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SIGNIFICANCE OF DIGITAL INNOVATIONS OF INDUSTRY 4.0. FOR POLISH ENTERPRISES ON THE EXAMPLE OF PODKARPACKIE AND LUBUSKIE VOIVODESHIPS

Piotr SYCZ[1], Elżbieta WOJNICKA-SYCZ*[2]

[1] Farenheit Universities: University of Gdansk; piotr.sycz@ug.edu.pl, ORCID: 0000-0002-9614-5065
[2] Farenheit Universities: University of Gdansk & Gdansk University of Technology;
elzbieta.wojnicka-sycz@ug.edu.pl, ORCID: 0000-0002-0016-5580
* Correspondence author

Purpose: The article examines the relevance of specific Industry 4.0 (I4.0) solutions for enterprises in Poland. It also verifies whether there is a positive relationship between the level of digital sophistication of enterprises and their innovation and competitiveness, and whether there is a need to cooperate with external entities in the implementation of these technologies.
Design: A survey of 673 enterprises in Podkarpackie Voivodeship and a qualitative survey of 23 experts from Lubuskie Voivodeship were conducted. Data from the quantitative survey were analyzed using the tetrachoric correlation coefficient, the statistical significance test for differences in shares, and logit regression. An Internet query was also conducted.
Findings: The research shows that the most complex solutions are still relatively the least implemented. More companies have advanced software than I4.0 solutions. Digital sophistication is higher for medium and large entities, companies with foreign participation, those with a presence in foreign markets, as well as those belonging to the region's strategic innovation industries and companies in the market services sector. The share of entities expecting to increase profits and revenues, as well as R&D expenditures and increase innovation was significantly higher among digitally advanced entities. It was confirmed that implementing digital innovations requires cooperation with external partners. Digital solutions are key to innovative industries in Lubuskie, and public support for digital transformation of businesses is present.
Research limitations: The main limitation is the lack of overall domestic survey data.
Practical implications: The presence of relevant organizations supporting the successful implementation of I4.0 technologies is needed. They provide expertise for companies. Companies can become more competitive and sustainable by implementing IT solutions. However, dissemination of knowledge about the benefits of I4.0 technologies is required, as well as public support for digital transformation**.**
Social implications: In the face of shrinking labor resources, automation and robotization, with fewer workers, will allow production to be maintained at current levels.
Originality: The originality of the article lies in the analysis of the level of digitization versus the innovation and competitiveness of companies, and the analysis of the importance of various external partners for the implementation of I4.0 technologies.

Keywords: Industry 4.0 technologies, Enterprises, IT solutions, Podkarpackie Voivodeship, Lubuskie Voivodeship.

Category of the paper: Research paper.

1. Introduction

Industry 4.0 is a manufacturing concept that includes industrial automation and modern digital solutions to improve working conditions and increase productivity and quality in industry (Milošević et al., 2020). In Industry 4.0, companies are shifting from mass production to mass personalization, allowing customers to customize the final product to their individual taste, choosing from a range of options (Weiking, 2020). In the era of Industry 4.0, digitization encompasses a wide range of data operations, automation, digital interface, and connectivity (Abdelkader et al., 2016, Sehlin et al., 2019).

Industrial change is being driven by global competition and the need to digitize to remain competitive. Urbanization and a growing middle class in developing countries are also driving demand for niche industrial products. The demands of sustainability and reducing resource waste and pollution are also driving the development of new digital technologies (EFFRA, 2013).

Companies are using the Internet to gather information and increase customer engagement. Increasingly, they are offering "products as services," for example, with special features tailored to the needs of individual customers. In addition, the potential of smartphones and remote working technologies are increasing the mobility of employees and managers. Real-time connectivity, through sensors, automation controllers and embedded systems, enables seamless and bidirectional interaction with objects and systems on a global scale in the form of the Internet of Things. The competitiveness and innovation of companies increasingly depend on the ability to analyze large amounts of data from business processes, products, and systems in real time.

In the Industry 4.0 paradigm, automation supports human labor not only in production, logistics and data collection, but also in business management. In the era of Industry 4.0, people do not need to operate physical systems and can control them using digital systems (Mentsiev et al., 2020). Unlike the concept of Computer Integrated Manufacturing, which aimed to create fully automated factories without people, Industry 4.0 seeks to effectively apply technology to assist and collaborate with people (Rauch et al., 2020).

The fourth revolution is linked to the large-scale introduction into use of new information technology (IT), mobile technology, machine learning and artificial intelligence (Walentynowicz, 2020). It is characterized by widespread access to the Internet, a decrease in the cost of digital storage, portable devices, smart sensors, the use of renewable energy sources

and artificial intelligence. The fourth revolution is characterized by autonomous vehicles, advanced robots like robots cooperating with humans in manufacturing plants, caring for the elderly or cleaning, the use of scanners and 3D printing, new smart materials like self-cleaning clothes and other (Furmanek, 2013; Bongonomin et al., 2019; Sycz, 2023). While the fourth industrial revolution focused on using technology to optimize the means of production, the fifth is about the combination of man and machine. Industry 5.0 considers human brainpower, creativity, and fault tolerance capabilities. It combines human abilities with system abilities which embraces skilling, up-skilling, and re-skilling of workers. Human needs and interests, health and well-being are central for the industry (Wang et al., 2024). In addition, Industry 5.0 emphasizes clean industrial technologies that promote sustainability and conserve natural resources (Ruiz-de-la-Torre et al., 2023).

Digital innovations originating from industry also result in the implementation of innovations in the sphere of operation of public and social organizations, manifested, for example, in renewable energy installations supported by digital systems, clean air sensors, intelligent traffic management system, electronic document circulation, online portals for public consultations, monitoring (cameras in public spaces), lighting sensors, parking space information based on sensor data, mobile applications for parking space payment, urban bicycle systems, etc. using digital management systems, carsharing, virtual city/municipality/museum guides based on sensors, electronic management systems, self-driving vehicles, smart homes, e-government, telemedicine, and many others (UMWL, 2022).

The objective of the article is to test the relevance of solutions related to Industry 4.0 for enterprises in Poland using the example of entities from the Podkarpackie and Lubuskie provinces. For this purpose, a survey was conducted on a representative sample of 673 enterprises of the Podkarpackie Voivodeship in the second half of 2020 and a qualitative study based on a Delphi survey of 23 experts from entities related to innovative key industries - areas of smart specialization of the Lubuskie Voivodeship in the autumn of 2021. In addition, the article sets quantitatively verified hypotheses:

H1. There is a positive relationship between the level of digital sophistication of enterprises and their innovation and competitiveness,

H2. Implementing digital innovation requires combining different sources of knowledge, that is working with external partners.

Data collected in the direct quantitative survey in the Podkarpackie province were analyzed using statistical and econometric methods, that is correlation analysis, frequency tables and test for statistical significance of differences in shares, and logit regression. Direct qualitative research data from the Lubuskie Voivodeship from 2021 was supplemented with a web query of further activities of the entities of this voivodeship for the implementation of Industry 4.0 solutions.

The following sections of the article include a review of the literature related to the characteristics of digital innovations related to Industry 4.0 and 5.0, presentation of research methods, research results, and conclusions and discussion.

2. Digital innovations related to Industry 4.0 and 5.0

Digital technologies associated with Industry 4.0. and 5.0. include Big Data analytics, cloud computing, the Internet of Things, robotization of processes, artificial intelligence, blockchain, augmented and virtual reality, digital twins of plants and people, autonomous vehicles, 3D printing, nanotechnology, sensors, cybersecurity, blockchain, cyber-physical systems, or green IT (Delloite, 2020; Seager et al., 2020).

With Big Data analytics, the collected data, which is nowadays available in huge volumes, is subject to analysis and, as a result, becomes information for decision-making. However, digital security solutions are also becoming necessary to secure this flow of information (da Silva et al., 2020). Cloud computing is the ability to use shared ICT resources made available over the Internet. It implies the use of Infrastructure as a Service (IaaS), Software as a Service (SaaS), and Platform as a Service (PaaS) (Ocicka, 2017).

Digital innovations also include efforts for direct machine-to-machine and business-to-business communication and the broader Internet of Things (IoT). The Internet of Things is the incorporation of objects into a network that acquire, collect, and process data, and are therefore smart. The Internet of Things works through sensors that enable machines to communicate with each other. Automatic identification technology, such as radio frequency identification (RFID) and beacons, works similarly (Han et al., 2020). Fog computing bridges the gap between remote data resources available through the cloud and IoT devices that generate large amounts of data for real-time processing (Anderson, 2013; Nowicka, Szymczak, 2020).

The Internet of Services, on the other hand, reflects services and their functionality, according to new business models, provided by different providers, available for use on demand, with the possibility of mutual integration (Furmanek, 2018).

Industry 4.0 technologies also include virtual and augmented reality and digital simulations in, among other things, product design using a digital twin, as well as in other enterprise systems. With virtual reality (VR), users are transported, usually using a set of headsets and glasses, into a virtual world. In augmented reality (AR), applications show the illusion of layers of graphical information superimposed over a certain portion of the user's field of view. The combination of the two technologies is mixed reality (Bongomin et al., 2020).

Digital twins are dynamic copies of real objects. They make it possible to make corrections in the functioning of machines and devices connected to the network. Digital twins supported by blockchain technology make it possible to track the flow of finished goods in a distribution

system and to design their flow in such a way as to avoid risks (Nowicka, Szymczak, 2020; Bongomin et al., 2020, Piróg et al., 2021).

The use of new technologies in logistics also includes digitally controlled warehouses, robotic and autonomous transport devices (AGVs), mobile, voice and visual systems to assist in picking parts, geolocation, RFID chips (Walentynowicz, 2020). Industries using Cyber-Physical Production Systems (CPS), arising from sensors and identification technologies, are more flexible. This is due to IT's support for the operation of networks of different organizations and networks within organizations, reconfigurable and modular systems, and good communication between manufacturers and customers (Beier et al., 2020).

Additive manufacturing, like using 3D printers, makes it possible to develop high-standard complex products in small batches, in decentralized plants. This enables highly customized production at an acceptable cost because excellent connectivity between machines and people reduces work-in-progress inventories (di Nardo, 2020).

Industry 4.0 also means extensive use of artificial intelligence, and therefore robots. In the era of Industry 4.0, autonomous robots can work alongside humans and in dangerous places for humans. They can often reduce human mistakes. Robots will reduce manual labor and enable improved ergonomics. All routine tasks will be performed by machines. The robot coordinator will perform both routine and emergency maintenance and repair tasks, and will involve other experts as needed. For example, some work on assembly lines requires lifting heavy parts. Robotizing them allows the worker to do the work in an easier and more ergonomic way and prevents errors and accidents (Weiking, 2020; Beier et al., 2020).

Automated vehicle systems are becoming an integral part of manufacturing systems. These are unmanned vehicles used to move materials along specific routes - so-called AGV technology (Bednarz, Popiel, 2018). The self-driving vehicle system is connected via mobile technologies, and communication between the machine and workers occurs through easy interfaces. Information circulates throughout the system, so each vehicle knows the status of itself and others, so that an order is assigned to a vehicle that will complete it more efficiently. Drones, on the other hand, are unmanned aircraft and therefore flying robots (di Nardo et al., 2020).

The primary challenge associated with Industry 4.0 relates to data security and privacy (Mantsiev et al., 2020; Ingaldi, Ulewicz, 2020). Data and information shared as part of Industry 4.0 solutions must be protected by cybersecurity solutions. Their loss, alteration or theft threatens the misuse of machines, resulting in a loss of customer confidence, production interruptions or loss of intellectual property (ENISA, 2019).

Blockchain enables cyber-security through identity proofing. The technology is an electronic list that chronologically records transactions between users. Each transaction is recorded as a block with data about its value and the time of its conclusion. This block is attached to the previous ones and together they form a chain. The technology stores data in multiple locations rather than in one central repository, which increases security. Blockchain in

industry can be used, for example, to validate products in the supply chain or verify payments (Rot, Zygala, 2018).

Digital transformation in the coming years will also support the conservation of natural resources, which is important within the Industry 5.0 paradigm. Green ICT refers to the reduction of infrastructure energy use using IT systems, resulting in a reduction of CO2 emissions and the cost of operating companies (Bokolo, 2020; Abraham, Dao, 2019). Green IT systems support sustainable business operations. They include environmental management systems and green supply chain management systems. A green IT system involves the use of real-time data to reduce the environmental impact of business operations. Green manufacturing should include only energy-efficient equipment, connecting voltage stabilizers to servers and other computer equipment. Green distribution is environmentally friendly delivery strategies by introducing more efficient operations and increasing the reuse of ICT infrastructure. Green procurement is the acquisition of electronic products with green labels. For green sourcing, companies can also use environmentally friendly purchasing practices that include reducing purchases, buying recycled ICT infrastructure. Green sourcing means reducing the use of energy to power and cool ICT infrastructure, by improving the energy efficiency of data centers. Replacing or getting rid of ICT infrastructure should involve eco-friendly disposal and recycling, which reduces handling costs associated with disposing of ICT-generated waste in landfills. Old ICT equipment can continue to be useful and can be refurbished and restored for use in other enterprises (Abraham, Dao, 2019).

Industry 5.0 is human centered. In comparison with automation, humans create unique values in the manufacturing system like creativity, decision-making ability, or cognition. Human workers achieve higher productivity thanks to automation. Human Digital Twins (HDTs) are digital representations of humans. This technology may harmonize humans and smart devices by usage of real-time sensing, analysis, and automated feedback. Thanks to HDTs, humans' natural senses and cognitive abilities are integrated into the smart manufacturing system (Wand et al., 2024).

Another trend within the industry of the future is the development of predictive analytics for remote machine maintenance. Predictive analytics allows manufacturers to monitor equipment performance using any number of performance indicators and automate the data collection process using IoT technology. In addition, IoT systems monitor who is entering facilities and what people or equipment employees are interacting with, which promotes safety in the workplace (Bogges, 2023).

3. Methods and data

In July-August 2020, a survey of a representative with respect to the industry, size, and territorial structure of a sample of enterprises in the Podkarpackie Voivodeship was conducted to assess the level of implementation of modern IT solutions in the form of technologies related to Industry 4.0 and various types of modern software. The territorial scope of the survey was defined by the survey's funder, the Marshal's Office of Podkarpackie (Piróg et al., 2021; Sycz, 2023). The survey was conducted during the COVID pandemic, which increased the use of IT tools, especially remote working solutions. The survey covered 673 companies. The survey consisted of telephone- and/or computer-assisted interviews, depending on the respondent's preference.

The results of the study were presented in the form of dichotomous variables, where 1 meant the presence of a trait and 0 meant the absence of a trait. Due to this form of data, the tetrachoric correlation index for dichotomous variables was used for the analysis (Ekström, 2011). In addition, contingency tables were drawn up showing the co-occurrence of two characteristics, that is the intensity of use of digital innovations and variables reflecting the development prospects of companies. This made it possible to calculate the share of entities, like those showing a profit, in populations of entities that have not implemented digital solutions and those with different levels of implementation intensity. This was followed by a statistical analysis of the significance of differences in proportions between groups depending on the percentage and size of the population in question (Szymczak, 2010). In addition, a model was estimated using logit regression to assess which characteristics of the surveyed entities (company size, foreign share, export activity, industry specifics) increase the chances of high sophistication in terms of implementations of Industry 4.0 and modern software solutions. An odds ratio was also calculated to determine how much more likely it is that an entity with a given characteristic stands out in terms of high intensity of implementations of Industry 4.0 and modern software technologies (more than 9 IT solutions).

Logit regression is a type of multivariate nonlinear regression with a binary dependent variable, that is, it can take only two values "0" or "1" (like the i-th respondent of the survey has implemented more than 9 digital innovations ($y_i = 1$), and another has not ($y_i = 0$)).

Logit regressions are used to determine the probability that the explanatory variable will take the value of 1 or that it will take the value of 0 given the parameters and values of the explanatory variables, which should also, but need not, be expressed in binary terms:

$$\text{Prob}\,(Y = 1) = F(\beta' x) \tag{1}$$

$$\text{Prob}\,(Y = 0) = 1 - F(\beta' X) \tag{2}$$

The set of structural parameters (β) reflects the effect of changes in the explanatory (X) variables (independent; causes and stimulants) on the explanatory (dependent; effect) variable (Y) (Greene, 2003).

In addition, in the second half of 2021, a Delphi survey was conducted among experts from companies and institutions/consulting firms in the smart specialization areas of Lubuskie Province. Lubuskie province's smart specialization areas are green economy, health and quality of life, and innovative industry. Part of the survey focused on future technologies, according to experts, for their industries. The survey consisted of sending the questionnaire to experts three times. In the second round, the experts' average responses were presented, and they were asked to respond to the most common responses and accept or not. Most of the experts agreed with the consensus answers in the second round, some were sent answers for a third time and, if not accepted, they submitted dissenting opinions. Twenty-three experts responded to the survey. Two responses each were from medical technology, the agri-food and bio-economy sector, tourism and recreation, and the automotive industry. Four each were from the metal and energy industries, while seven were from the ICT (information technology and computer industry) and R&D and technical expertise sectors. The survey was conducted as part of the preparation of a diagnosis for the Innovation Development Program of Lubuskie Voivodeship by 2030 (UMWL, 2022).

3.1. Research in the Subcarpathian Voivodeship

The most common Industry 4.0-related solutions used by Podkarpackie enterprises included remote work technologies in 2020, which was intensified by the pandemic (about 40 percent). One in three industrial enterprises had customized manufacturing technologies, and 7 percent planned to implement them. About 30 percent of entities had mesh networks, and 6.4 percent planned to implement them. Big Data or cloud computing, providing services remotely and geolocation, as well as self-controlling components of manufacturing systems were used by about one in five entities, and about 8 percent each planned to implement them, in addition to geolocation, which less than 4 percent of companies planned to implement. About 14% of entities had sensors and RFID systems as well as automated remote communication with business partners.

Blockchain, 3D printing or nanotechnologies, Internet of things, virtual or augmented reality (VR/AR), drones were used by less that 10% and more than 5% of respondents. The least popular were the most comprehensive solutions that is: collaborative robots (co-bots), artificial intelligence as chat bots, digital twin of a customer and/or plant, digitally controlled warehouses, autonomous vehicles, and exoskeletons. However, some companies were planning to introduce them. Continuously, therefore, many entities are not using many digital innovations, demonstrating the need for digital transformation. According to a Eurostat survey, 28% of large companies in Poland had robots in 2020-2021, and this was quite high in the EU, at the level of Denmark, Austria, and Slovakia, with Slovenia's highest score at 40% and Cyprus' lowest at 3%. Big data was used by 16% of large companies, an average low score for European countries (ranging from 9% in Lithuania to 36% in Belgium). Artificial intelligence (AI) and 3D printing were used by 17% of large companies each, which is average and average

low in the EU, respectively. Internet of things and cloud computing were used by 51% and 70% of large Polish enterprises each, respectively, similarly average compared to other countries. However, the rates for small and medium-sized enterprises are much lower, at 2% for Big Data analytics and artificial intelligence, which especially for AI is low in the EU, 3% for 3D printing (low level in the EU), 5% for robots (average level in the EU), 27% for cloud computing (average level) and 18% for Internet of things (average low level against the EU) (Prokopiuk, 2022).

Table 1.
Shares of firms using specific I 4.0 solutions (n = 673 or n = 128 in the case of solutions for manufacturing

I4.0 solutions	We are using (%)	We are not using, but we plan to use (%)
Remote work	37.8	5.7
Customized manufacturing (n = 128)	33.6	7
Mesh networking	29.4	6.4
Big Data or cloud computing	23.5	8.5
Providing services remotely	23	8.2
Geolocation	22.9	3.7
Self-controlling (via software) components of manufacturing systems (n=128)	20.3	7.8
Sensors and RFID systems	14.9	7
Automated remote communication with business partners	13.7	10.3
Blockchain	9.1	6.4
3D printing or nanotechnologies	7.9	6.7
Internet of things	6.6	7.1
Virtual or augmented reality (VR/AR)	6.4	6.5
Drones	5.7	7.9
Collaborative robots (co-bots)	4	4.9
Artificial intelligence E.g. chat bots	3.9	8.6
Digital twin of a customer and/or plant	2.5	3.4
Digitally controlled warehouses	2.4	5.8
Autonomous vehicles (self-driving)	1.3	4.5
Exoskeletons	0.74	3.12

Source: research in Podkarpackie province for Piróg et al. (2021).

In the Podkarpackie region, more entities have advanced software programs than strictly digital solutions related to Industry 4.0. Nearly 45% of entities have introduced electronic document workflows, and another 7.6% plan to implement them. One in four/five companies has software for work control, customer relationship management, knowledge management, or working in virtual teams.

About a dozen percent each of companies have implemented software to manage inventory, supplier relations and infrastructure (Table 2).

Table 2.
Shares of firms using specific advanced software (n = 672)

Advanced software	We are using (%)	We are not using, but we plan to use (%)
Electronic documentation workflow	44.5	7.6
Work control software	25.9	8.2
Customer relationship management software	22.9	9.1
Knowledge management software	21.4	7.9
Software for working in virtual teams	19.1	6.7
Inventory management software	17.7	6.6
Supplier relationship management software	16	8.6
Infrastructure management software	14.2	9.2

Source: research in Podkarpackie province for Piróg et al. (2021).

As shown by the logit regression model, the implementation of more than 9 solutions from Industry 4.0 and/or modern software is favored by being a medium and large company, having a foreign share, conducting export activities, as well as belonging to key innovative industries in Podkarpackie, that is smart specializations. In addition, many digital innovations were implemented by companies in the market services sector. Belonging to industry in general, except for industries from smart specializations, was statistically insignificant. The odds ratio showed that the chance that an exporting company implemented more than 9 IT solutions was more than four times higher than for those not exporting. Companies with foreign participation and medium and large companies were more than three times more likely to have been digitally advanced than domestic entities and small and medium-sized companies. The chance that a company was highly digitally advanced was more than twice as high for entities in smart specialization industries than for others, and for companies in the market services sector than for others (Table 3).

Table 3.
Logit regression for dependent variable: firm that introduced more than 9 IT solutions (of Industry 4.0 or advanced software)

Independent variable	Coefficient (Std. Error)	Odds ratio (Std. Error)
Constant	-3.565*** (0.316)	0.028 (0.009)
Foreign share	1.167 ** (0.495)	3.213 (1.589)
Export activity	1.483*** (0.292)	4.404 (1.288)
Medium or large company	1.163*** (0.298)	3.201 (0.954)
Smart specialization area	0.807*** (0.305)	2.242 (0.684)
Market services	0.854*** (0.337)	2.350 (0.792)
Industry	0.343 (0.361)	1.409 (0.509)
n	648	
Pseudo R^2	0.214	

Note. ** - statistically significant at p=0.05, *** - statistically significant at p=0.01, Std. – standard.

Source: own calculations in Stata based on research in Podkarpackie province for Piróg et al. (2021).

The percentage of entities expecting an improvement in financial performance: revenue and profit was higher for entities with any digital solution or advanced software than for those without and was rising for groups of entities with higher intensity of the use of IT solutions (Table 4). There was a significantly higher percentage of entities expecting an increase in R&D

expenditures in the group of companies with IT solutions than without them, and entities with high intensity of the use of IT solutions also stood out particularly here. Thus, modern technologies favor R&D, which in turn increases the chances of implementing solutions that are new to the market. Similarly, significantly more entities expected to implement new products and services among companies with IT solutions than without them. At the same time, greater digital sophistication of companies meant a significantly higher percentage of companies planning to innovate. In the case of R&D+I activities, statistically significant differences were also noted in the share of entities planning to increase R&D expenditures and innovation with higher digital sophistication compared to the total of entities with any IT solution. In the case of financial performance, such a statistically significant difference occurred only in terms of the expectation of profit by more entities with more than 9 IT solutions than those with any IT solution. Digitalization, therefore, particularly enhances the R&D and innovation potential of companies.

Table 4.
Percentage of entities that have implemented a given number of Industry 4.0 solutions expecting to see an increase in performance and R&D+I activities and the statistical significance of differences compared to those without Industry 4.0 solutions and those with any solution (in parentheses)

Expected growth	Lack of IT solutions (n = 259)	Any solution i4 (n = 414)	More than 5 solutions I4 (n = 84)	More than 9 IT solutions (i4 and advanced IT programs) (n = 90)
profit	0,16	0,25***	0.33***(ns)	0,36***(**)
revenues	0,16	0,26***	0.33***(ns)	0.33***(ns)
R&D expenditures	0,03	0,15***	0,29***(***)	0,3***(***)
introduction of new products and services	0,14	0,31***	0,49***(***)	0,52***(***)

Note. *** - statistically significant at p=0.01, ns - statistically not significant.

Source: own calculations in Stata based on research in Podkarpackie province for Piróg et al. (2021).

Companies that implemented differentiated IT solutions often collaborated with various external entities for this purpose, confirming the importance of reinforcing knowledge from the innovation system for technological upgrading. The highest correlation rates were for cooperation with business support organizations, scientific institutions, non-academic experts and, in the case of Industry 4.0-only solutions, with business customers. However, also in the case of cooperation with the other type of partners like consulting firms, cluster partners and suppliers such positive correlation with IT solution implementations occurred. The least important was cooperation with public administration, such as applying for a grant, but there was also a positive correlation coefficient for IT solutions. At the same time, there was a negative correlation regarding IT solution implementations and the situation of lack of any cooperation in this implementation, that is stand-alone implementation. This also means that

specialized skills are needed, which companies do not have internally, to implement advanced IT solutions successfully.

Respondents noted the positive effects of implementing at least 5 IT solutions. Particularly high positive correlation coefficients were for implementations of differentiated solutions and reduction of mistakes and errors, increase in the flexibility of production and its adjustment to current demand ("pull" system), increase in the customization of production and increase in innovativeness and revenues, as well as entering new markets (through product/service differentiation, export). This means that the implementation of several IT solutions improves operations within the organization and allows for better customization, stimulates innovation, and thus increases the competitiveness of companies, as manifested, for example, by entering new markets and increasing revenues.

Table 5.
Statistically significant tetrachoric correlation coefficients

Variables	Firms with:		
	over 5 I4.0 solutions	**over 5 IT solutions**	**over 9 IT solutions**
Cooperation during implementation of the solutions with:			
Business support organizations	0.407***	0.589***	0.551***
Public administration	ns	0.232**	ns
Scientific institutions	0.582***	0.428***	0.522***
Consulting firms	0.365***	0.328***	0.425***
Suppliers	0.428***	0.344***	0.383***
Cluster partners	0.324**	0.405***	0.402***
Business customers	0.511***	0.370***	0.482***
Experts not from science	0.609***	0.624***	0.538***
Implementation without cooperation	-0.373***	-0.314***	-0.393***
Effects of implementation of the solutions:			
Reduction of mistakes and errors	0.400***	0.500***	0.439***
Reduction of waste of materials, energy, time	0.360***	0.363***	0.468***
Reduction of operating costs	ns	0.190**	0.238***
Increase in work safety	0.215**	0.336***	0.369***
Increase in innovativeness	0.519***	0.521***	0.552***
Increase in the required qualifications of employees	0.398***	0.380***	0.353***
Increase in revenues	0.458***	0.439***	0.463***
Increase in the flexibility of production and its adjustment to current demand ("pull" system)	ns	0.498***	0.476***
Increase in the Customization of Production	0.499***	0.455***	0.587***
Entering new markets (through product/service differentiation, export)	0.409***	0.442***	0.474***

Note. ** - statistically significant at p=0.05, *** - statistically significant at p=0.01.

Source: own calculations in Stata based on research in Podkarpackie province for Piróg et al. (2021)

3.2. Research in Lubuskie province

In the Delphi survey, experts from key industries in the Lubuskie region were asked, among other things, about the direction of technological development in their industries. The answers

obtained indicate the crucial importance of IT solutions and digital innovations as the future direction of development of these industries.

Experts from all industries considered the following to be very important and quite important in the next 3 years: design of new products using new technologies (like ICT), development and improvement of existing products/services, digital innovations and/or their implementation in the industry, and new forms of product promotion and marketing. Experts also identified the most important specific new technologies/research areas that will be important in their industries in the next 3 years. Digital innovations and IT solutions will be important especially in metal, ICT, medical technologies and services, and specific solutions in this area were indicated by representatives of the automotive and tourism industries. These specific key IT solutions to be researched and implemented in Lubuskie industries are: design of new products using new technologies, development of algorithms for comprehensive patient care, IT booking techniques and tourist information; robotics, automation, Big Data, Internet of things, cyber security, augmented reality, additive printing, optometry, electromobility, blockchain, acceleration of data exchange (5G, 6G), automation of even more services previously handled by humans (autonomous cars), security issues related to digitization of electronic communication processes, solutions for confirming and securing identity (like in e-services, in tools for data circulation, or in electronic communications); solutions for realizing as many processes as possible in electronic form, including ensuring accessibility for as many services as possible: offices, medical institutions, etc. in digital form; use of artificial intelligence for, among other things, monitoring of water supply networks.

As part of the competition announced by the Office of the Marshal of the Lubuskie Voivodeship for Key Areas within the framework of smart specializations in September 2022, partnerships were selected that include the development and implementation of digital innovations, that is: Lubuskie Center for Digital Medical Technologies, Industry4Future[1], Innovative Industry - Sub-area: Industry 4.0 - Smart Factory 4.0[2], Smart City and IoT - smart management of resources in the economy, as well as Transport, Logistics and Autonomous Vehicles[3]. In addition, partnerships have been selected for space technologies that can support the development of new solutions in industry, as well as the Green Transformation partnership, which is now also supported by IT solutions. The partnerships include not only companies, but also research and development units, or pro-innovation institutions and social organizations. On September 28, 2023, selected partnerships signed Key Area Development Agreements within the Lubuskie Smart Specialization[4]. The example of the Lubuskie Voivodeship demonstrates the crucial importance of Industry 4.0 digital solutions for innovative industries

[1] https://innowacje.lubuskie.pl/inteligentne-specjalizacje/partnerstwa/Industry4Future, 28.09.23.
[2] https://www.lubuskiklaster.pl/partnerstwo-smart-factory-4-0-wyniki-konkursu/, 28.09.23; https://www.lubuskiklaster.pl/partnerstwo-smart-factory-4-0/, 30.09.23.
[3] https://lubuskie.pl/wiadomosci/19297/wybrano-partnerstwa-w-ramach-lubuskich-inteligentnych-specjaliza, 30.09.23.
[4] https://lubuskie.pl/wiadomosci/21242/te-partnerstwa-sa-kluczowe-dla-rozwoju-lubuskiego, 30.09.23.

and the efforts being made by various regional agents to transform the digital economy, as well as the public support occurring for this transformation.

4. Conclusions and discussion

Solutions related to Industry 4.0 are being implemented by companies in Poland, and the role of these implementations is growing. Research conducted in the Podkarpackie region, showed that still the relatively most complex solutions such as digital twin of a customer and/or plant, digitally controlled warehouses, autonomous vehicles (self-driving), exoskeletons are implemented least often. The most widespread, on the other hand, are remote work, customized manufacturing, mesh networking, Big Data or cloud computing, providing services remotely, geolocation and self-controlling components of manufacturing systems. More companies have advanced software such as Customer Relation Management or Enterprise Resource Planning than Industry 4.0 solutions. Digital sophistication is higher for medium and large entities with foreign participation, presence in foreign markets, and belonging to the region's strategic innovative industries, and market services companies. The share of entities expecting an increase in profit and revenue, as well as R&D expenditures and an increase in innovation was significantly higher among digitally advanced entities. This means that strong equipment with a modern digital solution is positively related to greater innovation and competitiveness of enterprises, which confirmed the first research hypothesis. In addition, it was confirmed that the implementation of digital innovations requires combining different sources of knowledge, like cooperation with external partners. Most often, digitally advanced companies collaborated on the implementation of digital innovations with business support organizations, scientific institutions, and non-academic experts. Hence the presence of suitable supporting organizations for successful implementation of I4.0 technologies is needed. They provide specialized knowledge for companies. An analysis of the correlation coefficients between the high intensity of implementations and the effects of these showed that the implementation of several IT solutions improves operations within the organization and allows for better adaptation to the needs of customers, stimulates innovation, and thus increases the competitiveness of companies, as manifested, for example, by entering new markets and increasing revenues. The example of the Lubuskie Voivodeship demonstrated the crucial importance of Industry 4.0 digital solutions for innovative industries, as well as the existing public support for digital transformation of enterprises.

At the same time, it should be noted that Polish companies are still focusing on Industry 4.0 solutions, although sustainability issues and the use of IT to reduce environmental impact are also noticeable. A recommended direction for further research and implementation in companies is the importance and potential of solutions related to better cooperation between

people and machines for combining the cognitive, decision-making and creative abilities of people with the speed of action and a smaller scale of mistakes, like due to fatigue, of machines. Thanks to broader implementations of Industry 4.0 and 5.0 technologies, Polish companies will be better able to face competition from cheaper manufacturers, like from China - it will be unprofitable to import customized products. They will also increase their competitiveness vis-à-vis European Union companies, which are also intensively implementing new technologies to reduce their costs and provide customized products and services. In addition, by implementing digital innovations, it will be possible to integrate supply chains in the European Union. The use of solutions such as co-robots, exoskeletons or solutions that reduce the negative impact on the environment will make it possible to relocate again to Poland those stages of production in the metal industry, for example, which have been moved out of here due to the lack of people willing to work hard or the environmental pollution caused by processing. The use of IT systems should also promote safety in the workplace through better monitoring. In the face of dwindling labor resources, automation and robotization, with fewer workers focused on creative work and machine control, will keep production at its current level. However, it is important to expand the knowledge of entrepreneurs and their representatives about Industry 4.0 and its solutions, as they are often unaware of the importance and potential of digital innovation[5].

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[5] Authors' experience from the 2021 workshop with Lubuskie enterprises.

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