УДК 338.45:621

INDUSTRY 4.0: THE EXPERIENCE OF EASTERN EUROPEAN COUNTRIES AND CHALLENGES FOR UKRAINE

ІНДУСТРІЯ 4.0: ДОСВІД СХІДНОЄВРОПЕЙСЬКИХ КРАЇН ТА ВИКЛИКИ ДЛЯ УКРАЇНИ

Sheiko I.A.
Candidate of Economic Sciences,
Senior Lecturer at Department of Economic Cybernetics
and Economic Security Management,
Kharkiv National University of Radio Electronics, Kharkiv, Ukraine

Storozhenko O.V.
Candidate of Economic Sciences,
Senior Lecturer at Department of Economic Cybernetics
and Economic Security Management,
Kharkiv National University of Radio Electronics, Kharkiv, Ukraine

The article deals with questions of digitization of the economy. The main theoretical aspects about Industry 4.0 were indicated. The experience of Eastern European countries was considered, the classification of the EU countries according to the level of readiness for the introduction of digital technologies was given. The matrix of SWOT-analysis of the prospects for implementing Industry 4.0 in the reality of industry in Ukraine was created.
***Key words:** digital economy, digitalization, automation, Industry 4.0, Internet of Things, industry, machine building, SWOT analysis.*

В статті розглядаються питання цифровізації економіки. Означені основні теоретичні аспекти щодо індустрії 4.0. Розглянутий досвід східноєвропейських країн, наведена класифікація країн ЄС відповідно до рівня готовності до впровадження цифрових технологій. Створена матриця СВОТ-аналізу перспектив впровадження технологій індустрії 4.0 у реалії промисловості України.
***Ключові слова:** цифрова економіка, цифровізація, автоматизація, індустрія 4.0, інтернет речей, промисловість, машинобудування, СВОТ-аналіз.*

В статье рассматриваются вопросы цифровизации экономики. Указаны основные теоретические аспекты относительно индустрии 4.0. Рассмотрен опыт восточноевропейских стран, приведена классификация стран ЕС в соответствии с уровнем готовности к внедрению цифровых технологий. Создана матрица СВОТ-анализа перспектив внедрения технологий индустрии 4.0 в реалии промышленности Украины.
***Ключевые слова:** цифровая экономика, цифровизация, индустрия 4.0, интернет вещей, промышленность, машиностроение, СВОТ-анализ.*

Problem statement. Industry 4.0 or Manufacturing IoT systems connect the components of a production process in a factory. Their purpose is to enable “smart manufacturing”. In smart factories, cyber-physical systems monitor physical processes and make decentralized decisions. Via their IoT connection, these cyber-physical systems can communicate and cooperate with each other and with humans in real time. Connected devices include manufacturing equipment and robots.

Industry 4.0, Smart Industry, Industrial Internet, Advanced Manufacturing are all terms that stand for a vision of the growing digitalisation, networking, and automation of industrial production. Things, data and services, people and machines – in Industry 4.0 everything could be connected to everything else. Existing production, logistical and working processes could change dramatically, resulting in great leaps of productivity. Many studies predict high investment in digitalisation because, thanks to the developments sketched above, an individual item customised according to the wishes of the customer could be produced at the cost of a mass-produced product – in a very short time and through minimal use of resources [6].

In the Ukrainian perspective, there is a large-scale digitalization of all branches of the economy and basic spheres of life, strengthening of investments in infrastructure development, innovations and modern technologies. After all, digital technology reduces barriers to entering new markets, allows you to automate a huge amount of mechanical work, upgrade equipment, optimize management processes. An important aspect: thanks to the introduction of the digital economy, small and medium-sized businesses have become global. Ukrainian companies can integrate into international value-added networks; some of them are already successfully implemented. This is a way to increase exports and produce more value-added products [13].

The aim of the article is investigating main trends in the development of digital technologies in the countries of the European Union and generalizing the prospects and threats of the introduction of Industry 4.0 elements in the reality of Ukrainian manufactory production.

The main research results. Three industrial revolutions have led to changes in the domain of manufacturing – mechanization through water and steam power, mass production in assembly lines, and automation using information technology. However, over the past years, industries together with researchers and policymakers worldwide have increasingly advocated an upcoming fourth industrial revolution (see Fig. 1) [3].

For example, the German government promotes the computerization of manufacturing industries in their *Industrie 4.0* (I4.0) program [5], while in the United States, *smart manufacturing* initiatives such as the Smart Manufacturing Leadership Coalition (SMLC) drive and facilitate the broad adoption of manufacturing intelligence [3]. In response to the challenges, most of the EU governments have made I4.0 a priority adopting large-scale I4.0 policies to increase productivity and competitiveness and improve the high-tech skills of their workforce.

The Fourth Industrial Revolution is characterized by the introduction of the *Internet of things* (IoT) and the *Internet of services* concepts into manufacturing, which enables *smart factories* with vertically and horizontally integrated production systems. In industries worldwide, highly flexible processes that can be changed quickly enable individualized mass production. Variants are self-determined through items delivering their own production data to intelligent machines [11], which are aware of the environment, exchange information, and control processes in production and logistics by themselves. In order to realize this vision, elements such as machines, storage systems, and utilities must be able to share information, as well as act and control each other autonomously. Such systems are called cyber-physical systems (CPS) [1].

Over the past few years, the European Union has addressed the topic of Industry 4.0 with the slogan "Advanced Manufacturing". A taskforce established in 2013 presented a working document (European Commission 2014) [4], which was primarily concerned with the challenge of the shrinking portion of manufacturing in the GDP of the European Union. In this publication on industrial policy titled "For a Renaissance of European Industry," the Commission stressed that digital technologies such as cloud computing, big data, the new industrial internet, applications, smart factories, robotics, and 3D printing were necessary conditions when it came to increasing the productivity of European industry. The Commission defined three objectives [4]:

– the faster commercialisation of advanced manufacturing technologies;

– reduction of demand shortfalls for advanced manufacturing technologies;

– promotion of skills for advanced manufacturing.

Likewise, in 2014 the new EU research programme Horizon 2020 was launched – by 2020 the Commission wants to earmark €77 billion of funding, including €24.4 billion for "research excellence"

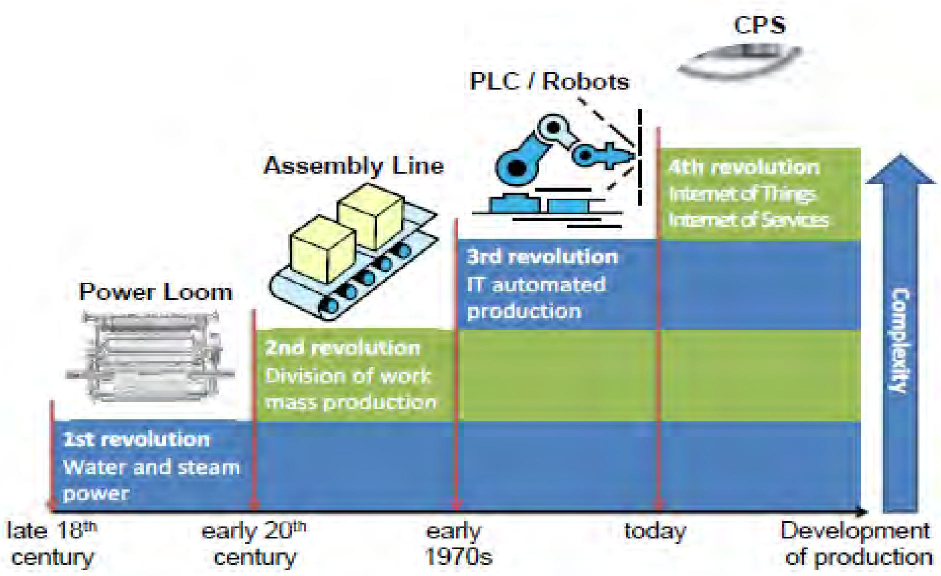

Fig. 1. Four industrial revolutions [3]

and €17 billion of funding for industrial innovations and so-called key technologies [4].

Furthermore, national and regional initiatives are to be connected and investments are to be supported through strategic partnerships and networks, which the European Commission hopes will alone generate around €50 billion in public and private investment in the digitalisation of industry: €37 billion investment in digital innovations; €500 million of European funds plus €5 billion of national and regional funding for so-called "Digital Innovation Hubs" (DIH); €6.3 billion for the first production lines of "Next-Generation Electronic Components"; €6.7 billion for the European Cloud Initiative.

The concept of I4.0 is based on linkage of virtual and physical parts of business processes along a supply chain. The virtualization is gained by the Internet of Things (IoT), the Internet of Services (IoS), and the Internet of people (IoP). Virtualization of material and people by attached barcode or RFID tag, electronic devices and tools by new IPv6, integration of IT systems that currently insularly support supply chain processes can create CPS, in which task can be simulated from product engineering to aftermarket services. There are 3 main pillars (technology, management, social aspect) that have to be well established similarly in both a company and a country. I4.0 is not solely based on automation. It can go hand in hand with lean and help to achieve additional benefits where traditionally low investments measures of lean cannot enable further process performance improvements [7].

Detail parts of CPS from a technology point of view are shown below [1]:

a. Big data and sensors e.g. RFID, bar codes – real-time monitoring and data processing from a vast number of resources finds essence for an end to end visibility and virtualization. However, it also leads to processing and data storing of the huge volume of data that today.

b. Autonomous active (e.g. robot) and passive parts (material) – passive items are those that are manipulated and processed within SC processes, active item is the one that manipulates and processes within SC. Thanks to IoT, items can become agents that can distributively control their SC processes because of their visibility and interconnectivity in a virtual SC model.

c. Simulation – simulation is indispensable for decentralized controlling to identify and assess all reasonably optimized variant of process execution.

d. IT horizontal and vertical integration – horizontal and vertical integration of process is discussed in the management part. However, the effective and efficient execution of processes requires the seamless transfer of data from transaction systems and their availability in multiple dimensions for each SC system item. That is a condition for effective Big Data utilization.

e. The Industrial Internet of Things – active and passive SC items are assigned of IPv6 and so they become virtually visible, easily identifiable, and are mutually interconnected. The system provides a certain level of controlling to active and passive process items and established the decentralized system.

f. Cyber security and data security – technology advancement brings a lot of benefits; however, it also creates a condition for a new form of crimes based on hacking IT system, stealing and abuse of data. Supply chain system is less sensitive to human errors in processes but more vulnerable to system hacking. Thus, data security has become an issue in I4.0.

g. The cloud, data centres, data network – Big Data require a huge volume of data to be processed and shared, hence, clouds, data centres and networks enabling sufficient connectivity are an important part of the system. Their capacity and security are an issue.

h. Additive manufacturing, 3D printing – production process is changed in some areas from centralized to the decentralized one. This is enabled by new technological devices, for instance, 3D printing. Thus, customers can print out a product at their location instead of organizing production and distribution from a remote distance. Additionally, it brings complete product customization.

i. Augmented reality, virtual reality, artificial intelligence – the Virtual reality of the supply chain can help detect issues that have to be sorted out. A virtual copy of the physical system can boost immediate action and provides more relevant data in the decision-making process.

Although McKinsey's research defines four clusters of technologies that need to be examined (Figure 2) [8]. Different drivers are leading to an acceleration of use on a large scale for each of these clusters.

The European manufacturing industry is responsible for 15% of GDP. Countries with an especially large manufacturing sector include Germany and Ireland, as well as various Eastern European countries. However, for a market to be promising for Industry 4.0 services, it also needs to be ready for these techniques. This depends on, for example, production process maturity, the degree of automation, the degree of innovation, industry openness, and internet use [6].

Industry 4.0 readiness is considerably greater in western and northern Europe than in other parts of Europe. As the founder of the movement, Germany scores particularly high. Combining readiness with the importance of the manufacturing sector reveals four types of European markets (Table 1) [6].

Even Eastern European countries appear mainly at zones of "Traditionalists" and "Hesitators", the experience of them will be useful for making clear the way Ukrainian economy should pass.

We analysed the objectives and main results of industrial policies at the Czech Republic and Poland.

Průmysl 4.0 (Industry 4.0) is a national initiative aiming to maintain and enhance the competitiveness of the Czech Republic in the wake of the Fourth Industrial Revolution. The concept was first presented during the 57th International Engineering Fair in Brno, September 2015 and approved by the Government of the Czech Republic on 24th August 2016. The Ministry of Industry and Trade plays a key role in the implementation process, however, there is a strong interdisciplinary cooperation between the ministries, social and industrial partners, and academia. The goal is to prepare not only the industry but the whole society for the economic and societal changes related to the fourth industrial revolution. P40 has a wide focus on the creation of a business and social environment, in which the Czech economy can reach its full potential. At the same, the initiative aims to mobilize the private sector, R&D and industry associations, and academia to actively participate in the implementation process [2].

The Czech Republic has one of the highest shares of industrial production per GDP among EU countries (approximately 32% GDP). Furthermore, the country has strong industrial ties to Germany, which is its strategic business partner. Czech companies mainly supply industrial components to its neighbouring country, thus integrating into the German industrial supply chain.

There are three main objectives of Průmysl 4.0. Firstly, to enhance the ability of Czech companies to be involved in the global supply chain. Secondly, the implementation of Industry 4.0 principles will lead to more efficient manufacturing, meaning

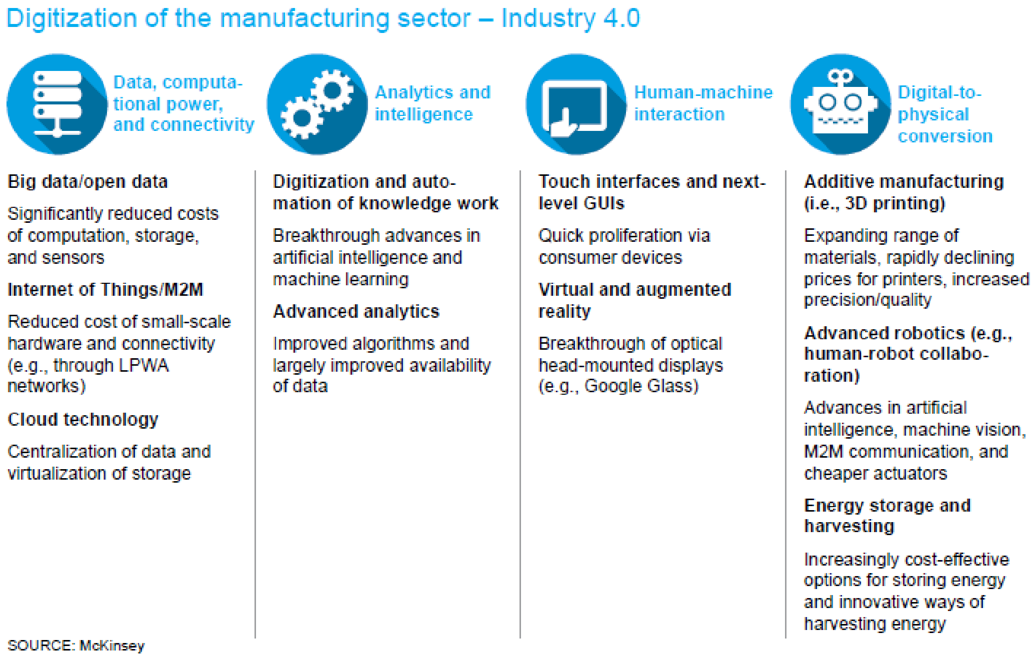

Fig. 2. Four main clusters of technologies of digitalisation [8]

Table 1

Classification of EU countries based on readiness to digitalization

Type	Readiness to digitalization	Countries
Frontrunners	These countries generally have a large manufacturing industry and modern, forward-looking business conditions and technologies.	Germany, Ireland, Sweden, Austria.
Potentialists	The manufacturing industries of these countries are in decline. However, they possess a modern and innovative outlook that gives them the potential to implement Industry 4.0 techniques.	Belgium, Finland, Netherlands, Denmark, United Kingdom, France.
Traditionalists	These mainly Eastern European countries have a thriving manufacturing industry, which could make them promising Industry 4.0 markets. However, so far these markets continue to focus on traditional manufacturing and are not ready for digitisation.	Czech Republic, Hungary, Slovakia, Slovenia, Lithuania.
Hesitators	These countries do not have a particularly strong manufacturing industry. In addition, the sector is not ready for Industry 4.0 in these countries.	Italy, Spain, Estonia, Portugal, Poland, Croatia, Bulgaria.

faster, cheaper and resource-effective production. Thirdly, to enhance the cooperation with R&D and industry association, universities and Academy of Sciences of the Czech Republic for the development of software solutions, patents, production lines, and export know-how.

The multidisciplinary approach requires close cooperation between policy makers from different sectors. Digitalizing the industry is perceived as a continuous bottom-up process, driven by companies to increase their competitive advantages. So far, no extra budget has been earmarked for the implementation of the initiative. Public funding is based on the financial tools already in place. The Operational Programs and subsidy programs of the ministries and the Technical Agency are available to support P40 related projects. The Government is currently looking into making changes to investment law for the benefit of the initiative. The financial resources allocated in the OP PIK (€4.5 billion) administrated by the Ministry of Industry and Trade already offers several suitable programs to support P40 activities.

The national innovation fund (€1.87 million) brings together financial resources from the European Structural and Investment Funds, OP PIK and additional €1.2 million from the private sector and it is considered as a possible source of a refundable form of financial support, of which part would be reinvested in the new projects. Further programs Trio (€140 million), Gama and Epsilon administrated by the MPO are considered as other options of the funding for the realization of the P40 activities. These programs aim to improve knowledge transfer between the industry and R&D institutions. At this stage, no model for private financing is in place. The Government is planning to explore different possibilities [2].

The main goal is to create an appropriate business and social environment with the main focus on building the data and communication infrastructure, an adaptation of education system, introducing new labour market instruments, and creating financial policy supporting companies with investment in the new technologies and know-how. At this stage, there is no more specific information available.

As about Poland, The Future Industry Platform was announced as a part of the Responsible Development Plan ('Morawiecki Plan') by the Ministry of Finance and Development in 2016 [9]. Providing industrial financing over a 25-year period, the Morawiecki Plan pursues an agenda of reindustrialisation through new partnerships, export-oriented support measures and comprehensive regional development. The main mission of the Platform will be to act as an integrator of all stakeholders interested in Industry 4.0, as well as an accelerator of the digital transformation of the Polish industry. The Platform seeks to achieve these goals through a mix of activities comprising knowledge transfer and awareness raising, as well as the development and application of digital transformation support measures. With a total planned investment of €235 billion over the next 25 years[1], the Plan seeks to unleash the potential of the economy to achieve development that improves the quality of life in Poland. The brief information about industrial policies of both countries is summarized in Table 2.

As about the reality of Ukrainian enterprises, our country has strong positions in the manufacturing industry, which could make them promising Industry 4.0 markets. However, these industries continue to focus on traditional manufacturing and are not ready for digitalisation.

In the Association of Industrial Automation of Ukraine (AIAU) report [13] (an initiator of introduction of Ukrainian Industry 4.0 approach), the data of the survey are described. The survey was attended by over 200 respondents, most of whom were representatives of business structures: small, medium-sized, and large industrial enterprises. Universities' researches and lectures also took a significant part. Respondents represent, in fact, the cut-off of the entire IoT lifecycle and key stakeholders-vendors, system integration, industrial enterprises, IT companies, education and research segments.

On the one hand, our respondents are well-informed with Industry 4.0 trends, recognize our lag, but also believe in the significant impact of digital transformation on the competitiveness of their enterprises in the future.

Two-thirds of the respondents are already positioning themselves as the Internet of Things (IoT) providers, and almost everyone plans to do so in the near future. And, at the same time, almost everyone thinks about the problem of cyber security of IoT, up to the need for certification of devices.

The key technological segments of the IoT are data analysis, platform or software development, and smart sensors. At the same time, interest in robotics and additive technologies, which is one of the important elements of the enterprises of the future, is relatively small. This is probably due to the significant entry threshold for these segments.

Of course, there are problems and barriers. Innovators suffer from a lack of investors and insufficient linkages within local economic systems. These barriers are powered by the lack of competence in advanced technologies such as machine learning, artificial intelligence, information security; the solution of that can be found in cooperation and partnership. Respondents defined that most important partners are financial and investment organizations, vendors of industrial automation, integrators and research centres. However, more than half of the respondents say that the partners are not ready for cooperation. Respondents hope for mutually beneficial cooperation, but there are barriers to communication: lack of formal structures or local associations. The ideology of IoT is a smart interaction, and the lack of such an interaction is pointed out by the majority of respondents [13].

Table 2

Industrial digitalization policies of Poland and Czech Republic

	Poland	Czech Republic
Challenges	1. Low salaries and the difference between GNP and GDP will be tackled through a reindustrialisation agenda; 2. The lack of investment for innovation and R&D; 3. Capital from different sources will be used to strengthen both industry and public sector institutions; 4. Foreign dependence; 5. Expected workforce shortages.	1. The lack of private investment for innovation and R&D; 2. Dependence of trade-off with Germany; 3. Expected workforce shortages; 4. Changing needs on the labour market, which together with the lack of technically skilled workforce in some of the engineering fields place the education system on the top priorities.
Objective	• Create a framework for digitising industry professional skills; • Build trust and share knowledge among stakeholders; • Promote the digitisation of industry; • Develop new business models for industry, material engineering, and automation processes; • Support the development of machine-to-machine and machine-to-human interfaces; • Promote integrated hardware and software solutions, ensuring data sovereignty and interoperability.	to enhance the ability of Czech companies to be involved in the global supply chain; to create business and social environment, in which the Czech economy can reach its full potential; to mobilize private sector, R&D and industry associations, and academia to actively participate in the implementation process.
Planned results	The overall objectives of the government for 2020 include: • increasing investment to over 25% of GDP; • increasing the share of R&D to 2% of GDP; • increasing the number of medium-sized and large enterprises to over 22 000; • increasing FDI in Poland by 70%; • improving the growth rate of industrial production, so as to exceed the growth rate of GDP; • setting GDP per capita of Poland at the level of 79% of the EU average.	At this stage, there are no results available. The main goal of the initiative is to create a business and social environment enabling all the Czech companies to sooner or later adapt on the changes and seize the new business opportunities arising from the Fourth Industrial Revolution.
Funding	A total planned investment of €235 billion over the next 25 years	At this stage, no model for private financing is in place.

The priority areas of the IoT are knowledge-intensive areas that require less funding – data analysis, software development, and some intelligent devices. That is, what can be successfully realized by both engineering companies and scientific teams, and where the main resource is qualified staff.

On January 17, 2018, the Cabinet of Ministers of Ukraine during its regular meeting approved the concept for the development of the digital economy and society of Ukraine for 2018–2020. According to the plan, within the next three years, the government will modernize digital infrastructure, promote the development of Internet technologies, and provide incentives for high-tech projects. The roadmap aims to cover 80 percent of the Ukrainian territory with broadband Internet by 2021 and carry out the digitalization of such sectors as education, medicine, ecology, infrastructure, and transport. Today, thanks to the digital economy, 22% of world GDP is created, and in China – 30% of its GDP ($3.4 trillion) [14]. According to the government's estimates, the planned digital economy development could increase the country's projected gross domestic product growth by 5 percent by 2021. Currently, about 35 percent of Ukraine's rural population has no access to the broadband Internet.

The integration of digital technologies in production processes, or the digitalization of industry, is a priority of state industrial policy. The state policy of stimulating the development of Industry 4.0 has three directions: the creation of Infrastructure of Industry 4.0 – industrial parks, industrial centres of technology; access to capital to create new innovative productions; development of digital skills for training personnel [14].

As for machine-building industry, due to digitalization production lines will reconfigure themselves automatically in order to optimise productivity. Some of that will be driven from above, with production lines responding dynamically to new or amended production orders, tying in seamlessly with logistics and the wider business. Some will be driven from the product itself, communicating with the line to determine the optimal route through the production process. For example, if there is a bottleneck at some point the production line, the product will recognize this and look to see if there are other processes that might be accomplished first, and instruct the line to reroute its progress [8].

Industry 4.0 also brings a higher degree of flexibility to the manufacturing process. This again is the logical next step to a process that has already taken us from mechanical line changeovers from one product type to another to push-button line reconfiguration. Under Industry 4.0, a single line will accommodate any type of product without the need for a changeover from one batch to another, for example through parts or products modifying robot profiles as they move along the line [10].

A case of successful digitalization of domestic machine-building enterprise is represented by state enterprise "FED" (Kharkiv) [15]. FED is one of the leading companies engaged in the production of components for aircraft engines and control systems for civil aviation purposes (actuators, power systems, components for high-lift control systems). The main users of our products in the Ukrainian market are JSC "Motor Sich", the designer bureau "Progress", Kharkiv Aviation Plant, SE "Antonov" and other Ukrainian enterprises. The company extensively cooperates with companies from Ukraine, Belarus, China, Czech Republic, and Canada [15].

With the goal of entering foreign markets, the company focused its business strategy on quality, innovation, and export. Managing these factors, as well as timing and price, was impossible without technological modernization, modern information technologies, and automation. Therefore, in 2011, the company launched a large-scale project on the implementation of an automated system for planning, accounting and analysis of Enterprise Resource Planning (ERP) business processes. And in 2013, FED launched a new project for the implementation of information technologies from IT-Enterprise-SmartFactory [15]. The digital transformation of the business using the elements of Industry 4.0 helped the enterprise to increase the capacity of the equipment and improve delivery time.

Then such modules were introduced: SmartFactory Production Management Modules (APS/MES, MRPII), PDM/PLM (design and technological preparation of production, archive of design and technological documentation), material inventory management, tool management, procurement management, controlling (scheduling and the actual cost price of the finished product), SmartManager (electronic document management of the enterprise). All these phases ensure integrated production management. In addition, IT-Enterprise modules for accounting and tax accounting, as well as personnel management and salary calculation, were introduced.

The first results of implementation were obtained during the year. Stability and reliability in terms management already then allowed the enterprise to guarantee the fulfilment of new orders from the world's leading aircraft manufacturers in the amount of more than hundreds of millions of dollars. The results of implementation at the end of 2017 are as follows:

1. The functionality of the system is implemented in full. As the main result, instead of the planned increase in throughput up to 10%, it increased to 15%. Production cycles at the same time reduced by an average of 25%.

2. The number of people involved in coordination tasks has decreased. For example, the dispatch service, previously engaged in planning tasks, was reduced from 10 to 2 people, while the amount of planning tasks increased several times.

3. Significantly increased the efficiency and productivity of all staff. The system eliminated unproductive losses of time and errors for various tasks of manual planning, coordination, preparation of production, and decision making at various levels. In general, the production planning process was reduced from a few days to a few minutes.

4. Annual sales growth of 30-70% pushes the growth of salary while maintaining high labour productivity.

Table 3

SWOT-matrix of digitalization of Ukrainian industry

STRENGTHS	WEAKNESSES
High developed IT sector High level of personnel education Scientific Potential of R&D centres and Universities The powerful basis of traditional sectors of manufacturing Suitable logistic for Ukrainian firms	Lack of vertical and horizontal integration Poor infrastructure Low salaries and expected work shortage The lack of private investments The concentration of financial resources at traditional sectors Digitalization is not a top priority for Ukrainian top managers Low productivity
OPPORTUNITIES	THREATS
Reducing trade barriers Increasing high-tech export Reducing production costs Reducing errors in planning Creating a more flexible research and educational system in line with labour market needs	Regress in traditional sectors of the economy Top-management resistance for changes Increasing competition on the Ukrainian market Data cybersecurity problems Standardisation and cybersecurity are not in line with global standards.

Analysis of experts' and researchers' opinion gives us the basis for creating SWOT-matrix of digitalization of Ukrainian industry.

Conclusions

The development of the digital economy and society of Ukraine is a crucial factor for the success of not only all reforms, but also Ukrainian business on the world stage. Ukraine is an important player in the global digital market, but unfortunately, solely as an exporter of IT services and brains.

High developed traditional sectors can be a good basis for providing elements of digitalization. For Ukraine, machine building is one of the most priority and export-oriented industries, where it already has world recognition. At the same time, our enterprises are critically in need of modernization and construction of modern digital models in management. Therefore, the sooner the machine-building enterprises will understand the importance of the development and implementation of enterprise resource planning systems, supply chain management systems, production process control systems (APS/MES-systems), and other enterprise management systems, the sooner Ukraine will take a step towards a strong industry.

REFERENCES:

1. R. Baheti and H. Gill, "Cyber-physical systems," The impact of control technology, pp. 161-166, 2011

2. Czech Republic: "Průmysl 4.0" Digital Transformation Monitor. May, 17 URL: https://ec.europa.eu/growth/tools-databases/dem/monitor/sites/default/files/DTM_Prumysl%2040_CZ%20v1.pdf

3. Demetrius Klitou, Johannes Conrads & Morten Rasmussen Key lessons from national industry 4.0 policy initiatives in Europe. Digital Transformation Monitor. May, 17 URL: https://ec.europa.eu/growth/tools-databases/dem/monitor/sites/default/files/DTM_Policy%20initiative%20comparison%20v1.pdf

4. European Commission 2014c: "Advancing Manufacturing – Advancing Europe": Report of the Task Force on Advanced Manufacturing for Clean Production, Commission Staff Working Document, SWD(2014) 120 final, Brussels.

5. German Federal Ministry of Education and Research, Zukunftsprojekt Industrie 4.0, available at https://www.bmbf.de/de/ zukunftsprojekt-industrie-4-0-848.html [accessed May 15, 2016]

6. Industry 4.0 in Europe. CBI. Ministry of Foreign Affairs URL:https://www.cbi.eu/market-information/outsourcing-itobpo/industry-40/

7. Kolberg, Dennis & ZГjhlke, Detlef. (2015). Lean Automation enabled by Industry 4.0 Technologies. IFAC-PapersOnLine. 48. 1870-1875. DOI: 10.1016/j.ifacol.2015.06.359.

8. McKinsey Industry 4.0 How to navigate digitization of the manufacturing sector. McKinsey Digital. 2015. URL: https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Operations/Our%20Insights/Industry%2040%20How%20to%20navigate%20digitization%20of%20the%20manufacturing%20sector/Industry-40-How-to-navigate-digitization-of-the-manufacturing-sector.ashx

8. McKinsey How to succeed: Strategic options for European machinery. Shifting growth patterns, increasing pace of digitization, and organizational change URL: https://www.mckinsey.com/~/media/McKinsey/Industries/Automotive%20and%20Assembly/Our%20Insights/How%20to%20succeed%20Strategic%20options%20for%20European%20machinery/How%20to%20succeed%20Strategic%20options%20for%20European%20machinery.ashx

9. Poland: Initiative for Polish Industry 4.0 – The Future Industry Platform. Digital Transformation Monitor. February, 2018. URL: https://ec.europa.eu/growth/tools-databases/dem/monitor/sites/default/files/DTM_Poland%20_vf.pdf

10. D. Rossek. Industry 4.0: a Machine Building perspective. Industrial Technology. March, 2015. (special issue) URL: https://www.industrialtechnology.co.uk/products--industry-40-a-machine-builders-perspective.html

11. K. Shirase and K. Nakamoto, "Simulation Technologies for the Development of an Autonomous and Intelligent Machine Tool," Int. J. Automation Technol., Vol. 7, No. 1, pp. 6-15, 2013

12. Smart Manufacturing Leadership Coalition, Implementing 21st Century Smart Manufacturing: Workshop Summary Report, Washington D.C., 2011.

13. Індустрія 4.0 в машинобудуванні: стан в Україні та перспективи розвитку. Аналітичний звіт. Асоціація підприємств промислової автоматизації України URL: https://industry4-0-ukraine.com.ua/2018/10/18/аналітичний-звіт-індустрія-4-0-в-машино/

14. Про схвалення Концепції розвитку цифрової економіки та суспільства України на 2018-2020 роки та затвердження плану заходів щодо її реалізації: розпорядження Кабінету Міністрів України від 17 січня 2018 р. № 67-р.

15. Система управления производством на предприятии ФЕД. IT-Enterprise.SmartFactory. URL: https://industry4-0-ukraine.com.ua/smart-factory/