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APPLICATION OF INTERNET OF THINGS IN INDUSTRY 4.0

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Introduction. Industry 4.0 is a concept that is considered a new phase in the Industrial Revolution, closely related to the application of information technologies and the digital transformation of manufacturing. The main purpose is to be created a more holistic and more connected ecosystem, focused on supply chain management in industrial companies. Implementation of solutions in Industry 4.0 is mostly related to the concept of the Internet of Things (IoT). Mass deployment of this type of technology in industrial enterprises is the basis of the so-called Industrial Internet of Things (IIoT). Achieving interoperability in the IIoT requires the combination of two technologies: the Internet of Things and the Internet of People.

Aim and tasks. This article describes the implementation of the concept of the Internet of Things in industrial enterprises, as a key technology factor for developing Industry 4.0.

Results. A brief overview of the evolution of industrial production - from the beginning of the Industrial Revolution to the emergence of Industry 4.0 is made. The main principles for implementing Industry 4.0 solutions ensure that the entire production process is computerized. Industry 4.0 solutions are mostly associated with the concept of the Internet of Things (IoT) whose definition and essence are obtained in this article. Based on the various concepts of the IoT are presented solutions that can be used in the industry, namely: in consumer devices in technology used in public organizations in infrastructure applications in industrial applications, also called the Industrial Internet of Things (IIoT). Therefore, we can say that there is a significant potential for improving production processes as regards: optimization of operations, forecasting equipment support, inventory optimization, improving workers' security, shipping chain optimization, etc.

Conclusions. The application of the Internet of Things in enterprises is an important and decisive step in the process of their digital transformation and transition to Industry 4.0. The interaction between humans and machines, carried out through Internet technologies, leads to the emergence of the Internet of Everything, which will be a basic concept in industrial production in the coming years. However, the role of man in the production process should not be completely eliminated, but solutions should be sought that support and intellectualize his work.

Keywords: Industry 4.0, Internet of Things, Industrial Internet of Things, supply chain.

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ЗАСТОСУВАННЯ ІНТЕРНЕТ РЕЧЕЙ В ІНДУСТРІЇ 4.0

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Вступ. Індустрія 4.0 – це концепція, яка вважається новим етапом промислової революції, тісно пов'язаним із застосуванням інформаційних технологій та цифровою трансформацією виробництва. Основна мета полягає у створенні більш цілісної та взаємопозв'язаної екосистеми, орієнтованої на управління ланцюгами поставок у промислових компаніях. Впровадження рішень в Індустрії 4.0 здебільшого пов'язане з концепцією Інтернету речей. Масове впровадження цього типу технологій на промислових підприємствах є основою так званого Індустріального Інтернету Речей. Досягнення сумісності в Індустріальному Інтернет речей вимагає поєднання двох технологій: Інтернету речей та Інтернету людей.

Мета і завдання. У цій статті описано реалізацію концепції Інтернету речей на промислових підприємствах як ключового технологічного чинника для розвитку Індустрії 4.0.

Результати. Зроблено короткий огляд еволюції промислового виробництва – від початку промислової революції до виникнення Індустрії 4.0. Основні принципи впровадження рішень Індустрії 4.0 забезпечують комп'ютеризацію всього виробничого процесу. Рішення Індустрії 4.0 здебільшого пов'язані з концепцією Інтернету речей, визначення та суть якої наведено в цій статті. На основі різних концепцій Інтернет речей представлені рішення, які можуть бути використані в галузі, а саме: в споживчих пристроях в технологіях, що використовуються в громадських організаціях, в інфраструктурних додатках в промислових додатках, які також називаються Індустріальним Інтернетом Речей. Тому можна сказати, що існує значний потенціал для вдосконалення виробничих процесів, що стосується: оптимізації операцій, підтримки обладнання для прогнозування, оптимізації запасів, підвищення безпеки працівників, оптимізації ланцюга судноплавства тощо.

Висновки. Застосування Інтернету речей на підприємствах є важливим і вирішальним кроком у процесі їх цифрової трансформації та переходу до Індустрії 4.0. Взаємодія між людьми та машинами, що здійснюється за допомогою Інтернет-технологій, призводить до появи Інтернету всього, що буде базовим поняттям у промисловому виробництві в найближчі роки. Однак роль людини у виробничому процесі не слід повністю виключати, а слід шукати рішення, що підтримують та інтелектуалізують його працю.

Ключові слова: Індустрія 4.0, Інтернет речей, Індустріальний Інтернет речей, ланцюги поставок.

Introduction. Industry 4.0 is a concept that is considered a new phase in the Industrial Revolution, closely related to the application of information technologies and the digital transformation of manufacturing. It is also called smart manufacturing and it reflects the symbiosis between physical production and operations with intelligent digital technology, machine learning, big data, the internet of things, etc. The main purpose is to be created a more holistic and more connected ecosystem, focused on supply chain management in industrial companies. Industry 4.0 implies not only investment in new technologies but changing the way business is operated and the attitudes of entrepreneurs to use technologies for growth and development [1]. Implementation of solutions in Industry 4.0 is mostly related to the concept of the Internet of Things (IoT) This is a system of interconnected computing devices equipped with unique identifiers and with the possibility of interacting both with each other and with the external environment without human intervention. As a result, a continuous flow of information is obtained to be used to optimize activities in business organizations. The Internet of Things is one of the fastest-growing technological trends, with estimated global revenue for 2021 expected to reach $ 520 billion [2]. Mass deployment of this type of technology in industrial enterprises is the reason to talk about the so-called Industrial Internet of Things (IIoT). Achieving interoperability in the Industrial Internet of Things requires the combination of two technologies: the Internet of Things and the Internet of People. As a result, Cisco [3] introduces the notion of the Internet to Everything (IOE).

Analysis of recent research and publications. Based on an overview of scientific literature on the subject, the article describes the evolution of industrial production and the main focus is on the fourth stage in its development - Industry 4.0. The fundamental principles of implementing solutions from Industry 4.0 are described, among which the concept of the Internet of Things is of the greatest importance.

The Industrial Revolutions – from Industry 1.0 to Industry 4.0

The transition from early primitive production to the present day passes through 4 significant industrial revolutions, and the next, fifth revolution, is in the very foreseeable future.

The industrialization of production began in England in the 18th century with the advent of the steam engine, which marked the beginning of the First Industrial Revolution. Until now, the main productive force has been human and animal labor, whose efficiency has not been high enough for the growing needs of the population. The first manufactories appeared, which grew into factories run by the newly emerging entrepreneurial class. The most developed industries during this period were the textile and mining industries and metallurgy, which introduced many other inventions powered by wind, water, and steam [4].

A new push to industry, which marked the beginning of the Second Industrial Revolution (technological revolution), gave the introduction of the Bessemer process for steel production, the application of electricity in the industry in the late 19th century, and at a later stage - the invention of conveyor lines and mass production. Thanks to the efforts of several scientists such as Volta, Faraday, Edison, Tesla, intermittent electricity becomes manageable and can successfully replace the previously used production forces. The use of electricity to drive machines increases production efficiency and makes them more mobile, as they are equipped with their energy sources. Mass production, production lines, and the division of labor also help to increase the capacity and efficiency of enterprises. Leading industries during this period were steel production, railway transport, and the chemical industry.

The third industrial revolution began in the late 1960s when the first electronic devices such as transistors appeared and began to be produced, and integrated circuit chips were created, and they enable machine automation and replacement of workers on the assembly line with computer operators.

The ubiquitous application of computers leads to the development of software systems that upgrade the capabilities of electronic hardware. The first specialized computer programs appeared, which allowed the planning and tracking of material and other resources needed for the production process. The new global network (Internet) as well as the need to use renewable energy sources, became the main prerequisites for the development of industry in the late 20th and early 21st century. The third industrial revolution is also associated with the processes of globalization, the opening of national economies, and relocation of production to countries with less developed economies, to achieve lower costs and higher efficiency [5].

The growing penetration of the Internet and information technology in manufacturing in the early 21st century marks the beginning of the Fourth Industrial Revolution, which gained popularity as Industry 4.0 [6-9]. It is associated with increasing the possibilities for digitalization and automation of production processes and the introduction of distributed computer calculations, increasing the capacity of computer systems.

Industry 5.0 is a future trend, but already entering our lives. The term was first introduced in December 2015 by Michael Rada [10]. It is characterized by closer cooperation between man and machine, including the widespread use of robots in production, as well as the introduction of waste-free technologies and the development of the circular economy. Bionics and biotechnology are introduced in the production process, which allows, based on biological sensors, to carry out better control, organization, and personalization of production.

Industry 4.0 – nature and characteristics

The term Industry 4.0, which is associated with the Fourth Industrial Revolution, was first used at the Hannover Messe trade fair in 2011 by Prof. Wolfgang Wahlster, who suggests that humanity is on the verge of a new revolution led by Internet technologies. In his address, he concluded that companies can be successful in regions with high wages and high competition if they move to the so-called. "Smart" enterprises [11].

The Federal Ministry of Economic Affairs and Energy in Germany defines Industry 4.0 as a basic platform that "networks industrial production by using state-of-the-art information and commutations technology in a smart manner" [12].

The concept of Industry 4.0 has 3 main components [13].

- First, "industry" defines its industrial orientation.
- Second, "0" is a reference to the generations of Internet technologies - Web 1.0, Web 2.0, Web 3.0, Web 4.0.
- Third, "4" stands for the Fourth Industrial Revolution.

Industry 4.0 is associated with connecting the Internet of Things to manufacturing techniques so that systems can exchange information, analyze it, and use it to direct intelligent action. It also includes cutting-edge technologies, including value-added production, robotics, artificial intelligence, modern materials, and augmented reality [14]. The main characteristics of Industry 4.0 are [15]:

1. Vertical networking – the processes in which information derived from digitalization leads to changes in the physical world, enabling businesses to respond quickly to changes in the environment, consumer requirements, inventory dynamics, or unexpected failures in the equipment. Intelligent enterprises are interconnected by their systems, which allows continuous interaction and adjustment of work.

2. Horizontal integration through global value-creation networks. The cycle of transformation of information flows between the physical, digital and again the physical environment allows a higher level of transparency. Companies can identify their problems more quickly and respond to them. Networks, within the organization, can record all operations in the chain, as well as record, analyze and evaluate every aspect of business process at any time.

3. Engineering of business processes related to product develempent and production activities. It covers the entire value chain and is carried throughout the product lifecycle. New synergies are emerging between product development and production systems.

4. Acceleration through exponential technologies – an increasingly autonomous and highly cognitive ecosystem is being created. It relies on technologies such as machine learning, deep neural networks, advanced robotics, and the industrial Internet of Things to further accelerate efficiency.

Fundamental principles for implementation of Industry 4.0 solutions

Daron Underwood, Vice President R&D defines 4 main principles of Industry 4.0 [16]:

1. Interoperability – refers to the ability of machines to connect and communicate with each other and with people via the Internet. Technologies related to the Internet of Things (IoT) and the Internet of People (IoP) are used, which are united in the so-called Internet of Everything (IoE).

2. Transparency in information - it requires information systems to be able to create virtual copies of the physical world by transforming digital data into sensory data. The merging of the physical and the virtual world allows the creation of an information model following the context. The information obtained is necessary for the participants in the IoE to meet the requirements addressed in the production process. The information must be available to all participants in the process in real-time.

3. Technical assistance – refers to the ability of information systems to assist people in making decisions and quickly dealing with problems, through comprehensive collection and visualization of data in a human-readable way. It also focuses on the ability of cyber systems and robotic components to replace humans in time-consuming, harmful, or exhausting tasks.

4. Decentralization of decisions – cyber-physical systems need greater autonomy which allows them to make their own decisions and perform their functions in a decentralized way. The solutions are distributed throughout the system to maximize response time and optimize flexibility while the system continues to operate. Decision-making can be transferred to a higher level in cases of accidents, disruptions, or conflicts with the set goals.

The concept Internet of Things

According to The International Telecommunication Union Internet of Things is "*A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.*" [17].

The term Internet of Things was first used by Keven Ashton in his presentation about Procter and Gamble in 1999 in the context of the application of radiofrequency interference in the company's supply chain [18]. The solution assumes that all information about "things" is collected and processed computerized, without human intervention. The concept was later developed by Cisco, who defined it as the time when Internet-connected objects would become more than human. Their research shows that this happened in 2008-2009 [19].

The definition has changed over the years, mainly due to the convergence of multiple technologies, real-time analysis, machine learning, commodity sensors, and embedded systems, but it always includes the use of one of the following technologies:

- to identify the object from the physical world – all "things" are provided with an interface or means for their identification in the network. For this purpose, in addition to RFID, bar codes, QR codes, real-time location tools, etc. can be used. For objects connected to the Internet, their MAC address and IPv6 addressing are applied;
- for measurement – they are mostly in the form of sensors and provide the conversion of data from the external environment into electronic while having the ability to perform calculations;
- for data transmission – all technologies for cable and wireless data transmission are included. Priority is given to the protocols of the IEEE 802.15.4 standard;
- for data processing – various processing techniques are used such as classification, sorting, filtering, calculation, etc., based on which the information collected from the items is transformed in a way that makes it more understandable to people or others, "Things" to which it will be retransmitted.

The basis of the ubiquity of the Internet of Things technology is three global technological trends: easy access to connectivity, in particular the Internet, the high computing power of modern computer systems and cloud computing, and the associated "big data".

Aim and tasks. The article describes the implementation of the concept of the Internet of Things in industrial enterprises, as a key technology factor for developing Industry 4.0. It presents the characteristics and peculiarities of Industry 4.0 and outlines the basic principles of its implementation in factories. The main focus is directed to describe the nature and characteristics of concepts Internet of Things and Internet of Everything and their application in industry.

Results. Based on the literature review, we can differentiate solutions based on the Internet of Things in the industry in several categories:

- Consumer devices – includes connected vehicles, home automation devices, smart homes, wearable devices for health monitoring, devices with remote monitoring.
- Technologies used in public organizations – medical devices for monitoring and notification, public transport, devices for control and monitoring of mechanical, electrical, and electronic systems in public buildings, etc.
- Infrastructure applications – monitoring and control of sustainable urban and rural infrastructure such as bridges, railways, street traffic, environmental monitoring, etc.
- Applications for industry, also called Industrial Internet of Things (IIoT).

IIoT has significant potential to improve production processes in the following areas [20].

- optimization of operations - allows a comprehensive view of the production process and taking corrective action by people, and in many cases – by machines;
- forecasting equipment maintenance – production equipment can be always monitored thanks to sensors and network connectivity. In this way, more efficient methods for machine maintenance can be planned, to increase production capacity and productivity;
- optimization of the inventory – using storage sensors the stocks are also monitored in real-time and if necessary, the necessary materials and consumables are ordered;
- improving worker`s safety - each worker is equipped with a location sensor and an NFC marker, which tracks his work with the machines and helps to create more efficient work schedules;
- supply chain optimization – sensors are installed along the entire supply chain, thus monitoring the movement of inventories and production at any time.

The main applications of the Industrial Internet of Things are [21]:

1. Autonomous vehicles – free-moving robots that can be coordinated and perform automated tasks in a controlled manner without human supervision.
2. Monitoring the usage of machines – important information about the performance of each machine is sent through the operator`s control panel and thus it is established which equipment works most efficiently.
3. Related tools – they increase productivity by eliminating human error.
4. Automation of buildings – reduce electricity costs by monitoring its consumption, adjusting lighting, optimizing heating, ventilation, and air conditioning, implementation of IIoT in fire safety systems.
5. Quality control of the production - high-resolution cameras, acoustic sensors, and highly efficient image processing software are used. They identify defects in the size, shape, and degree of completion, as well as check the correctness and legibility of labels, barcodes, and QR codes.
6. Smart logistics – using sensors to monitor assets once they leave the confines of the enterprise. Monitor their location, ambient temperature, humidity, and movement.
7. Wearable devices – used to monitor the safety of workers. For this purpose, sensors connected to the body record the environmental conditions and monitor the vital signs of the worker such as temperature, pulse, saturation, and respiratory rate.

The first sector to implement IoT was the Energy industry, where the global digital transformation has been completed.

The market size of IoT in the sector is expected to grow from $20.2 billion in 2020 to $35.2 billion by 2025 [22]. Next are the distribution systems for the transmission of oil, gas, electricity, and water. The manufacturing sector also makes the most of the technological capabilities of the Internet of Things, with manufacturers in all sectors connecting their factories to be more productive and efficient. The global income Industrial Internet of Things is estimated to be $77.3 billion in 2020 [23]. Another industry with widespread IoT technologies is agriculture, where farmers collect data on their crops and livestock in various ways. For example, sensors are used in agricultural machinery that connects them to the Internet, thus gaining access to data on crop yields, as well as information obtained from analyzes of when is the best time to plant certain crops Estimated revenue of the sector market is predicted to be $7 billion by 2025 [24-25].

The Industrial Internet of Things is influencing 3 technological trends that are applied in Bulgarian`s everyday lives: the introduction of sensors in the household, offering cheap storage options, and access to better equipment, providing easy and cheap communication channels.

The new, built-in sensors, combined with advances in connectivity, security, interoperability, and analysis, create potential opportunities to improve the production process. This creates additional competitive advantages for those manufacturing companies that implement this type of solution in their production processes.

One of the most innovative examples of implementation of IIoT in manufacturing is a usage of a robotic manufacturing arm that automatically attaches nuts to a bolt. The hand has a 3D laser scanner to identify the parts, take the correct nut, screw in the bolt nut, check and adjust the torque, and then move. The process includes many operations that are constantly monitored and controlled by many different sensors. All of them must transfer their data to a centralized server. Real-time software must automatically select the various torques for maximum efficiency [26-28].

Another solution related to IoT is the ability to monitor the quality of the atmospheric air or to ensure the rational use of water resources through smart devices that communicate with each other in real-time, connected to a complex cloud system. This is achieved through comprehensive monitoring and analysis of water consumption in the industrial sphere, which leads to a reduction of the company's costs and the achievement of an ecological effect on the environment [27-31].

The Industrial Internet of Things requires the combination of two technologies: the Internet of Things and the Internet of People which results in the concept of an Internet of Everything (IoE). IoE combines 4 basic elements called pillars: Things, Data, People, and Processes. The information from their interaction leads to decision-making and actions that create new capabilities, richer experiences, and unprecedented economic opportunities for people, businesses, and the state [32-33].

1. Things – they can be any objects from reality that contain embedded technology to interact with servers and the environment. They connect to a network and can communicate with each other via a secure and reliable platform, via Wi-Fi, Bluetooth, Cellular, and NFC. The devices are equipped with sensors that capture the physical aspects of the environment and transform them into an electronic signal, such as a temperature sensor, motion sensor, radiation sensor, etc. The sensors send the data to a device called a controller, which is responsible for collecting data and maintaining the Internet connection. The controller also decides if to take any action or to forward the data to another computer system.

2. Data – they are values related to everything around us. Data is everywhere, but very often in itself, it is useless. To be of people`s benefit, they must be interpreted and analyzed through correlations or comparisons which transform the data into useful information. When this information is applied and understood, it becomes knowledge.

3. People – the data itself is useless if not used by people. They help a person to make an informed decision and it is the person who creates added value in the economy. That is why people are one of the four pillars of the IoE. They are a central figure in any economic

system. They interact in their role as producers or consumers, with the common goal of improving their well-being by meeting their needs. Whether or not people are directly involved in the interaction, the data derived from the IoE serves to increase the value to humanity.

4. Processes – they have an important role in determining how the other 3 elements interact to add value. The right process makes connections relevant and adds value as the right information is delivered to the right person, at the right time, in the right way.

During this interaction 3 types of connections are formed:

- M2M (Machine to Machine), in which machines interact without human intervention;
- M2P (Machine to People), in which the machine connects with the person;
- P2P (People to People), in which people interact with each other.

The main areas affected by IoE are:

- user experience – customer relations are improved;
- innovation – reduces the time for which products are created that meet the specific needs of consumers and the market as a whole;
- worker productivity;
- optimization of assets, which reduces costs;
- deliveries – losses and delays in deliveries are identified, thus improving the efficiency of logistics.

To maximize the effect of the implementation of IoE, it is necessary for the company to invest in high-quality technologies and tools; adopt and follow inclusive staff practices; develop effective management practices.

The application of IoE in the industry depends on the type of formed interaction.

The M2M connection is based on sensors, actuators, and controllers. They must have a network connection for communication and to be programmed to instruct the device how to interpret data and how to transmit this data based on predefined parameters. M2M is used for remote asset monitoring, maintenance forecasting, and flexible manufacturing.

Humans are an important element in IoE, especially when using the data collected by M2M. M2P-type connections appear, which help management to make optimal decisions. Their application in the industry is for operations analysis, real-time supply chain management, IT achievement, and physical security.

To achieve full interaction within the IoE, it is necessary to provide connections between people of the P2P type. In the manufacturing sector, they are used for remote expertise in joint product development and mobile collaboration throughout the enterprise.

Conclusion. To meet the growing needs of consumers and achieve high competitiveness, the modern industrial enterprise must take advantage of all technological innovations that can increase its efficiency, speed up the production process and automate labor-intensive and routine operations. The application of the Internet of Things in enterprises is an important and decisive step in the process of their digital transformation and transition to Industry 4.0. However, the role of man in the production process should not be completely eliminated, but solutions should be sought that support and intellectualize his work. The interaction between humans and machines, carried out through Internet technologies, leads to the emergence of the Internet of everything, which will be a basic concept in industrial production in the following years.

REFERENCES

1. Epicor (2020). What is Industry 4.0 – the Industrial Internet of Things (IIoT)? https://www.epicor.com/en/resource-center/articles/what-is-industry-4-0/

2. Bain & Company (2018, August 8). *Bain & Company predicts the Internet of Things market will more than double to $520 billion by 2021*. https://www.bain.com

3. Evans, D. (2012). The Internet of Everything How More Relevant and Valuable Connections Will Change the World. Cisco Internet Business Solutions Group.

4. Deane, P. (1979). *The First Industrial Revolution*. Cambridge University Press.

5. Shherev, N. (2018). Razvytye na yndustryjata v Bъlgharyja – sъstojanye y prespektyvy. *Predyzvykatelstva pred yndustryalnyja rastezh v Bъlgharyja*, (pp. 13-23). Sofyja [In Bulgarian].

6. Ramazanov, S. Petrova, M. (2020). Development management and forecasting in a green innovative economy based on the integral dynamics model in the conditions of «Industry - 4.0». *Access to science, business, innovation in digital economy,* ACCESS Press, 1(1), 9-30. https://doi.org/10.46656/access.2020.1.1(1)

7. Ramazanov, S., Stemplewska, L. (2020). Decision-making in conditions of dilemma: risks and mixed information uncertainty. *Access to science, business, innovation in digital economy,* ACCESS Press, 1(2): 112-121, https://doi.org/10.46656/access.2020.1.2(3)

8. Linde, I., Philippov, D. (2021). What do your customers think about? To guess or to know? *Access to science, business, innovation in digital economy*, ACCESS Press, 2(1), 17-27. https://doi.org/10.46656/access.2021.2.1(2)

9. Petrova, M., Aleksandrov, M. (2018). *Automating the virtual hosts maintenance in a multi-site environment,* International Congress on Business and Marketing (ICBM'18), Marmara Eğitim Köyü Maltepe / İstanbul, TÜRKİYE, Proceedings of the International Congress on Business and Marketing, 2018 Maltepe University, Istanbul, 392-404.

10. Rada, M. (2015, December 1). INDUSTRY 5.0 - from virtual to physical. https://www.linkedin.com/pulse/industry-50-from-virtual-physical-michael-rada/

11. Lydon, B. (2014, February 19). The 4th Industrial Revolution, Industry 4.0, Unfolding at Hannover Messe 2014. Retrieved from https://www.automation.com

12. Federal Ministry of Economic Affairs and Energy. (2021, July). Federal Ministry of Economic Affairs and Energy. Retrieved from Frequently asked questions on Industrie 4.0: https://www.bmwi.de/Redaktion/EN/FAQ/Industrie-4-0/faq-industrie-4-0.html

13. Ovcharova, Zh. (2018). Vnedrjavane na Yndustryja 4.0 v malkyte y sredny predpryjatyja: mynymyzyrane na ryskovete y opredeljane na vъzmozhnostyte. In B. s. kamara, Yndustryja 4.0 – predyzvykatelstva y posledycy za ykonomycheskoto y socyalnoto razvytye na Bъlgharyja (pp. 5-11). Sofyja: Fondacyja Frydrykh Ebert, Bjuro Bъlgharyja [In Bulgarian].

14. Sniderman, B., Mahto, M., & Cotteleer, M. J. (2016). *Industry 4.0 and manufacturing ecosystems. Exploring the world of connected enterprises.* Westlake, TX: Deloitte University Press.

15. Deloitte. (2015). *Industry 4.0. Challenges and solutions for the digital transformation and use of exponential technologies*. Zurich: Deloitte AG.

16. Underwood, D. (2017, April 24). Industry 4.0: Key Design Principles. Retrieved from https://www.automate.org: https://www.automate.org/editorials/industry-4-0-key-design-principles

17. The International Telecommunication Union. (2012). Recommendation ITU-T Y.2060.

18. Elder, J. (2019, August 20). How Kevin Ashton named The Internet of Things. https://blog.avast.com/kevin-ashton-named-the-internet-of-things

19. Evans, D. (2011). The Internet of Things How the Next Evolution of the Internet Is Changing Everything. CISCO White Paper. http://www.cisco.com/web/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf

20. Marynova, N. (2020). Potencyal na yndustryalnyja Ynternet na neshhata za podobrjavane na proyzvodstvenyte procesy. Nauchno-praktycheska konferencyja „Ykonomykata na Bълgharyja – 30 ghodyny sled nachaloto na promenyte“ (pp. 445-452). Svyshhov: AY Cenov. [In Bulgarian].

21. Avent Abacus (2020). 7 game-changing Industrial IoT applications. https://www.avnet.com

22. Markets and Markets (2020, May). *Internet of Things (IoT) in Energy Market*. https://www.marketsandmarkets.com/Market-Reports/iot-energy-market-251659593.html

23. Statista (2021, March 10). *Industrial Internet of Things market size worldwide from 2017 to 2025**. Retrieved from https://www.statista.com: https://www.statista.com/statistics/611004/global-industrial-internet-of-things-market-size/

24. Lazova, V. (2020, 01 20). Kak ynternet na neshhata transformyra yndustryyte. Retrieved from https://enterprise.bg: https://enterprise.bg/blog-news/iot-industriya

25. Statista.com (2021). *Agricultural IIoT market revenue worldwide 2020-2025*. https://www.statista.com/statistics/1222813/worldwide-agricultural-industrial-iot-market-value

26. Anghelov, A. (2019, 12 02). Yzkustvenyjat yntelekt (AI), Yndustryalnyjat ynternet na neshhata (IIoT) y gholemyte danny (BIG Data) – kljuchovy faktory pry vъvezhdane na Industry 4.0. https://it.dir.bg/pr-zone/izkustveniya-intelekt-ai-industrialniya-internet-na-neshtata-iiot-i-golemite-danni-big-data-klyuchovi-faktori-pri-vavezhdane-na-industry-4-0

27. Profit.bg (2021, 01 7). Kak Ynternet na neshhata pomagha za podobrjavane na kachestvoto na vъzdukha? https://profit.bg/kak-internet-na-neshtata-pomaga-za-podobryavane-na-kachestvoto-na-vazduha

28. Shmygol, N., Schiavone, F., Trokhymets, O., Pawliszczy, D., Koval, V., Zavgorodniy, R., Vorfolomeiev A. (2020). *Model for assessing and implementing resource-efficient strategy of industry*. CEUR Workshop Proceedings, 2713, 277-294.

29. Tsimoshynska, O., Koval, M., Kryshtal, H., Filipishyna, L., Arsawan, W. E., & Koval, V. (2021). Investing in road construction infrastructure projects under public-private partnership in the form of concession. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, 2, 184–192. https://doi.org/10.33271/nvngu/2021-2/184

30. Mikhno, I., Koval, V., Korenyuk, P., Smutchak, Z., & Bozhanova, V. (2021). Modeling corporate games to increase the ecological value of entrepreneurship and innovative business. *E3S Web of Conferences*, 255, 01027.

31. Bublyk, M.I. (2013). Economic evaluation of technogenic losses of business entities on fuzzy logic based opportunities. In: Agnieszka Strzelecka (Ed.). *Zarzadzanie organizacja w warunkach niepewnosci.* (pp. 19-29). Chestochowa: Politechnika Chestochowska, Wydzial Zarzadania.

32. Kuzmin, O., Bublyk, M., Shakhno, A., Korolenko O., & Lashkun H. (2020). Innovative development of human capital in the conditions of globalization. *E3S Web of Conferences*, 166, 13011. https://doi.org/10.1051/e3sconf/202016613011

33. Kuzmin O.Ye., Bublyk M.I., & Rybytska O.M. (2014). The application of fuzzy logic to forecasting of technogenic damage in the national economy. *Bulletin of Lviv Polytechnic National University*, 790, 63 – 73.