2
Romania	1.4	3.3	7.9	4.0	4.7	9.2	2.2	3.3	9.3
Slovakia	3.4	13.5	18.2	6.6	14.2	20.4	5.5	10.0	17.3
Slovenia	**9.4**	**21.1**	**33.8**	**16.3**	**26.4**	**32.2**	3.0	9.4	10.8
Spain	3.9	8.2	17.8	4.8	7.8	16.5	4.6	11.7	20.6
Sweden	5.0	12.4	23.2	13.5	17.3	26.8	2.3	5.6	14.4

Source: Own study based on Eurostat data

It follows that Slovenia outperforms other EU countries in terms of the percentage of enterprises using IoT technology in both production and logistical processes (this share is the highest among small, medium, and large enterprises). The situation is slightly different in the case of auxiliary production processes. Specifically, in the group of large enterprises, Finland leads (31.8%), in the group of medium-sized enterprises, Malta takes the lead (17.7%), and among small enterprises, companies from the Czech Republic have the highest share of IoT usage (9.7%).

It should be noted that in this study, all variables are stimulants. These variables contribute to the development potential of enterprises in a given country. The results of the linear ordering are presented collectively for all groups of variables - the use of IoT technology in the selected processes - but are broken down by company size (Tables 2-4). Based on the results of the analysis, a ranking of EU countries was created, which allows for a comparison of the extent to which enterprises in each country utilized IoT - based technology in the analyzed processes.

Table 2. Utilization of IoT technology in processes occurring in small enterprises

Country	Distance from the pattern	**Development measure**	**Ranking position in the group of small enterprises**
Austria	4.6362	0.909	10
Belgium	2.8429	0.944	2
Bulgaria	6.5915	0.870	26
Croatia	6.4574	0.873	25
Cyprus	6.4319	0.873	24
Czechia	4.7775	0.906	12
Denmark	5.6050	0.890	18
Estonia	5.8548	0.885	20
Finland	**2.4961**	**0.951**	**1**
France	6.4054	0.874	23
Germany	4.4849	0.912	8
Greece	4.8668	0.904	13
Hungary	5.4290	0.893	17
Ireland	5.2709	0.896	15
Italy	3.3058	0.935	4
Latvia	4.4490	0.912	7
Lithuania	4.5087	0.911	9
Luxembourg	5.8649	0.884	21
Malta	3.9848	0.921	5
Netherlands	6.0235	0.881	22
Poland	5.3349	0.895	16
Portugal	5.8484	0.885	19
Romania	6.6354	0.869	27
Slovakia	4.7375	0.907	11
Slovenia	3.1726	0.937	3
Spain	5.1188	0.899	14
Sweden	4.2819	0.916	6

Source: Own study based on Eurostat data

Analyzing the 2021 data, Finland offers the best conditions for development potential in terms of process management using IoT technology in small enterprises. This is quite surprising given the fact that Finland surpasses Slovenia in the percentage of enterprises using IoT only in the area of auxiliary production processes.

In total, 13 countries also have favorable conditions for development in the context of IoT utilization, as indicated by a high development measure index—resulting in a score exceeding 0.9 (Table 2).

Table 3. Utilization of IoT technology in processes occurring in medium enterprises

Country	**Distance from the pattern**	**Development measure**	**Ranking position in the group of medium enterprises**
Austria	4.6362	0.909	11
Belgium	2.8429	0.944	3
Bulgaria	6.5915	0.870	26
Croatia	6.4574	0.873	25
Cyprus	6.4319	0.873	22
Czechia	4.7775	0.906	12
Denmark	5.6050	0.890	21
Estonia	5.8548	0.885	24
Finland	2.4961	0.951	8
France	6.4054	0.874	20
Germany	4.4849	0.912	13
Greece	4.8668	0.904	14
Hungary	5.4290	0.893	18
Ireland	5.2709	0.896	16
Italy	3.3058	0.935	4
Latvia	4.4490	0.912	6
Lithuania	4.5087	0.911	5
Luxembourg	5.8649	0.884	17
Malta	3.9848	0.921	2
Netherlands	6.0235	0.881	23
Poland	5.3349	0.895	9
Portugal	5.8484	0.885	19
Romania	6.6354	0.869	27
Slovakia	4.7375	0.907	7
Slovenia	**3.1726**	**0.937**	**1**
Spain	5.1188	0.899	15
Sweden	4.2819	0.916	10

Source: Own study based on Eurostat data

Based on the results presented in Table 3, it can be observed that countries such as Slovenia, Malta, and Belgium have achieved high ranking positions, suggesting that they have advanced IoT technology implementations in the group of medium-sized enterprises. On the other hand, countries like Bulgaria, Croatia, and Romania hold lower positions, indicating lower utilization of IoT technology in these nations. Additionally, it is worth noting Finland, which, despite a lower ranking position, has a relatively small distance from the pattern and a high development measure, suggesting that Finnish medium-sized enterprises are well-developed and advanced in their use of IoT technology.

Table 4. Utilization of IoT technology in processes occurring in large enterprises

Country	**Distance from the pattern**	**Development measure**	**Ranking position in the group of large enterprises**
Austria	3.411	0.920	10
Belgium	2.121	0.950	4
Bulgaria	5.973	0.859	26
Croatia	5.491	0.871	24
Cyprus	5.101	0.880	22
Czechia	2.939	0.931	7
Denmark	4.266	0.900	16
Estonia	5.170	0.878	23
Finland	**1.111**	**0.974**	**1**
France	4.923	0.884	21
Germany	4.190	0.901	15
Greece	5.731	0.865	25
Hungary	4.404	0.896	18
Ireland	4.918	0.884	20
Italy	2.106	0.950	3
Latvia	1.832	0.957	2
Lithuania	2.751	0.935	6
Luxemburg	3.802	0.910	13
Malta	3.658	0.914	11
Netherlands	4.339	0.898	17
Poland	2.494	0.941	5
Portugal	4.892	0.885	19
Romania	6.349	0.850	27

cd. tab. 4

Slovakia	3.754	0.912	12
Slovenia	3.293	0.922	9
Spain	3.837	0.910	14
Sweeden	3.283	0.923	8

Source: Own study based on Eurostat data

An analysis of the results in Table 4 reveals a significant variation in the degree of IoT technology utilization among different countries in the group of large enterprises. Countries such as Finland, Latvia, and Italy stand out due to their advanced technological implementations. These countries show strong commitment to the development and implementation of IoT technologies, which may be driven by economic benefits, innovation, or digital technology-based development strategies. It is also noteworthy that Poland ranks highly in this group of enterprises, holding the 5th position.

Conclusions

Modern technologies in manufacturing enterprises are a topic gaining significance in the era of globalization and increasing competition in markets. It is attracting interest from both the scientific and business communities, which see it as holding great potential, especially in processes that involve complex operations. Every company that seeks to grow and attract increasingly demanding customers should follow trends and modern technologies, not only to carry out high-level processes but also to achieve a competitive advantage and adapt to changing market conditions. Currently, traditional management, supported by individual technological resources/systems, proves insufficient, and it becomes necessary to intensify the development and use of various forms of resources (Górska, Daroń, 2023, pp. 2213-2222; Purnamawati et al., 2022, pp. 149). Only skillful, synergistic integration of these resources can allow companies to build more sustainable competitive advantages (Yusoff et al., 2019, pp. 626-637) that align with the key market requirements for production and service delivery critical for the survival of enterprises (Barney et al., 2010, pp. 1464-1479). In this regard, technologies such as the Internet of Things (IoT) undoubtedly offer many new possibilities. It is predicted that the total number of IoT devices across all industries worldwide will exceed eight billion by 2030. The main industries currently with over 100 million connected IoT devices include energy, gas, air conditioning, water management, waste management, retail and wholesale, transport and warehousing, and public administration. By 2030, it is also forecasted that IoT-connected devices in areas such as (autonomous) vehicles, IT infrastructure, asset tracking and monitoring, and smart grids will increase to over one billion (Vailshery, 2024). However, as specialists from Abas Business Solutions Poland point out, not everything that is technically feasible is economically justified (Abas, 2024). Companies do not necessarily believe that implementing smart systems such as IoT, cloud computing, blockchain, and similar technologies will provide them with a significant competitive advantage, nor do they believe that the positive impact of these systems is directly proportional to the number of smart systems used or that the capital invested will directly translate into financial benefits (Stanisławski, Szymonik, 2021, pp. 3996). In many enterprises, the current technical infrastructure is not sufficient for the Internet of Things. Smart, network-connected products usually require the creation of a new technological system, including hardware such as sensors, processors, radio components, user software, interfaces, controllers, network connections for communication between objects and the Internet, big data repositories, analytical tools, cloud or server storage, security features, and connections to external data sources or other business systems like ERP. Although three-quarters of enterprises consider the Internet of Things to be "very important" or "extremely important," most are still at the assessment or planning stage of its implementation, and only 9% have fully completed their IoT projects in operational terms (Abas, 2024). The reasons for this hesitation in manufacturing plants often include a lack of financial resources, insufficient knowledge, and security concerns. Most IoT projects undertaken by medium-sized enterprises are focused on connecting objects into networks and gathering data for process optimization. This means that IoT applications are primarily limited to improving internal processes. In large enterprises, on the other hand, new revenue streams are expected from IoT's potential to enhance customer benefits. In this case, companies transfer the information gained to their product range and develop new offerings and services. Among the top-performing companies in this area are those from Finland, Latvia, Belgium, and Poland. For Polish enterprises, initial steps have already been taken, but they are still far from becoming fully intelligent factories. According to experts from Business Solutions Poland, old and new infrastructures will coexist for many years. Manufacturing companies that seize the opportunities of the Fourth Industrial Revolution and treat IoT as a driving force for their digital transformation projects early on may gain a competitive edge. However, small enterprises face significant challenges in implementing modern IT technologies. In this area, Poland ranks only 16th out of 27 countries studied. Leading the way in this field are industrial enterprises from Finland, Belgium, Slovenia, and Italy. In terms of applying IoT technology configurations in both production and logistical processes, Slovenia's enterprises dominate, with the highest usage rates among small, medium, and large enterprises, outpacing other EU countries.

Based on the research conducted, countries that may still be in the early stages of IoT technology adaptation or show less engagement in this area have been identified. This could be due to various factors such as limited financial resources, a lack of awareness of the potential benefits of IoT, or resistance to technological change. As a result, countries and companies that invest in and develop IoT technology earlier may gain a competitive advantage by increasing operational efficiency, improving product and service quality, and better understanding customer needs. Conversely, countries and companies that lag in IoT adoption may risk falling behind and struggling to maintain competitiveness in the global market. Therefore, it is essential for countries and companies to recognize the potential of IoT technology and take steps toward its effective implementation and utilization.

In relation to the conducted research, some limitations should be noted. Some authors suggest that the decision to implement IoT technology only partially is insufficient to improve organizational performance (Sarosh et al., 2021, pp. 100225; Ivanov et al., 2021, pp. 2055-2078; Imran et al., 2018, pp. 2055-2078; Bremer, 2015, pp. 1-13). It is also noted that the literature lacks empirical studies on how IoT implementation can lead to better organizational outcomes in enterprises, such as organizational agility, efficiency, or process performance (Evdokimov et al., 2011, pp. 105-185; Minoli, Occhiogrosso, 2018, pp. 1-13; Kumar et al., 2023, pp. 106-138; Tsang et al., 2021, pp. 1534-1556). Undoubtedly, developing a research sample that covers both the degree of IoT advancement in production and logistical processes and the capabilities and effects of its implementation would yield more detailed results. A particularly interesting element for further research would be to include enterprises representing specific industries in the research group. This would allow for identifying potential differences in the approach to the analyzed issues across various EU countries. Such differences, considering the diverse nature of the potential research group, should be expected.

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