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IMPACT OF THE INDUSTRY 4.0 PARADIGM ON KEY SOFTWARE REQUIREMENTS

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Abstract. The main characteristic of the Industry 4.0 concept is the increased intelligence of the technologies used. Innovative technologies impose new requirements on products, on production processes and, accordingly, on the requirements design methodology. This article discusses the key technologies specific to the Industry 4.0 paradigm, their associated key requirements, the impact of these requirements on the composition of requirements engineering documentation, and the key business analyst skills required to work within the Industry 4.0 concept. The object of the study is the impact of the key technologies of Industry 4.0 on the process of forming and changing product requirements. The research method is the analysis of the available scientific literature on this issue and the construction of a hypothesis on this basis. As a result of the study, key product requirements were identified in terms of Internet of Things (IoT) technologies, and the necessary skills for business analysts to work with these requirements were formulated.

Keywords: Industry 4.0, Internet of Things, IoT, requirements development, RE, cyberphysical system, CPS

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ВЛИЯНИЕ ПАРАДИГМЫ ИНДУСТРИИ 4.0 НА ОСНОВНЫЕ ТРЕБОВАНИЯ К ПРОГРАММНОМУ ОБЕСПЕЧЕНИЮ

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Аннотация. Основной характеристикой концепции «Индустрия 4.0» является повышенный интеллект используемых технологий. Инновационные технологии предъявляют новые требования к продукции, к производственным процессам и, соответственно, к методологии проектирования требований. В этой статье обсуждаются ключевые технологии, характерные для парадигмы Индустрии 4.0, связанные с ними ключевые требования, влияние этих требований на состав документации по разработке требований, а также ключевые навыки бизнес-аналитика, необходимые для работы в рамках концепции Индустрии 4.0. Объектом исследования является влияние ключевых технологий Индустрии 4.0 на процесс формирования и изменения требований к продукции. Метод исследования заключается в анализе доступной научной литературы по данному вопросу и построении на этой основе гипотезы. В результате исследования были определены ключевые требования к продукту с точки зрения технологий Интернета вещей (IoT), а также сформулированы необходимые навыки бизнес-аналитиков для работы с этими требованиями.

Ключевые слова: индустрия 4.0, интернет вещей, IoT, разработка требований, RE, киберфизическая система, CPS

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Introduction

The fourth industrial revolution (Industry 4.0) involves a new approach to production based on the massive introduction of information technology into industry, large-scale automation of business processes, and the spread of artificial intelligence. Industry 4.0 is based on the Industrial Internet of Things (IIoT) and cyber-physical systems - intelligent autonomous systems that use computer algorithms to monitor and control physical objects such as machines, robots and vehicles. A further development of the paradigm is the involvement of the end consumer in the process of developing new products, forming requirements for them, i.e. a certain level of customization of production. Accordingly, the process of developing product requirements and the overall approach to change management is changing. The purpose of this article is to identify how the key technologies of industry 4.0 are changing the process of creation and subsequent operation of requirement engineering (RE).

Literature Review

There are nine fundamental technologies (autonomous robots, simulation/digital twins, horizontal and vertical systems integration, industrial Internet of Things, cloud computing, additive manufacturing, big data and artificial intelligence analytics, cybersecurity, augmented reality) in Industry

4.0 (Thames and Schaefer, 2016). Their unification into one coherent system will allow to develop the concept of Industry 4.0 and ensure a new level of production efficiency, uniting partners in a common value chain and implementation of innovative business models (Roblek et al., 2016).

Industry 4.0 makes processes faster, more flexible and more efficient, which ultimately increases a company's competitiveness (Mohamed, 2018). The data obtained from the IoT sensor system and other sources and the subsequent analytics of the received data are used for decision support and thus directly affect the requirements engineering process. The applied technologies make it possible to speed up prototyping, increase flexibility, and introduce equipment that will adjust its parameters (Russmann et al., 2015). In a broad sense, Industry 4.0 characterizes the current trend in the development of automation and data exchange, which includes cyber-physical systems, the Internet of Things and cloud computing. It represents a new level of organization of production and management of the value chain throughout the entire life cycle of manufactured products (Rossini et al., 2021).

The concept of Industry 4.0 affects consumer perception of innovative products, quality, variety and speed of delivery. To increase the value of the product, the Product Service-System (PSS) is being implemented, self-learning algorithms and intelligent decision support systems are used. Cybernetic systems such as Product-Service System (PSS) and Cyber-Physical Systems (CPSs) are based on the use of information and communication technologies in the implementation of business models. All this makes it possible to reduce uncertainty, increase work efficiency, and timely detect bottlenecks (Zheng et al., 2018). The result is intelligent manufacturing, allowing many new features to be added to existing products. Customers have the opportunity to order a product with their own design, change their requirements and, as a result, receive a unique and relevant product in real time (Chawla et al., 2020).

The success of Industry 4.0 depends solely on engineering that can combine existing technological and digital solutions into a single complex, into what is called “cyber-physical systems”. Industry 4.0 is a challenge primarily for companies operating in the field of industrial engineering (Sony, 2020).

The main competitive advantages of Industry 4.0 are associated with the exclusion of the human factor as the weakest link in the production process (Brozzi et al., 2020):

1. High product quality due to automation and robotization of production, the absence of rejected products, in case of unprofitability of robotic solutions in the transition period - preventive elimination of defects through the digitalization of production processes.
2. High production efficiency due to accelerated automated implementation of new technological and production solutions.
3. High planning of future workload of enterprises, cost reduction due to optimization of resource-intensive processes, planning of operating costs, use of predictive analytics.
4. The transition to horizontal integration of production processes, in which the production cycle is distributed among several companies that produce similar goods / services in the same production niche.
5. High flexibility of production processes, fast automated changeover leads to customization of the product line.
6. Full production load by minimizing equipment downtime and industrial accidents.
7. Direct interaction "product - consumer", automatic collection and machine processing of data, incl. marketing. Optimization of production both for the production of non-standard products with specified technical characteristics (personalized production), and for performing standard operations.

CPS is an infrastructural foundation that should become the basis for the implementation of the scenario for the development of future production. The main task of the development of cyber-physical systems can be called a deep interaction between the physical and digital elements of the system. Hence, the main technological areas that critically affect the formation of CPS are IoT / IIoT data exchange technologies (Kl tzer and Pflaum, 2015). Information processing is provided by a whole range of tools from analysis based on Big Data and more complex tools of predictive analytics and Data Mining, focused on logical sequences that are already inaccessible to humans, to artificial intelligence with its inherent self-learning methods (artificial neural networks, deep/shadow learning). The issue of including the listed analysis technologies in CPS is debatable, they are redundant for the implementation of a typical technical process, but, on the other hand, change management in these processes is impossible without them. The executive body in the system can be a person or a machine: a machine is a robot or machine, here the interaction is based on M2M technologies, now such tasks are effectively solved by machine learning (Mishra and Tyagi, 2022). A person in CPS is redundant, although interaction with the digital world at this level is not difficult and is built on the basis of traditional interfaces or solutions VR, AR, MR (virtual, augmented, mixed reality), nevertheless, this level is no longer included in the CPS technosphere.

From the point of view of practice, we are talking about the integration of information and operational technologies. Integration can be carried out in two directions:

1. Business applications use technological data;
2. Technological tasks are optimized taking into account business information

One of the fundamental technologies on which the concept of Industry 4.0 is based is the Internet of Things. Building an IoT system requires taking into account new specific requirements, such as scalability, interoperability and a new level of security. Security and privacy are the most important requirements, therefore, they should be taken into account at an early stage of the requirements engineering process (Gulzar and Abbas, 2019). In addition, resource control, energy awareness and efficiency, quality of service, flexibility are considered as one of the important issues in requirements engineering (Yaqoob et al., 2019). As the number of devices increases, accounting for and meeting these requirements becomes more difficult.

The process of forming requirements and managing them is one of the most important stages of preparation, on which the success of creating and completing engineering projects depends (Ilyin and Ilyashenko, 2018). How accurately the requirements are formulated, and how the requirements engineering process is organized, depends on the success of creating complex systems and products. Requirements define the goals, constraints, necessity, functions, and prerequisites for the product to be developed (Ilin et al., 2018). Requirements engineering combines requirements generation and management. The first part is the collection, extraction, fixation, transformation, specification and analysis of requirements using various approaches, methods and notations. The second part is systematization (distribution) and building links between requirements using attributes. Its purpose is tracing to control and analyze changes. The requirements management process is part of requirements engineering and is divided into several parts, including the identification, discovery, documentation, analysis, tracing, and prioritization of requirements. It also covers requirements agreement and change management with notification to relevant stakeholders, is continuous, and spans the entire development project lifecycle (De Lucia and Qusef, 2010; Kasauli et al., 2021; Shah and Patel, 2014).

Materials and Methods

The purpose of the study is to analyze existing information, generate ideas and conduct new research. The research approach is to create a theory. Data collection was carried out by collecting materials (scientific articles) on the topics of Industry 4.0, cyber-physical systems and, mainly, the Internet of things. The data found was then analyzed and selected based on its relationship to requirements engineering and relevance to the current state of development of CPS and IoT technologies.

First, the Industry 4.0 paradigm has been expressed through another CPS entity that is at its core and has some more specific attributes that can be described. The basics of CPS were learned and then further decomposed into IoT technology, which has even more specific attributes related to functional requirements. After that, the relationship between CPS, IoT and requirements engineering was analyzed, and ways to change RE within Industry 4.0 were obtained.

Results and Discussion

In order to understand the relationship between the Industry 4.0 paradigm and requirements engineering, it is necessary to understand the components of Industry 4.0.

According to Drath and Horch, "Industry 4.0" can be understood as the application of the general concept of cyber-physical systems to industrial production systems (cyber-physical production systems) (Drath and Horch, 2014). A cyber-physical system is a complex system of computational and physical elements that constantly receives data from the environment and uses them to further optimize control processes. Networks and computers monitor and control physical processes, typically with feedback loops in which physical processes affect computations and vice versa (Alguliyev et al., 2018; Lee et al., 2019). CPS provides a number of benefits to the industry. First, CPS allows to see the most important data that is generated in real time. This helps to understand critical issues and take preventive action or make some other important decision. Secondly, the level of automation of various processes is increased through the use of autonomous decision-making algorithms that can work in situations with an obvious solution.

There are the following predictions that represent the future of Industry 4.0 and drive the development of CPS:

1. The communication infrastructure in production systems will be implemented everywhere.

2. Field devices, machines, plants, factories and even individual products will be connected to the network (Internet or private network) and will be able to store knowledge about themselves outside their physical body on the network.

Based on these forecasts, the most important components of CPS and the Industry 4.0 paradigm can be identified:

1. Physical objects (instruments, machines, plants, factories, products).
2. Tools that connect physical objects to the network.
3. Network to which physical objects are connected.
4. Virtual data models of the specified physical objects.
5. Services based on available data.

According to Camarinha-Matos et al, the Internet of Things can be considered as a subset of CPS (Camarinha-Matos et al., 2013). The IoT can be represented through the first three components of the CPS highlighted above. IoT has more specific attributes than CPS, which helps to understand its impact on requirements engineering (Camarinha-Matos and Katkoori, 2021). Thus, we will focus more on IoT in terms of results as shown in the figure below.

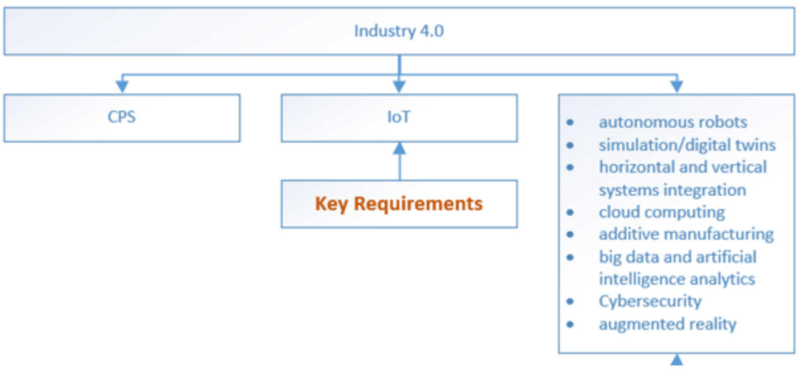

Fig. 1. The place of key product requirements in the Industry 4.0 paradigm

The idea of the Internet of Things is to connect not only people and computers, but also everyday objects to the Internet. This can be achieved by equipping things with computing and communication capabilities, thus fully matching the physical world with the digital one (Yaqoob et al., 2019). IoT components include sensors, controllers, actuators that help generate data from a physical object, process and transmit it, and perform appropriate actions. All these things and the network that provides communication between them form the IoT architecture. Each IoT application has its own optimal architecture, but there are some basic requirements that apply to almost any project. These requirements differ from those considered in pure software development projects due to some new components - smart things (Kim et al., 2016). Thus, IoT is associated with such functional requirements as scalability, flexibility, interoperability, diverse support for quality of service and, most importantly, security (Hazra et al., 2021).

The requirements of scalability, interoperability and security in the IoT concept can be considered as the main ones that can change the RE process.

The term "scalable" means managing the connectivity of a large number of network devices. The requirement for scalability is important because an IoT application involves the installation of many smart things: sensors, controllers, actuators. These devices must be synchronized and connected to each other and/or to the server/cloud. The number of devices dependent on each other and using the same network can be huge, which can lead to performance degradation.

Interoperability ensures compatibility between different devices and networks. In the IoT paradigm, enabling communication between devices from different vendors is a key requirement (Aftab et al., 2020; Kim et al., 2016). Nowadays, there are many vendors who produce and sell all kinds of smart things with different price, quality and features. Therefore, it is likely that businesses may use devices from different manufacturers (Ilin et al., 2019). This can lead to a serious issue where devices do not sync and communicate properly. Another problem that can lead to failure in the exchange of data between smart things is related to the network and, in particular, to the adaptation of network protocols that allow communication between devices (D. Borremans et al., 2018). Presetting the compatibility requirements with all the necessary details helps to avoid this problem.

Security is an important requirement in the IoT environment. Data generated by smart things can get to attackers and be used to harm a company using IoT. This situation can easily outweigh the benefits of the technology and force a company to stop using it. This is why the IoT architecture must be secure enough to prevent devices from being activated by unauthorized means. In addition, security mechanisms should be lightweight, since the resources of most devices are limited (Ilin et al., 2017).

As mentioned above, these requirements can be classified as functional. Based on this fact, it is possible to conclude that the main requirements document that is changed by the IoT application is the Software Requirements Specification (SRS). The SRS differs from other documents in that it contains a very specific description of the requirements rather than a general idea of the system. In SRS, business analysts describe in detail the solution being created, including functional and non-functional requirements. Thus, when creating an IoT solution, the focus in SRS should be on scalability, interoperability, and security.

It has been found that the SRS document changes to meet the requirements of the IoT, but this change is not the only one that affects the RE. To be able to create SRS documents, business analysts need to understand in detail all aspects related to the most important requirements. Therefore, they require new knowledge and skills related to scalability, interoperability, security. To solve the problem of scalability, business analysts must gain knowledge in the field of systems analysis. Systems analysis can be viewed as a problem-solving technique that breaks down a system into its component parts in order to study how well these component parts work and interact to achieve their goal (Fayoumi and Williams, 2021; Tilley, 2019). Knowledge in this area is necessary when considering a complex system with a large number of different components in detail. Business analysts also need to be familiar with system architecture. The architecture of systems is closely related to all stated requirements. It allows to connect many smart things and make them work together, helps to integrate devices from different manufacturers into one network, and makes it possible to protect data from unauthorized access.

The system architecture helps to establish relationships between all the components so that it becomes clear to all stakeholders how all the components of the system will function together. The problem of interoperability is mainly related to the integration of various devices into a single system. Another area requiring the attention of business analysts is cybersecurity. Knowledge in this area helps to specify the requirements so that the end system can be classified as secure enough to process and store data from IoT sensors.

There are challenges that arise when developing requirements for IoT solutions.

For a system with a huge number of components that can be randomly integrated into different systems at different times, the complexity of defining requirements, in particular security and privacy requirements, is a significant problem.

The main barriers to defining and analyzing IoT privacy and security are:

1. The complexity of determining the composition of the information that needs to be protected, determining to whom to provide / restrict access and the moment of information protection.

2. The difficulty of accurately determining the mutual influence of Internet of Things technologies and determining what new risks and problems this mutual influence can lead to (Sutcliffe and Sawyer, 2013).

3. The changing nature of the environment plays an important role in dealing with IoT privacy and security vulnerabilities.

This study focuses mainly on IoT technology, since it is one of the key parts of Industry 4.0 and has the most specific attributes that change the development of requirements. Further research related to this topic is possible, with a focus on other key Industry 4.0 technologies such as the digital twin, decision-making algorithms, and machine learning.

At the moment, there is a lack of a sufficient amount of archival material on the topic related to the impact of these technologies on the requirements of the engineering field. It is also promising to discuss how CPS affects the collection and analysis of non-functional requirements. There are many points of view on how Industry 4.0, CPS and IoT relate to each other. This issue is also of interest for further research.

Conclusions

The future of manufacturing is moving towards Industry 4.0. This paradigm is closely related to IoT technology. The use of IoT is associated with the increasing importance of functional requirements such as scalability, interoperability and security. This requires several changes in how requirements are developed. The major changes affect the documentation of the Software Requirements Specification and the skills that business analysts need to have in order to understand the identified requirements in detail and, as a result, give a consistent and complete description of the system being developed.

REFERENCES

Bartodziej C.J. 2017. The concept Industry 4.0, in: Bartodziej, C.J. (Ed.), The Concept Industry 4.0: An Empirical Analysis of Technologies and Applications in Production Logistics, BestMasters. Springer Fachmedien, Wiesbaden, pp. 27–50. https://doi.org/10.1007/978-3-658-16502-4_3

Aftab H., Gilani K., Lee, J., Nkenyereye L., Jeong S., Song J. 2020. Analysis of identifiers in IoT platforms. Digital Communications and Networks 6, 333–340.

Alguliyev R., Imamverdiyev Y., Sukhostat L. 2018. Cyber-physical systems and their security issues. Computers in Industry 100, 212–223.

Brozzi R., Forti D., Rauch E., Matt D.T. 2020. The advantages of industry 4.0 applications for sustainability: Results from a sample of manufacturing companies. Sustainability 12, 3647.

Camarinha-Matos L.M., Goes J., Gomes L., Martins J. 2013. Contributing to the Internet of

Things, in: Camarinha-Matos, L.M., Tomic, S., Graca, P. (Eds.), Technological Innovation for the Internet of Things, IFIP Advances in Information and Communication Technology. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 3–12. https://doi.org/10.1007/978-3-642-37291-9_1

Camarinha-Matos L.M., Katkoori S. 2021. Challenges in IoT Applications and Research, in: IFIP International Internet of Things Conference. Springer, pp. 3–10.

Chawla V., Angra S., Suri S., Kalra R. 2020. A synergic framework for cyber-physical production systems in the context of industry 4.0 and beyond. International Journal of Data and Network Science 4, 237–244.

Borremans A.D., Zaychenko I.M., Iliashenko O.Yu. 2018. Digital economy. IT strategy of the company development. MATEC Web of Conferences 170, 01034. https://doi.org/10.1051/matecconf/201817001034

De Lucia A., Qusef A. 2010. Requirements engineering in agile software development. Journal of emerging technologies in web intelligence 2, 212–220.

Drath R., Horch A. 2014. Industrie 4.0: Hit or Hype? [Industry Forum]. Industrial Electronics Magazine, IEEE 8, 56–58. https://doi.org/10.1109/MIE.2014.2312079

Fayoumi A., Williams R. 2021. An integrated socio-technical enterprise modelling: A scenario of healthcare system analysis and design. Journal of Industrial Information Integration 23, 100221.

Gulzar M., Abbas G. 2019. Internet of things security: a survey and taxonomy, in: 2019 International Conference on Engineering and Emerging Technologies (ICEET). IEEE, pp. 1–6.

Hazra A., Adhikari M., Amgoth T., Srirama S.N. 2021. A comprehensive survey on interoperability for IIoT: taxonomy, standards, and future directions. ACM Computing Surveys (CSUR) 55, 1–35.

Ilin I., Frolov K., Bolobonov D. 2017. The Role of the Internet of Things in Innovative Business Models 11.

Ilin I., Lepekhin A., Levina A., Iliashenko O. 2018. Analysis of Factors, Defining Software Development Approach, in: Murgul, V., Popovic, Z. (Eds.), International Scientific Conference Energy Management of Municipal Transportation Facilities and Transport EMMFT 2017. Springer International Publishing, Cham, pp. 1306–1314. https://doi.org/10.1007/978-3-319-70987-1_138

Ilin I., Levina A., Borremans A., Kalyazina S. 2019. Enterprise architecture modeling in digital transformation era, in: Energy Management of Municipal Transportation Facilities and Transport. Springer, pp. 124–142.

Ilyin I.V., Ilyashenko V.M. 2018. Formation of requirements for a reference architectural model for the digital transformation of a medical organization. Nauchnyj vestnik Uznogo instituta menedzhmenta 82–88. https://doi.org/10.31775/2305-3100-2018-4-82-88

Kasauli R., Knauss E., Horkoff J., Liebel G., de Oliveira Neto F.G. 2021. Requirements engineering challenges and practices in large-scale agile system development. Journal of Systems and Software 172, 110851.

Kim J., Yun J., Choi S.-C., Seed D.N., Lu G., Bauer M., Al-Hezmi A., Campowsky K., Song J. 2016. Standard-based IoT platforms interworking: implementation, experiences, and lessons learned. IEEE Commun. Mag. 54, 48–54. https://doi.org/10.1109/MCOM.2016.7514163

Klotzer C., Pflaum A. 2015. Cyber-physical systems as the technical foundation for problem solutions in manufacturing, logistics and supply chain management, in: 2015 5th International Conference on the Internet of Things (IOT). IEEE, pp. 12–19.

Lee J., Azamfar M., Singh, J. 2019. A blockchain enabled Cyber-Physical System architecture for Industry 4.0 manufacturing systems. Manufacturing letters 20, 34–39.

Mishra S., Tyagi A.K. 2022. The role of machine learning techniques in internet of things-based cloud applications, in: Artificial Intelligence-Based Internet of Things Systems. Springer, pp. 105–135.

Mohamed M. 2018. Challenges and benefits of industry 4.0: An overview. International Journal of Supply and Operations Management 5, 256–265.

Roblek V., Mesko M., Krapez A. 2016. A complex view of industry 4.0. Sage open 6, 2158244016653987.

Rossini M., Costa F., Tortorella G.L., Valvo A., Portioli-Staudacher A. 2021. Lean Production and Industry 4.0 integration: how Lean Automation is emerging in manufacturing industry. International Journal of Production Research 1–21.

Russmann M., Lorenz M., Gerbert P., Waldner M., Justus J., Engel P., Harnisch M. 2015. Industry 4.0: The future of productivity and growth in manufacturing industries. Boston consulting group

9, 54–89.
Shah T., Patel S. 2014. A review of requirement engineering issues and challenges in various software development methods. International Journal of Computer Applications 99, 36–45.
Sony M. 2020. Design of cyber physical system architecture for industry 4.0 through lean six sigma: Conceptual foundations and research issues. Production & Manufacturing Research 8, 158–181.
Sutcliffe A., Sawyer P. 2013. Requirements elicitation: Towards the unknown unknowns, in: 2013 21st IEEE International Requirements Engineering Conference (RE). Presented at the 2013 IEEE 21st International Requirements Engineering Conference (RE), IEEE, Rio de Janeiro-RJ, Brazil, pp. 92–104. https://doi.org/10.1109/RE.2013.6636709
Thames L., Schaefer D. 2016. Software-defined cloud manufacturing for industry 4.0. Procedia cirp 52, 12–17.
Tilley S. 2019. Systems analysis and design. Cengage Learning.
Yaqoob I., Hashem I.A.T., Ahmed A., Kazmi S.A., Hong C.S. 2019. Internet of things forensics: Recent advances, taxonomy, requirements, and open challenges. Future Generation Computer Systems 92, 265–275.
Zheng P., Lin T.-J., Chen C.-H., Xu X. 2018. A systematic design approach for service innovation of smart product-service systems. Journal of cleaner production 201, 657–667.

СПИСОК ИСТОЧНИКОВ

Bartodziej C.J. 2017. The concept Industry 4.0, in: Bartodziej, C.J. (Ed.), The Concept Industry 4.0: An Empirical Analysis of Technologies and Applications in Production Logistics, BestMasters. Springer Fachmedien, Wiesbaden, pp. 27–50. https://doi.org/10.1007/978-3-658-16502-4_3
Aftab H., Gilani K., Lee, J., Nkenyereye L., Jeong S., Song J. 2020. Analysis of identifiers in IoT platforms. Digital Communications and Networks 6, 333–340.
Alguliyev R., Imamverdiyev Y., Sukhostat L. 2018. Cyber-physical systems and their security issues. Computers in Industry 100, 212–223.
Brozzi R., Forti D., Rauch E., Matt D.T. 2020. The advantages of industry 4.0 applications for sustainability: Results from a sample of manufacturing companies. Sustainability 12, 3647.
Camarinha-Matos L.M., Goes J., Gomes L., Martins J. 2013. Contributing to the Internet of Things, in: Camarinha-Matos, L.M., Tomic, S., Graca, P. (Eds.), Technological Innovation for the Internet of Things, IFIP Advances in Information and Communication Technology. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 3–12. https://doi.org/10.1007/978-3-642-37291-9_1
Camarinha-Matos L.M., Katkoori S. 2021. Challenges in IoT Applications and Research, in: IFIP International Internet of Things Conference. Springer, pp. 3–10.
Chawla V., Angra S., Suri S., Kalra R. 2020. A synergic framework for cyber-physical production systems in the context of industry 4.0 and beyond. International Journal of Data and Network Science 4, 237–244.
Borremans A.D., Zaychenko I.M., Iliashenko O.Yu. 2018. Digital economy. IT strategy of the company development. MATEC Web of Conferences 170, 01034. https://doi.org/10.1051/matecconf/201817001034
De Lucia A., Qusef A. 2010. Requirements engineering in agile software development. Journal of emerging technologies in web intelligence 2, 212–220.
Drath R., Horch A. 2014. Industrie 4.0: Hit or Hype? [Industry Forum]. Industrial Electronics Magazine, IEEE 8, 56–58. https://doi.org/10.1109/MIE.2014.2312079
Fayoumi A., Williams R. 2021. An integrated socio-technical enterprise modelling: A scenario of healthcare system analysis and design. Journal of Industrial Information Integration 23, 100221.
Gulzar M., Abbas G. 2019. Internet of things security: a survey and taxonomy, in: 2019 International Conference on Engineering and Emerging Technologies (ICEET). IEEE, pp. 1–6.
Hazra A., Adhikari M., Amgoth T., Srirama S.N. 2021. A comprehensive survey on interoperability for IIoT: taxonomy, standards, and future directions. ACM Computing Surveys (CSUR) 55, 1–35.
Ilin I., Frolov K., Bolobonov D. 2017. The Role of the Internet of Things in Innovative Business Models 11.
Ilin I., Lepekhin A., Levina A., Iliashenko O. 2018. Analysis of Factors, Defining Software Development Approach, in: Murgul, V., Popovic, Z. (Eds.), International Scientific Conference Energy

Management of Municipal Transportation Facilities and Transport EMMFT 2017. Springer International Publishing, Cham, pp. 1306–1314. https://doi.org/10.1007/978-3-319-70987-1_138

Ilin I., Levina A., Borremans A., Kalyazina S. 2019. Enterprise architecture modeling in digital transformation era, in: Energy Management of Municipal Transportation Facilities and Transport. Springer, pp. 124–142.

Ilyin I.V., Ilyashenko V.M. 2018. Formation of requirements for a reference architectural model for the digital transformation of a medical organization. Nauchnyj vestnik Uznogo instituta menedzhmenta 82–88. https://doi.org/10.31775/2305-3100-2018-4-82-88

Kasauli R., Knauss E., Horkoff J., Liebel G., de Oliveira Neto F.G. 2021. Requirements engineering challenges and practices in large-scale agile system development. Journal of Systems and Software 172, 110851.

Kim J., Yun J., Choi S.-C., Seed D.N., Lu G., Bauer M., Al-Hezmi A., Campowsky K., Song J. 2016. Standard-based IoT platforms interworking: implementation, experiences, and lessons learned. IEEE Commun. Mag. 54, 48–54. https://doi.org/10.1109/MCOM.2016.7514163

Klotzer C., Pflaum A. 2015. Cyber-physical systems as the technical foundation for problem solutions in manufacturing, logistics and supply chain management, in: 2015 5th International Conference on the Internet of Things (IOT). IEEE, pp. 12–19.

Lee J., Azamfar M., Singh, J. 2019. A blockchain enabled Cyber-Physical System architecture for Industry 4.0 manufacturing systems. Manufacturing letters 20, 34–39.

Mishra S., Tyagi A.K. 2022. The role of machine learning techniques in internet of things-based cloud applications, in: Artificial Intelligence-Based Internet of Things Systems. Springer, pp. 105–135.

Mohamed M. 2018. Challenges and benefits of industry 4.0: An overview. International Journal of Supply and Operations Management 5, 256–265.

Roblek V., Mesko M., Krapez A. 2016. A complex view of industry 4.0. Sage open 6, 2158244016653987.

Rossini M., Costa F., Tortorella G.L., Valvo A., Portioli-Staudacher A. 2021. Lean Production and Industry 4.0 integration: how Lean Automation is emerging in manufacturing industry. International Journal of Production Research 1–21.

Russmann M., Lorenz M., Gerbert P., Waldner M., Justus J., Engel P., Harnisch M. 2015. Industry 4.0: The future of productivity and growth in manufacturing industries. Boston consulting group 9, 54–89.

Shah T., Patel S. 2014. A review of requirement engineering issues and challenges in various software development methods. International Journal of Computer Applications 99, 36–45.

Sony M. 2020. Design of cyber physical system architecture for industry 4.0 through lean six sigma: Conceptual foundations and research issues. Production & Manufacturing Research 8, 158–181.

Sutcliffe A., Sawyer P. 2013. Requirements elicitation: Towards the unknown unknowns, in: 2013 21st IEEE International Requirements Engineering Conference (RE). Presented at the 2013 IEEE 21st International Requirements Engineering Conference (RE), IEEE, Rio de Janeiro-RJ, Brazil, pp. 92–104. https://doi.org/10.1109/RE.2013.6636709

Thames L., Schaefer D. 2016. Software-defined cloud manufacturing for industry 4.0. Procedia cirp 52, 12–17.

Tilley S. 2019. Systems analysis and design. Cengage Learning.

Yaqoob I., Hashem I.A.T., Ahmed A., Kazmi S.A., Hong C.S. 2019. Internet of things forensics: Recent advances, taxonomy, requirements, and open challenges. Future Generation Computer Systems 92, 265–275.

Zheng P., Lin T.-J., Chen C.-H., Xu X. 2018. A systematic design approach for service innovation of smart product-service systems. Journal of cleaner production 201, 657–667.

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