Methodology for evaluating the readiness of internal logistics processes for Industry 4.0

IOP Conf. Series: Materials Science and Engineering **947** (2020) 012005 doi:10.1088/1757-899X/947/1/012005

Methodology for evaluating the readiness of internal logistics processes for Industry 4.0

M Zoubek, M Šimon

Faculty of Mechanical Engineering, Department of Industrial Engineering and Management, University of West Bohemia, Pilsen, Univerzitn í8, 301 00, Czech Republic

zoubekm@kpv.zcu.cz, simon@kpv.zcu.cz

Abstract. The field of internal logistics is one of the critical areas of a company and has a great potential within the concept of Industry 4.0. The basic premise of smart production is to have a complete overview of all the logistics movements of products, i.e. from entry, through production to dispatch. Furthermore, this is exactly what the digitization of internal logistics allows. The development of Industry 4.0 based on digitization and automation presents excellent challenges for logistics and opportunities for further growth and development. Companies should optimize, automate and digitally transform internal logistics into a more autonomous and flexible form. However, a company must be prepared for this Industry 4.0 concept and know its level of maturity in this area. The primary purpose of this article is to describe a methodology for assessing the readiness of internal logistics processes, which are structured into several areas to cover the entire area of internal logistics. These processes are evaluated using the methodology, and the company's current level is assessed according to specific indicators for each area of internal logistics. By implementing elements from modern logistics, the aim is to increase the level of the company.

1. Introduction

Based on advanced digitization in industrial enterprises, it seems that the combination of internet technologies and technologies oriented in the field of intelligent objects (machines, production equipment, supporting equipment and products) is leading to a new fundamental paradigm shift in industrial production [1]. We are at the beginning of the Fourth Industrial Revolution (or Industry 4.0), which is already fundamentally influencing the way goods are produced and distributed. At the core of this revolution is the connection of the virtual cyber world with the world of physical reality [2]. Industry 4.0 is a digitization trend that focuses on automating production and creating so-called 'smart factories'. In these smart factories, intelligent machines, storage systems and production equipment in the form of cyber-physical systems are integrated into the production environment. These systems are able to independently exchange information and communicate, trigger actions, assess risks, control each other independently and make decisions [3]. The concept of Industry 4.0 also brings with it principles and essential technologies for autonomous functionality, which are applied to the production environment within smart factories. The main components used by Industry 4.0 include the Cyber-Physical System (CPS), the Internet of Things (IoT), Big Data and Data Mining (DM) and the Internet of Services (IoS) [4]. Cloud storage, augmented reality, autonomous robots, sensors and more are other key technologies and principles [5].

In addition to the digitization and automation of production processes, Industry 4.0 also has a significant impact on internal logistics, which is also gradually becoming a digital system thanks to the implementation and integration of technologies corresponding to Industry 4.0. Logistic support of production and modern distribution logistics have already been given a new name in the current debates about Industry 4.0, and there is talk of Logistics 4.0 or Smart Logistics [6]. The future challenges of internal logistics are primarily driven by growing individualization in all areas of the company and increasing customer requirements for logistics services. This creates the need for flexible and adaptable internal logistics systems as well a transparent and continuous exchange of information [7].

2. Literature review of the main topics for the methodology

The methodology proposed in this paper for the evaluation of internal logistics processes includes essential topics which are: internal logistics within the Industry 4.0 concept, logistics evaluation audit and readiness models for maturity assessment in Industry 4.0. Therefore, these key areas are subjected to literature research, and scientific methods such as analysis, synthesis, comparison and abstraction.

2.1. Internal Logistics and Logistics 4.0

The system of internal logistics is corporate logistics (supply logistics, production logistics and distribution logistics) [8]. Logistics can be divided according to the area of its application within the logistics chain, where internal logistics focuses on logistics processes within a company [9]. The primary operational functions of internal logistics are manipulation, warehousing, internal transport within a company (warehouse, production, etc.), picking and packaging [10]. The integration of new technologies into logistics promises to enable real-time monitoring of material flows, better storage and better handling of manipulation units [1]. Most authors describing logistics within the concept of Industry 4.0 identify and mention similar technologies and applications that are based on the principles of this concept and implemented in the field of internal logistics. The leading technologies of Logistics 4.0 are listed according to their sources in Table 1.

Table 1. Technologies of Logistics 4.0

Sources	Technologies of Logistics 4.0
Wang (2016) [11]	Big Data, Smart Sensors, RFID, IoT, IoS, Smart Robots, Autonomous AGV, GPS
Galindo (2016) [12]	RFID, CPS, IoT, IoS, Big Data, RTLS,
Schmidtke et al. (2018) [13]	Autonomous AGV, Mobile terminals, Cloud IT platforms, IoT, Data Mining
Wahrmann et al. (2019) [14]	Wearable Scanners (barcodes, RFID tags), Voice-Direct Headsets, Smart Glasses, Activity Trackers
Glistau and Machado (2018) [15]	RFID, WLAN, EDI, GPRS, Big Data, Data Mining, Smartphones, EDI, 5G network, Tablets, Cloud storage
Zou and Zhong (2018) [16]	Exoskeletons, Autonomous AGV, Drones, Collaborative Robots, RFID
Horenberg (2017) [6]	Autonomous AGV, Smart Robots, Blockchain Technology, CPS, Drones, Big Data

2.2. Logistics audit methodologies

This part describes the evaluation of logistics audit systems and methodologies, based on which the dimensions of internal logistics for the methodology are determined. Logistics audit is a standardized analytical and project process that focuses on the logistics functions of the corporate management system. The purpose of a logistics audit is to diagnose the state of the logistics system in the company

and define a program to increase its productivity. The project nature of this program makes it possible to implement both immediate organizational interventions leading to rapid effects and fundamental conceptual changes in logistics processes [17]. The logistics audit aims to provide management with comparative material on the state of logistics in the company and to show the potential for changes in logistics activities in order to achieve a more efficient performance of the company [18]. Several methods of logistics audits were examined in detail, where the main parameters sought were the areas of internal logistics that the audit evaluates, as well as the potential for evaluating internal logistics corresponding to Industry 4.0. That is the integration of this concept into the logistics audit. Three critical methodologies and their main parameters were evaluated, which are shown in Table 2.

Table 2. Evaluation of logistic audits

Methodology by source	Evaluated areas in internal logistics	Integration of Industry 4.0	Field of application	Evaluation method
CHLA [19]	Material flow, Information system, Planning, Strategy	No	Universal	Point and subjective evaluation
VDA 6.3 [20]	Manipulation, Transport, Storage, Packaging	No	Automotive	Point evaluation
MMOG/LE [21]	Manipulation, Supply, Packaging, Material Identification	No	Automotive	Point evaluation

2.3. Readiness models for maturity assessment in Industry 4.0

Using readiness models, we can identify and evaluate the current state of the company in various areas within the concept of Industry 4.0. The individual models have standard foundations and very similar principles, which are based on CMMI models [22]. The analysed dimensions and levels are always defined. In some models, the dimensions are further extended to sub-dimensions for greater detail. In addition to dimensions, the method of evaluation is also essential. The similarity in the method of evaluation is given by individual degrees of maturity, readiness in given dimensions. There are usually four to six levels of readiness. The CMMI model has five levels from initial, controlled, defined, quantitatively controlled to optimizing [23]. Table 3 provides an overview of the detailed models analysed with the main parameters sought for use in the proposed methodology.

Table 3. Analysed models of readiness and their main parameters

Readiness model by source	Analysed dimensions/areas	Potential of the logistics	Method of assessing readiness	The purpose of the model
RM1 [24]	6 dimensions	Yes	6 degrees	Descriptive Comparative Prescriptive
RM2 [25]	Without dimensions	Yes	6 degrees	Comparative
RM3 [26]	5 dimensions	Yes	5 degrees	Descriptive
RM4 [27]	4 dimensions	Yes	5 degrees	Descriptive
RM5 [28]	7 dimensions	Yes	5 degrees	Descriptive
RM6 [29]	3 dimensions	Yes	5 degrees	Descriptive

Maturity models are arranged logically from the lowest level to the highest level. Degrees or levels have their names and their characteristics of requirements and properties for meeting a given degree within a given dimension. A total of 20 preparedness models were found, which evaluate companies within Industry 4.0 and their readiness for this concept. Within the methodology, we focus primarily on models that evaluate internal logistics. A selection was made in terms of quality and relevance, and models that contain the potential for evaluating internal logistics were further analysed.

2.4. Evaluation of literary research

The first part of the paper deals with the research of the main areas - internal logistics and Logistics 4.0, logistics evaluation audits and models of readiness for the concept of Industry 4.0. It is, therefore, possible to summarize the main findings:

- Based on the analysis and synthesis, we can state that the technical aspects of Logistics 4.0 in specific areas are based on technological assumptions and principles from the comprehensive general concept of Industry 4.0.
- The sources for Logistics 4.0 mention the principles and technologies that will be a necessary part of logistics processes in a company that will apply the attributes of Industry 4.0.
- After comparison and analysis, it was found that the logistics audit systems do not reflect the development within the concept of Industry 4.0 and do not evaluate the internal logistics processes with this regard.
- The activities of internal logistics, which evaluate some logistics audits, such as warehousing, material handling, packaging, supply, etc. are not evaluated in detail according to indicators.
- Based on a comparison of a company's readiness models for Industry 4.0, it is quite evident that internal logistics plays a minimal role here and the level of readiness is not assessed in detail
- According to the method of abstraction, it can be stated that for a smaller number of models directly conceived for logistics, the evaluation is performed in a general form instead for the whole area. Internal logistics occurs in the models as a separate evaluated area minimally

3. Methodology for evaluating the readiness of internal logistics processes

Based on the theoretical conclusions above and their related shortcomings, a new methodology is proposed to increase the readiness of internal logistics processes for Industry 4.0. It assesses all internal logistics processes and tries to structure them. Using the methodology, the processes are then evaluated, the current level is assessed, and modern elements are implemented in an effort to increase the level of the logistics processes. The methodology for evaluating the readiness of a company for Industry 4.0 is described in the analytical part, which has three main phases, which are also partial goals.

3.1. Definition and structure of the methodology in terms of company attributes

The methodology is designed with special consideration of the requirements of industrial enterprises. When dealing with production management systems, we must take into account the specifics of a company and its situation, as well as logistics systems. An adequately designed logistics system must make a positive contribution to the overall performance of a company and meet specific requirements in the industrial enterprise. Each company is also associated with certain features or characteristics that must be taken into account in any intervention in its internal logistics processes. These are, for example: the type of production and its repeatability, the size and type of the enterprise, the internal logistics system in the enterprise, logistics technology, data processing and information flow, and more. Table 4 summarizes the underlying assumptions and limitations of the proposed methodology.

Table 4. Summary of requirements and limitations of the methodology

Attribute	Assumption and limitations
Company size	Medium-sized companies
Branch of business	Manufacturing industrial enterprises

Production repeatability	It doesn't matter, it's not a limitation
Data availability	Available data from information systems, monitoring, control panels, etc.
Complexity of logistics processes	It doesn't matter, it's not a limitation
Primary focus	Functional and economical logistics management
Logistics technology	It doesn't matter, it's not a limitation

The analytical part of the proposed methodology is the subject of this practical study. Its phases are chosen according to a logical sequence. The aim of the analytical part is data collection, evaluation and identification of problem areas in the field of logistics. Indicators determining the effectiveness of the proposed methodology are also included. The analytical part itself takes place in three primary phases, and these are described below.

3.2. Analytical Phase 1 - Determination of internal logistics dimensions, levels and indicators for evaluation

Analytical phase 1 includes the main steps, such as defining the critical dimensions of the internal logistics system, setting the levels for evaluation and setting the evaluation indicators of the individual dimensions of internal logistics.

3.2.1. Step 1 - Determination of dimensions The dimensions of the internal logistics are determined using the methods of logistics audits according to MMOG/LE [21], VDA 6.3 [20] and the Chamber of Logistics Audits (CHLA) [19]. The specified dimensions and sub-dimensions cover all the internal logistics processes. The five main dimensions of the methodology are: *Manipulation Storage Supply Packaging Material identification*

These 5 main dimensions, which were selected for the methodology as the main activities of internal logistics, must be further broken down into sub-dimensions, because the dimensions are very general and evaluating it as a whole area is inefficient and meaningless.

Manipulation dimensions – The material is moved from one place to another, and an information change of location is performed. This is the manipulation between the receipt and storage of material, the production sector and the dispatch of finished products. Specified sub-dimensions:

- Manipulation technology
- Information security during manipulation
- Manipulation unit

Storage dimensions – Loading the material and storing it, entering it in the information system where the material is stored, the method of requesting the material from the warehouse, physical removal, preparation for removal and again the information entry into the system. Specified sub-dimensions:

- Storage technology
- Information security during storage
- Material receipt and shipping

Supply dimension – What is important is the technique used for loading the material (randomly, intervals, Milk Run), how the material is required (paper order, kanban, EDI, electronic system, a system of empty packages and free positions, etc.). Specified subdimensions:

- Workplace supply technology
- Method of material delivery
- Information about material recalls

Packaging dimensions – The packaging is made of different materials, and it has different functions (protection, breathability, etc.). Packing can be done manually in a carton with insulating tape, or using various tools and technologies, or the process is fully automated and robotic. Specified sub-dimensions*:*

- Packaging technology, method of packaging

- Types of packaging and packaging material
- Environment and packaging management

Material identification dimensions – It is a process of placing an identifier and scanning, and loading into the system. Interconnected production and storage systems must know precisely where, when and in what quantity a particular component is to enable this modern approach to production. In internal logistics, therefore, the most important thing for traceability is a well-set system of material marking and information acquisition within the entire internal logistics flow. Specified sub-dimensions:

- Method of identification
- Information security and identification intensity

3.2.2. Step 2 - Levels of evaluation of logistics processes The level of readiness of internal logistics processes from Industry 4.0 is divided into six levels based on analysis and synthesis. Therefore, six levels of preparedness, including the zero level, are set for the methodology of evaluating all the sub-dimensions as follows:

- Level 0 - Processes are not explicitly defined
- Level 1 - Certified process management
- Level 2 - Digitized data collection (from processes), implementation of automation
- Level 3 - Part of the processes is automated, connected to an external data source
- Level 4 - Processes are automated, with limited human intervention
- Level 5 - Processes are automated, only human-controlled

The levels are evolving, and the brief definition only gives a general idea about what each level means. However, for the evaluation within the methodology, the levels are characterized in even more detail.

3.2.3. Step 3 - Intersection of dimension and level parameters and links between levels In this step, links between the individual levels are first created, and they are used to create the intersection of the parameters of the dimension (sub-dimension) and the level of readiness.
The subject of the third step is to determine:

- Links between individual levels, a transition to a higher level
- Define and describe the intersection of these two parameters, a brief description
- Assign for a given subdimension and level, in addition to the characteristic, also the logistic elements used in the given level

An example of the characteristics of the fourth and fifth levels, including the assigned logistics elements, is shown in Table 5. These levels correspond to Industry 4.0. This is the dimension of manipulation and its sub-dimension of manipulation technology. However, this characteristic is performed for all levels, including elements.

Table 5. Demonstration and characteristics of the subdimension of manipulation technology

Level	Characteristics of the subdimension	Logistics elements
4	Manipulation technology is automated, controlled and guided by IS. A person loads and unloads material. There is no autonomous solution, and there is a gradual robotization of workplaces. Automated manipulation technology is only used for material transport.	Automated manipulation equipment - forklifts, trains, trucks guided by sensors built into the ground. Collaborative robots.

5	Manipulation technology is fully automated, controlled and guided by IS. The human role is only as overseer. Artificial intelligence is used - a robot loads and unloads material. Manipulation technology connects the line and the warehouse autonomously, there is a link to robotic workplaces.	Automated manipulation equipment - unmanned forklift, autonomous forklift, trains, drones. The robot loads and unloads material. Autonomous AGV.

3.2.4. Step 4 - Determination of indicators Indicators are used to evaluate the sub-dimensions. These are of a general type, which is of a qualitative nature, and their task is to find out in more detail the type and condition of the company and the initial information. Another type are evaluation indicators, which are quantifiable in nature and are at the core of determining the level of internal logistics in a company. Each of the defined sub-dimensions contains 2-3 quantifiable indicators, which by their nature, provide a complete picture of the area. For example, the indicators in Table 6 are evaluated for the package dimension or its sub-dimension.

Table 6. Indicators for packaging sub-dimensions

Packaging	**Indicators**		
Packaging technology	Degree of automation	Technical equipment	Customizable product size
Types of packaging	Packaging identification	Packaging standardization	-
Environment and packaging management	Applicability (repeatability)	Attitudes towards packaging management	Carbon footprint

An important note for understanding the principle is that these indicators will then be used in a structured questionnaire and, based on the answers and evaluation, the company will be classified at a certain level according to the indicators (0 - 5). The individual levels will be divided as a percentage for each indicator.

3.3. Analytical Phase 2 - Evaluation tool and structured interview
Phase 2 of the analytical part of the methodology is focused on conducting a structured interview with employees of the company. In phase 2, the data created in phase 1 of the same part of the methodology are needed. This is an essential part of the proposed methodology, as the results of the evaluation largely depend on the quality of the structured interview. The questionnaire is designed to match the levels and indicators. Thus, a total of 38 questions are created, and the answers are in the form of brief sentences, a percentage, or a multiple-choice style question. The questions are designed so that not only one evaluation body answers them.

3.4. Analytical Phase 3 - Final evaluation of the level of internal logistics
The last phase of the analytical part aims to determine the final evaluation of each sub-dimension, the evaluation of each parent dimension and the overall level of internal logistics in the company. In this phase, the answers are evaluated using the scales for each indicator. The essence of determining the level of internal logistics is multi-criteria evaluation, i.e. evaluation using criterion functions. A responsible employee at the company is asked questions related to a specific indicator in the given area. Each indicator is always evaluated by levels from level 0 to level 5. The employee then chooses from the above options and does not know how many points they will receive for a specific answer. This is carried out in the same way for all 38 indicators. The output of the analytical phase is an evaluated, structured interview with a clear score in each indicator. The individual dimensions of logistics are interlinked, and the output is an assessment of the current level of internal logistics, and the company will discover the areas where its level can be improved and increased.

3.5. The current state of methodology and its future extension - implementation phase

Currently, the newly proposed methodology is being verified in companies. The output is an assessment of the current level of internal logistics. The methodology is therefore descriptive, and the company will find out the areas where there is the potential to improve and increase its level. This means that the company knows where to improve, but does not know the implementation steps to achieve it. Therefore, the methodology can be extended by an implementation part in the future. The result of phase 3 of the analytical part is also the input to the implementation part. At the very beginning of the implementation phase, these outputs are further processed into the values of the levels of individual sub-dimensions or indicators. The implementation phase deals with the design of corrective measures aimed at improving the situation in the identified areas. The implementation phase can be divided into three key steps. The first steps include processing the outputs from the analytical part and a detailed overview of individual areas. The next step is the definition and scope of measures to achieve a higher level in the area, including the necessary methods and tools. The third step is the implementation of the measures.

4. Conclusions

Internal logistics is an essential part of factory production processes and an integral part of the supply chain. Internal logistics is a suitable area for applying the principles of Industry 4.0. The vision of smart logistics is to connect warehouse systems, internal logistics, transportation technology and planning software into one interconnected network that can automatically create and modify logistics processes related to other links in the production chain. Digitized internal logistics ensures the smooth automated transfer of materials, goods and machines within a company - between warehouses and the production area. The field of internal logistics has many possibilities and great potential within the concept of Industry 4.0. We decided to exploit this potential by creating a missing methodology for the evaluation of internal logistics processes in companies. To be able to implement new technologies and raise and improve a company's level, it is necessary to know its current level and the logistics processes themselves. The methodology, therefore, contains an analytical part divided into the main steps for determining the current level of internal logistics in the company in individual dimensions. Using the criterion function it is possible to link these dimensions and determine the overall level of internal logistics of the company. This methodology can, therefore, be used as a diagnostic tool. The methodology also has the potential for expansion, while an implementation section can be added to the analytical part and the methodology will become more comprehensive. After evaluating its current level, a company implements measures to increase the level of any of its inadequate dimensions. Verification of the methodology and results from companies will be the subject of another article, as well as a possible extension of the methodology with an implementation section.

Acknowledgments

This research was supported by the project SGS-2018-031 Optimizing the parameters of a sustainable production system.

References

[1] Hofmann E and Rüsch M (2017). Industry 4.0 and the current status as well as future prospects on logistics. *Computers in industry*, **89**, 23-34.
[2] Mařík V (2016). *Průmysl 4.0: výzva pro Českou republiku*. Management Press.
[3] Kagermann H Helbig J Hellinger A and Wahlster W (2013). Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Securing the future of German manufacturing industry; *final report of the Industrie 4.0 Working Group*. Forschungsunion.
[4] Schmidt R Möhring M Härting R C Reichstein C Neumaier P and Jozinović P (2015, June). Industry 4.0-potentials for creating smart products: empirical research results. In *International Conference on Business Information Systems* (pp. 16-27). Springer, Cham.
[5] Rüßmann M Lorenz M Gerbert P Waldner M Justus J Engel P and Harnisch M (2015). Industry 4.0: The future of productivity and growth in manufacturing industries. *Boston Consulting Group*, **9(1)**, 54-89.

[6] Horenberg D (2017). Applications within Logistics 4.0: A research conducted on the visions of 3PL service providers (Bachelor's thesis, University of Twente).
[7] Günthner W and Ten Hompel M (2010). *Internet der Dinge in der Intralogistik* (p. 360). Heidelberg: Springer.
[8] Sixta J and Mačát V (2005). *Logistika: teorie a praxe*. CP Books, as.
[9] Stehlík A *Logistika – strategický factor manažerského úspěchu*. 1. vyd. Brno : Studio Contrast, 2002. 231 s. ISBN-80-238-8332-1
[10] Martin H (2012). *Transport-und Lagerlogistik: Planung, Struktur, Steuerung und Kosten von Systemen der Intralogistik*. Springer-Verlag.
[11] Wang K (2016, November). Logistics 4.0 Solution-New Challenges and Opportunities. In *6th International Workshop of Advanced Manufacturing and Automation*. Atlantis Press.
[12] Domingo Galindo L (2016). *The challenges of logistics 4.0 for the supply chain management and the information technology* (Master's thesis, NTNU)
[13] Schmidtke N Behrendt F Thater L and Meixner S (2018). Technical potentials and challenges within internal logistics 4.0. In *2018 4th International Conference on Logistics Operations Management (GOL)* (pp. 1-10). IEEE.
[14] Wahrmann D Hildebrandt A C Schuetz C Wittmann R and Rixen D (2019). An autonomous and flexible robotic framework for logistics applications. *Journal of Intelligent & Robotic Systems*, **93(3-4)**, 419-431.
[15] Glistau E and Coello Machado N I (2018). Industry 4.0, logistics 4.0 and materials-Chances and solutions. In *Materials Science Forum* (Vol. **919**, pp. 307-314). Trans Tech Publications.
[16] Zou O and Zhong R Y (2018, July). Automatic Logistics in a Smart Factory using RFID-enabled AGVs. In *2018 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)* (pp. 822-826). IEEE.
[17] Komora Logistických Auditorů. Nová metodika logistického auditu. *Ostrava: KLA*
[18] Malindžák D and Marková Z (2010) Systém komplexného logistického auditu. **15** (2010), mimoriadne číslo 1. *Acta Montanistica Slovaca*, s. 82-89.
[19] Tvrdoň L Bazala J and David R (2012). A new approach of the logistics audit. In CLC 2012: (pp. 66-71).
[20] der Automobilindustrie, V. V. (2009). *Qualitätsmanagement in der Automobilindustrie Bd, 4: Sicherung der Qualität in der Prozesslandschaft*. VDA.
[21] Peinado J and Graeml A R (2008). Mensuração do desempenho logístico: a percepção da eficácia da ferramenta MMOG-LE por fornecedores da indústria automobilística. *Simpósio de Administração da Produção, Logística e Operações Industriais (Simpoi)*, **11**.
[22] CMMI, P. T. (2010). CMMI for Development, Version 1.3. *Software Engineering Institute*.
[23] Paulk M C Curtis B Chrissis M B and Weber CH V. Capability maturity model, version 1.1. *IEEE software 10*, no. **4** (1993): 18-27.
[24] Lichtblau K Stich V Bertenrath R Blum M Bleider M Millack A and Schröter M (2015). IMPULS-industrie 4.0-readiness. *Impuls-Stiftung des VDMA, Aachen-Köln*.
[25] Werner-Lewandowska K and Kosacka-Olejnik M (2019). Logistics 4.0 Maturity in Service Industry: Empirical Research Results. *Procedia Manufacturing*, **38**, 1058-1065.
[26] De Carolis A Macchi M Kulvatunyou B Brundage M P and Terzi S (2017, July). Maturity models and tools for enabling smart manufacturing systems: comparison and reflections for future developments. In *Ifip international conference on product lifecycle management* (pp. 23-35). Springer, Cham.
[27] Sternad M Lerher T and Gajšek B (2018). Maturity levels for logistics 4.0 based on NRW's Industry 4.0 maturity model. *Business Logistics in Modern Management*.
[28] Krajcovic M Grznar P Fusko M and Skokan R (2018). Intelligent Logistics for Intelligent Production Systems. *Communications-Scientific letters of the University of Zilina*, **20(4)**, 16-23.
[29] Oleśków-Szłapka, J and Stachowiak A (2018, September). The framework of logistics 4.0 maturity model. In *International Conference on Intelligent Systems in Production Engineering and Maintenance* (pp. 771-781). Springer, Cham.