A FRAMEWORK FOR A LOGISTICS 4.0 MATURITY MODEL WITH A SPECIFICATION FOR INTERNAL LOGISTICS

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We understand the maturity of an industrial enterprise in the context of the fourth industrial revolution as the state of the of internal and external conditions that support basic concepts of Industry 4.0 such as vertical and horizontal integration of production systems and enterprises or digital integration of engineering throughout the value chain. The ongoing trends of digitization and automation are causing many fundamental changes that will affect the entire area of logistics. On the way to Industry 4.0, intelligently controlled machines and robots will take over increasingly challenging tasks from humans. This is good news for logistics, whose complex processes with minimal standardization options are often limiting factors to expanding the automation of logistics and warehousing activities. An important aspect however is the company's readiness for the concept of Industry 4.0. Models of readiness evaluate the maturity of the company and are the main content of this paper, which is mainly of a search nature and compares the existing individual models. The analysis is based on knowledge of the main theoretical topics, which are described in the introductory part. Systematic research and evaluation of literature, comparison and analysis of models and interviews with experts are the basic development phase for the design of a new model of maturity which is focused on the evaluation of internal logistics processes. It is mainly a framework model with the main parameters, which is the subject of further development.

KEYWORDS

Logistics 4.0, Industry 4.0, internal logistics, maturity, model, manipulation

1 INTRODUCTION - EFFICIENT INTERNAL LOGISTICS TOWARDS INDUSTRY 4.0

Due to the scope of Industry 4.0, there are multiple definitions and perspectives of this concept from academics, business entities, consulting companies and practical associations. In general, the Industry 4.0 concept is understood as a close connection between production and modern information and communication technologies. This idea is already implemented in many areas, which include automation, robotics and modern warehousing concepts. Investment in digitization is essential for the growth of all industrial companies, regardless of their size or industry. Among the main elements of Industry 4.0 it is possible to generally define digitization of production and products, enterprise information systems, robotic workplaces, communication infrastructure and also an important part will be the role of employees in the company. Company management should create a strategy in which to evaluate the readiness of these elements for automation. The key issue will be improved connectivity between the various elements of the production process.

Smart technologies of Industry 4.0 will also be reflected in internal logistics processes and activities, as this area has great potential within the concept. Internal logistics is a very important part of factory production processes; areas such as warehousing, handling and supply of input materials to production lines and workplaces are key processes in the company. Internal logistics covers planning, implementation, control, efficient flow and storage of materials, semi-finished and finished products and the production environment. If they use the concept of Industry 4.0 as a basis, most warehouse operations in the future will be fully automated, from the receipt of goods, through warehousing to picking and assembly for production.

Flexibility and interconnection are important not only for individual parts of the warehouse, but for warehouse processes as a whole. This means interconnection of individual areas in the company, such as integral interconnection of logistics and production. The process of supplying workplaces is between the warehouse and production, which is carried out on the basis of certain principles and techniques. This process is different according to the type of production. For serial production, it is possible to automate on the basis of standards using trains or conveyors. For small series and custom production, this is still very difficult due to process complexity and irregularity. Self-learning robots can be the link which eliminates this shortcoming.

A software-controlled warehouse connected to material flow is one of the central aspects of the Industry 4.0 concept. Finally there should be self-sufficient production, where machines themselves ensure the ordering and importing of parts or materials from production, the input warehouse or intermediate warehouse.

2 MAIN ASPECTS OF INDUSTRY 4.0

The historical milestones are that the main definition of Industry 4.0 is based on a document presented at the Hanover Trade Fair in 2013 and a basic vision of the fourth industrial revolution was described in 2011. In brief, the first three industrial revolutions arose as a result of mechanization, electricity and the use of computer technology [Kagermann 2013]. During the fourth industrial revolution, areas such as automation, digitization and robotics are experiencing the greatest expansion, computer technology is connected to robots and these entities communicate independently. [Sarvari 2018]. Businesses will have to change the processes they have worked with so far to adapt to a new era of digitization and the introduction of the Internet of Things and services into the production environment and the Industry 4.0 concept [Muhuri 2019]. Industry 4.0 and its implementation suggest changes in business paradigms and production models that will be reflected at all levels of production processes, including all production process workers, cyber system designers and end users. The implementation strategy in corporate sectors involves the introduction of independent automation, configuration, diagnostics and problem solving, as well as new knowledge and intelligent decision-making [Botlíková 2020].

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, auxiliary equipment and products) leads to a new fundamental paradigm shift in industrial production [Hofmann 2017]. Digitization is based on three main pillars: digitization and integration of horizontal and vertical value chains, digitization of products and services offered, and digitization of businesses and customer access [Vaidya 2018].

Principles of intelligent manufacturing and logistics are also the basic driving force for maximizing the added value of individual processes across a company, which is given by the synergy of the key principles described in Table 1 [Gunal 2019].

Table 1. Principles of Industry 4.0 [Gunal 2019]

Interoperability	In enterprise environment, this means connecting machines, people, materials, products, information and communication technologies into system (system interconnectivity)
Virtualization	It means creating a virtual copy of smart factory by linking data from physical sensors with virtual data from factory simulation models
Decentralization	The ability of cyber-physical systems to make decisions for themselves and to produce.
Real-time	The ability to collect and analyse data; provide acquired knowledge immediately (in order of milliseconds).
Service orientation	Software units divided into discrete, autonomous, and network-accessible units, each designed to address individual interest.
Modularity and reconfigurability	Flexible adaptation of smart factories to changing requirements by replacing or expanding individual modules.

Similar technological attributes are mentioned by most authors, for example Big data, Cyber-Physical Systems (CPS), cloud storage, implementation of autonomous robots, Internet of Things, use of augmented reality and additive manufacturing, sensors [Mařík 2016]. Intelligent machines and production equipment, storage systems and production equipment in the form of cybernetic physical systems for the production environment, which are able to independently exchange information and communicate, trigger actions, evaluate risks, control each other independently and make decisions [Rüßmann 2015].

3 LOGISTICS 4.0

Industry 4.0 will change and improve traditional logistics and its self-concept. Logistics has become a fundamental pillar of the value chain for suppliers, manufacturers and retailers. In a dynamically changing and uncertain logistics environment, meeting essential requirements is becoming increasingly difficult. Highly dynamic and uncertain logistics markets and huge complex logistics networks require new methods, products and services. Today's customer behaviour is leading to new logistics challenges and opportunities. There is a shift from traditional supply chains to an open supply network. Experts talk about Logistics 4.0 or so-called Smart Logistics. The main principles of Logistics 4.0 intersect in many respects with the principles of Industry 4.0. Logistics 4.0 is a crucial element of digitization, although it is not yet as popular a topic as Industry 4.0 itself.

3.1 General vision of Logistics 4.0

The vision of Logistics 4.0 is a process that seeks to eliminate the human factor and to the greatest extent possible automate the process. The strategy of manufacturing companies is towards a future where we have a perfect overview of not only where a piece is right now, but it will also be necessary to know who had it in hand, where and when it was moved, why, and if it had any consequences. This cannot be achieved without perfect information systems and will have to be ensured not only during production, but also during storage operations, material delivery, or even during the return from production towards the warehouse. Logistics 4.0 could bring better results in automation, providing extensive information, increasing flexibility, and eliminating the human factor [Barreto 2017].

A complete overview of the information and ensuring the traceability of the components will be done by scanning and tagging using RFID, QR codes, or barcodes. An important social trend in logistics and transport is to measure the impact on the environment. In the area of supply, companies are more often choosing the Just in Time method. Also, we are seeing the expansion of artificial intelligence. In the field of Logistics 4.0., this is represented mostly with AI-driven vehicles [Strandhagen 2017].

Logistics 4.0 does not replace systems such as lean logistics, but complements and improves them where management is inefficient or too complex. Integrated products, services, processes, technologies and even organizations and networks can be supported throughout the lifecycle. In contrast, several obstacles can be identified, such as insufficient technical standardization and uncertainty about economic values and costs. Also, regulatory uncertainties and infrastructure problems are emerging. From a human point of view, skills and knowledge in particular are addressed as possible obstacles [Winkelhaus 2020].

3.2 Development stages of logistics

Like Industry 4.0, logistics has undergone three revolutionary changes in the past. The first innovation (Logistics 1.0) was caused by the mechanization of transport at the end of the 19th and the beginning of the 20th century. The second innovation (Logistics 2.0) was driven by the automation of handling systems from the 1960s. The third innovation (Logistics 3.0) was the logistics management system of the 1980s. We are now at the beginning of the fourth logistics innovation, Logistics 4.0. The main drivers are IoT and IoS (Internet of Things and Internet of Services) and the interconnection of the physical and virtual world. Over the last 60 years, corporate logistics has undergone development that can be divided into four phases [Wang 2020].

3.3 Technical components of Logistics 4.0

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. Articles and studies have been analysed in which a number of technologies used in the modern concept of logistics appear. The leading technologies of Logistics 4.0 are listed according to their sources in Table 2.

Table 2. Technology in Logistics 4.0

Source	Logistics technology 4.0
[Wang 2020]	Big Data, Smart Sensors, RFID, IoT, IoS, Smart Robots, Autonomous AGV, GPS

[Galindo 2020]	RFID, CPS, IoT, IoS, Big Data, RTLS,
[Glistau 2018]	RFID, WLAN, EDI, GPRS, Big Data, Data Mining, Smartphones, EDI, 5G network, Tablets, Cloud storage
[Zou 2018]	Autonomous AGV, Drones, Collaborative Robots, RFID

Logistics is a suitable area of application for the principles of Industry 4.0. The integration of CPS and IoT systems into logistics promises to enable real-time monitoring of material flows, better handling of manipulation units and accurate risk management. [Hofmann 2017]

This new logistics paradigm is the result of the growing use of the Internet to enable real-time communication with other machines and people and through advanced digitization. According to the authors [Barreto 2017], efficient and powerful Logistics 4.0 must rely on and use the following technological applications:

- Resource Planning
- Warehouse Management Systems,
- Transportation Management Systems
- Intelligent Transportation Systems and
- Information Security.

4 BUSINESS READINESS FOR THE INDUSTRY 4.0 CONCEPT

Here we describe the readiness (maturity) models for the Industry 4.0 concept which are commonly used to measure the maturity of an organization or process related to a specific target state. Their use is an important characteristic, because on the basis of their use it is possible to identify the current state and readiness for Industry 4.0 concept comprehensively in the whole company or in various areas of it. Alternatively, these models try to find potential places to improve the state of readiness for the future. Maturity models come in many modifications, ranges, and these complex models should equip companies with practical knowledge of the following aspects:

- What is Industry 4.0 and what are the tangible benefits it could bring?
- What is the level of readiness of the company and sub-areas and facilities?
- How can the company gradually and purposefully improve and increase its level?

4.1 General overview of maturity models

The essential concept on which most types of readiness (maturity) models are based is the Capability Maturity Model (CMM), and the more recently developed Capability Maturity Model Integration (CMMI) [Torrecilla Salinas 2016]. It contains basic elements of effective processes for one or more disciplines and describes the path of evolutionary improvement from immature to disciplined and mature processes with improved quality and efficiency. This is a model that aims to help the organization plan, define, implement, develop, evaluate and improve processes. It is not a methodology, but a model that determines goals that the company should achieve without precisely prescribed procedures [CMMI Product Team 2002]. The CMMI model works with five important levels of maturity. From the first lowest initial level, through a controlled, defined, quantitatively controlled level, to the highest fifth optimizing level. [Paulk 1993] SPICE (Software Process Improvement and Capability Determination) is a similar model. Other models for process assessment have been created based on SPICE, most notably Automotive SPICE for the automotive industry. This model works with six levels of readiness, from level 0 and an incomplete process to level 5, where the process is optimized [Lami 2010].

The analysed areas (dimensions) are always defined. For some models, they are further extended to subdimensions. In addition to dimensions, the method of evaluation is also important. The similarity in the method of evaluation is given by individual degrees of maturity in given areas (dimensions). There are usually four to six degree of readiness which are arranged logically from the lowest to the highest level. Degrees have their own names and their own characteristics of requirements and properties for meeting a given degree within a given area (dimension) [Amaral 2019].

4.2 Main aspects of maturity models

An important part of the literature search was given at the beginning of the publications with a basic division of models for maturity assessment according to the level of scope [Viharos 2017]. Models can be divided by:

1) **macro level**, where evaluations are carried out in relation to countries and show the preconditions for the development of industry and digitization of individual monitored countries, the priority is to improve a country's competitiveness by increasing its innovation capacity and digitization.
2) **micro level**, which assesses the readiness of the entity itself – a company.

At a micro level, it is not necessary to compare a large number of companies and dozens of indicators. The company itself, or its sub-areas, is evaluated. [Basl 2018]

This research focuses on micro models, for which there are many modifications and methodologies. The aim is to analyse individual models and their main attributes. An analysis was performed for individual models with the following characteristics and attributes.

Source type – Models are mainly from foreign universities, various engineering associations, or consulting companies, they are often combined with academia and industrial associations.

Analysed dimensions and areas – All analysed dimensions of each examined model are listed. Dimensions range from a minimum of 3 to 9 dimensions. In some models, dimensions are further divided into subdimensions.

Method of readiness assessment – Models with several levels, often from 4 to 6, are used for final assessment, and these levels are characterized.

Model intent – The preparedness model can be used to determine and evaluate the current state of readiness and inclusion in the appropriate level, i.e. descriptive purpose. Or it may be a model of readiness of a comparative nature. The third feature may be a prescriptive model [De Carolis 2017].

Evaluation of internal logistics – The main area searched for models of readiness was internal logistics. The models are divided into three groups A, B, C. In group A there are models that are designed directly for the evaluation of internal logistics, models included in group B contain internal logistics partly in some of the areas. Models in group C do not focus on logistics and do not evaluate internal logistics processes.

Model categories – The main categories of model implementation are roadmaps, maturity models, readiness models or so-called frameworks for evaluation. [Schmitt 2019]

The individual models were analysed in detail and a summary with their main characteristics can be seen in Table 3.

Table 3. Analysed maturity models with main parameters

Maturity model	Source	Source type	Analys. dimen.	Group of models	Method of assessing maturity	Model intention
Impuls – Industrie 4.0 Readiness	[Lichtblau 2015]	Acad. Pract. Assoc.	6	B	5 levels from 1 (Outsider) to 5 (Top performer)	Comp. Descr. Prescr.
Maturity Model for Assessing	[Carolis 2017]	Acad. Pract. Assoc.	5	B	5 levels from 1 (Initial) to 5 (Digital oriented)	Comp.
An Industry 4 Readiness Assessment Tool	[Agca 2018]	Acad. Cons. Co.	6	B	6 levels from 1 (Beginner) to 4 (Expert)	Comp. Descr. Prescr.
The Singapore Smart Industry Readiness Index	[EDB Singapore 2018]	Pract. Assoc.	3	B	6 levels from 0 (None) to 5 (Converged, Adaptive)	Comp.
The Logistics 4.0 Maturity Model	[Oleskow-Szlapka, Stachowia 2019]	Acad.	3	A	5 levels from 1 (Ignoring) to 5 (Integrated)	Comp.
Roadmapping towards industrial digitalization based on an Industry 4.0	[Schumacher et al. 2018]	Acad. Pract. Assoc.	8	B	Assessment into 4 levels.	Comp. Descr.
Contextualizing the outcome of a maturity assessment for Industry 4.0	[Colli et al. 2018]	Acad.	5	B	6 levels from 1 (None) to 6 (Integrated)	Comp. Descr.
acatech Industrie 4.0 Maturity Index	[Zeller et al. 2018]	Acad. Pract. Assoc.	4	A	6 levels from 1 (Computerisation) to 6 (Adaptability)	Comp.
Maturity and Readiness Model for Industry 4.0 Strategy	[Akdil et al. (2018)]	Acad.	3	B	4 levels from 0 (Absence) to 3 (Maturity)	Comp. Descr. Prescr.
A Smartness Assessment Framework for Smart Factories	[Lee et al. 2017]	Acad.	4	B	5 levels from 1 (Checking) to 5 (Autonomy)	Comp.
Intelligent Logistics For Intelligent Production Systems	[Krajcovic et al. 2018]	Acad.	7	A	Assessment into 5 levels (uses level 0).	Comp. Prescr.

Maturity Levels For Logistics 4.0 Based On NRW'S Industry 4.0 Maturity Model	[Gajšek and Sternad 2018]	Acad.	4	A	5 levels from 1 (Unconnected analog production) to 5 (Completely networked production)	Comp.
Logistics 4.0 Maturity in Service Industry: Empirical Research Results	[Lewandowska and Kosacka – Olejnik 2019]	Acad.	1	A	Evaluation in 6 levels to which they are assigned technology.	Comp. Descr.
Industry 4.0 MM	[Gökalp and Sener 2017]	Acad.	5	C	6 levels from 0 (Incomplete) to 5 (Optimizing)	Descr. Prescr.
Digital Maturity Model	[Back and Berghaus 2016]	Acad. Pract. Assoc.	9	C	5 levels from 1 (Not valid) to 5 (Full valid)	Descr. Prescr.
Asset Performance Management Maturity Model	[Dennis et al. 2017]	Cons. Co.	6	C	5 levels from 0 (Initial) to 4 (Excellence)	Comp.
Towards a Smart Manufacturing Maturity Model	[Mittal et al. 2018]	Acad. Pract. Assoc.	5	C	5 levels from 1 (Novice) to 5 (Expert)	Comp.
A Preliminary Maturity Model	[Sjödin et al. 2018]	Acad. Pract. Assoc .Cons. Co.	3	C	4 levels from 1 (Connected technologies) to 4 (Smart, predictable manufacturing)	Comp. Descr. Prescr.
The Degree of readinnes for the implementation of Industry 4.0	[Pacchini et al. 2019]	Acad.	8	C	6 levels from 1 (Embryonic) to 5 (Ready)	Comp. Prescr.
Defining and assessing industry 4.0 maturity levels	[Bibby and Dehe 2018]	Acad.	3	C	4 levels from 1 (Minimal) to 4 (Exelllence)	Comp. Descr.
A Maturity Model for Logistics 4.0: An Empirical Analysis and a Roadmap	[Facchini et al. 2020]	Acad.	7	A	5 levels from 1 (Ignoring) to 4 (Integrated)	Comp.

5 RESULTS – COMPARISON OF ANALYSED READINESS MODELS

A total of 36 models were analysed in the search of industry 4.0 maturity models. In terms of quality and detailed analysis, 21 models were worked with, which are also listed in the table, including their main parameters. Table 3 shows models that contain at least a partial evaluation of internal logistics, so these are models in groups A and B, but also models in group C are shown, which do not contain an evaluation of internal logistics.

Some models are very complex, some are more concise. From the general point of view of logistics, quality models were gradually focused on the area of internal logistics and also on the evaluation of Logistics 4.0. Internal logistics as a dimension/area itself occurred in a small number of models, so the area of logistics was also examined in general, where we subsequently looked for internal logistics activities - for example in the field of warehousing, handling, and material identification. After reviewing and analysing the readiness models, it can be stated that none of the models comprehensively evaluate a company's readiness within the concept of Industry 4.0 in the field of internal logistics and do not focus specifically on the area. They do not evaluate the overall area of internal logistics, nor its partial activities or even the concept of logistics activities within the company in detail.

For most models, logistics is generally contained within one dimension/area, or it is addressed by partial dimensions or criteria and questions in various questionnaires and evaluation forms. However, it is only a briefly defined form of focus and evaluation. The area of internal logistics is not the only parameter that is monitored and analysed in them. Readiness assessment levels are an important factor. Their number and their characteristics are analysed. The models work with different levels of readiness (0 to 6) and each contains the minimum requirements that must be met for the level to be completed. Levels are mostly from the role of an outsider, through beginner, advanced, experienced, professional to the greatest expert, some models use levels with a brief description from digital novice, integrated and interoperable, fully implemented to a fully digitally oriented entity. This is, for example, an important part of group C models, which do not evaluate internal logistics but serve as inspiration for determining readiness levels for the new proposed model. In Table 4, only models from group A are selected, which are directly designed for internal logistics evaluation. The evaluated dimensions are assigned to them. The models use 5 (some 6) levels to evaluate company readiness and have the potential to evaluate internal logistics.

Table 4. Logistics maturity models from group A with dimensions

The Framework of Logistics 4.0 Maturity Model	[Oleskow-Szlapka, Stachowiak 2019]	3 – Management. Flow of material (automation and robotization in warehouse and transportation, IoT, 3D printing, 3D scanning, AR). Flow of information (Data driven services, Big data, RFID).
Intelligent Logistics For Intelligent Production Systems	[Krajcovic et al. 2018]	7 – Shopping logistics. Factory logistics. Warehouses logistics. Distribution logistics. Identification. Supply chain logistics. Logistics way.
Maturity Levels For Logistics 4.0 Based On Nrw's I4.0 MM	[Gajšek and Sternad 2018]	4 – Purchase logistics. Internal logistics. Distribution logistics. After sales logistics.
Logistics 4.0 Maturity in Service Industry: Empirical Research Results	[Lewandowska and Kosacka – Olejnik 2019]	General dimension Logistics 4.0
A Maturity Model for Logistics 4.0: An Empirical Analysis and a Roadmap for Future Research	[Facchini et al. 2020]	7 – Knowledge. Strategy and Leadership. Employees. IT Systems. Smart Products. Smart Warehouses. Technologies.

As already mentioned, the disadvantage of the models is the evaluation according to levels, which are very general, and there is only a brief verbal description for each dimension, meaning that the models are not comprehensive. Models do not cover the entire area of internal logistics in order to evaluate processes from material receipt to final shipment, including information flow. However, these models were just the inspiration and cornerstone.

Thorough analysis provided the basis for the creation of a new model of readiness with 2 main parameters defined. These parameters are:

- Levels of evaluation of logistics processes (levels)
- Dimensions of internal logistics (will be further expanded by partial dimensions)

These main parameters enter into the intersection and create the design of the whole model. Although a number of other attributes enter the model, the main one is the determination of dimensions and levels.

6 THE FRAMEWORK OF A MATURITY MODEL FOR THE EVALUATION OF INTERNAL LOGISTICS IN THE CONTEXT OF INDUSTRY 4.0

The design of the model took place in several main stages. The approach to designing the new maturity model included systematic research and literature reviews and interviews with experts. It goes without saying that at the beginning of the proposal, the literature on Industry 4.0 and its main definitions was examined. This was the basic development phase. Subsequently, the authors focused on maturity models. This was the main development phase for the design, architecture and structure of the new model - its framework. The abstraction method was used to search for the area of internal logistics and current models were found to have shortcomings in this area, which has great potential in the field of modern technologies. However, based on a comparison of the models, it was possible to determine a new model for the basic architecture. Models were compared, analysed and their similarity and principles served as inspiration for the new model and determination of a relevant framework. Concepts relevant to the new model structure were derived from the models, such as evaluated dimensions (usually 3 - 10 dimensions), levels (usually 4 - 6), method of evaluation (own internal evaluation or evaluation based on an external auditor), method of representation (quantification, graphic form of evaluation, etc.). Using concept mapping techniques, the characteristics of existing maturity models were extracted and evaluated in terms of their applicability to our model.

Another aspect influencing the model design and form is the focus of the authors, who specialize in the field of industrial engineering. In addition to the academic area, the industrial area is also important, where professional interviews took place within the framework of cooperation and workshops.

6.1 *Model design procedure*

In the next phase, the overall framework of the model, evaluated dimensions and levels of readiness and their characteristics are defined. The procedure corresponds in some way to the sub-goals that are related to the design of the model. These are the following sub-goals:

1) Determine the main dimensions and subdimensions of internal logistics processes.
2) Determine the levels evaluating the readiness of logistics processes in individual dimensions
3) Characterize internal logistics processes from the lowest to the highest level
4) Assign logistics elements to all subdimensions where they are usable
5) Define the links and relationships between levels evaluating the readiness of logistics processes.
6) Determine the levels corresponding to Industry 4.0
7) Evaluation tool - mathematical and graphical evaluation
8) Verification, testing and verification of the model

6.2 Determination of maturity levels

Once the main architecture of the new model is obtained, readiness levels are determined. These levels then determine the true digital readiness of the business. 5 levels of readiness were set + level 0, i.e. a total of 6 levels. The set levels are evolved and a brief definition describes what each level means. Levels 4 and 5 correspond to Industry 4.0 and meet its requirements.

Table 5. Determining maturity levels with characteristics

Level	Level characteristics
Level 0	Processes are not explicitly defined. Information systems and simple software are not used.
Level 1	Certified process management takes place here, which is controlled by the human factor. It uses simple software and basic information systems.
Level 2	The use of automated elements in standardized processes is beginning. Data collection is partially digitized and data are processed by information systems only within the company.
Level 3	Most processes are automated with partial human cooperation. Digitized technologies and information systems are used for data collection, which are also connected to external sources.
Level 4	Processes are digitized and automated, with limited human intervention. It uses smart information systems that connect all areas, including external sources.
Level 5	Processes are fully automated and human-controlled. The control of all systems is autonomous. Online communication thanks to sophisticated information systems that connect all company areas, including external sources.

6.3 Determination of dimensions and subdimensions

Internal logistics deals with material flow and also with the accompanying flow of information. Internal logistics is a relatively wide area containing several other sub-areas. Therefore, it is necessary to divide the model of readiness for the concept of Industry 4.0, which will be focused on the processes of internal logistics, into the following main dimensions:

- Manipulation
- Storage
- Supply
- Packaging
- Material identification.

These 5 main dimensions, which were selected for the methodology as the main activity of internal logistics, must be further broken down into subdimensions because they are very general and evaluate it as a whole area, which is inefficient and meaningless, and our model is intended for detailed evaluation. Table 6 shows the distribution of the subdimensions.

Table 6. Distribution of dimensions and subdimensions

Dimensions	Subdimensions
Manipulation	Manipulation technology
	Information transfer manipulation
	Manipulation units
Storage	Storage technology
	Information transfer storage
	Material receipt and shipping
Supply	Workplace supply technology
	Supply technique principles
	Information provision of material needs
Packaging	Technology and method of packaging
	Types of packaging and packaging material
	Environment and packaging management
Material identification	Method of identification
	Information security and scanning intensity

Links were created between the individual levels and on the basis of them the intersection of the parameters of the dimension (subdimension) and the level of readiness was created. This was done with regard not only to the technologies currently used but also to the technologies envisaged, based on trends and developments corresponding to Industry 4.0. The characteristic is derived mainly from the definition of levels (Table 5), in sequence from the lowest level to the highest with an ascending characteristic. It is assumed that the highest levels (Level 4 and Level 5) make full use of technologies and principles based on the Industry 4.0 concept.

6.4 Demonstration of a model of readiness for the manipulation dimension

The following Table 7 shows the model of readiness for the manipulation dimension. Individual levels (from 0 to 5) are characterized and the appropriate logistical elements are assigned to these levels.

Table 7. Demonstration of the dimension of manipulation

DIMENSIONS OF MANIPULATION		
SUBDIMENSION - MANIPULATION TECHNOLOGY		
LEVEL	CHARACTERISTICS OF THE SUBDIMENSION	EXAMPLE LOGISTICS ELEMENTS
0	The manipulation system is not defined and there is no process control of the manipulation - no transport routes are specified. Manually controlled manipulation equipment, including loading and unloading. The share of automation is 0%. Manipulation technology is not guided (no information system or signalling). Use of non-ecological diesel engines without emission standards.	Manual manipulation equipment - picking truck, manual pallet truck, crane technology.
1	Manipulation system is defined, process control set according to standards. We know the goal, subject, quantity and responsible person of the manipulation. Manipulation technology is mechanized and controlled manually by humans. Human loads and unloads material. The share of automation is 0%. Manipulation technology is guided by standard industrial methods. Implementation of hybrid propulsion units reducing CO2, NO and airborne particles. (CNG, LPG).	Mechanical manipulation equipment - forklifts, belt conveyors, crane technology, pallet trucks, platform trucks, tractors.
2	The manipulation system and process control is adapted for automation in standardized activities. Trolleys move along defined routes. Manipulation technology is switched to electric drive. Manual loading/unloading. The share of automation between 0% - 25%. Manipulation technology guided according to signalling and digital recording. Implementation of electric drive units and their partial automation	Mechanical and electrical manipulation equipment - forklifts, belt conveyors, tractors, crane technology, pallet trucks.
3	Manipulation equipment connected to the IS, receives basic instructions via the IS. Human loads and unloads material. Manipulation technology improved with navigation and motion sensors for more efficient movement of technology. The share of automation between 25% - 50%. Manipulation technology guided according to the signalling of wireless technology with partial communication between workplaces. Implementation of electric drive units and their majority automation	Automated manipulation equipment - forklifts, tractors, trains, trucks guided by magnetic tape
4	Manipulation technology is automated, controlled and guided by IS. Human loads and unloads material. There is no autonomous solution, there is a gradual robotization of workplaces. Automated manipulation technology is only used for material transport. The share of automation between 50% - 75%. Manipulation technology guided according to information system with partial online communication. Manipulation equipment for electric drives.	Automated manipulation equipment - forklifts, trains, trucks guided by sensors built into the ground, shuttle.
5	Manipulation technology is fully automated, controlled and guided by IS. One only oversees here. Artificial intelligence is used - the robot loads and unloads material. Manipulation technology connects the line and the warehouse autonomously, there is a link to robotic workplaces. The share of automation between 50% - 80%. Manipulation technology guided according to information system with partial online communication. Manipulation equipment for electric drives or alternative fuels.	Automated manipulation equipment - unmanned forklift, autonomous forklift, trains, shuttle, drones. Collaborative Robots,

Given the requirements of Industry 4.0 (vertical and horizontal integration), the transfer of information is a key issue. Almost every major dimension of the model contains a subdimension that evaluates the transmission of information in that dimension. This subdimension is processed in the same way as the subdimension of the handling technique in Table 7, i.e. each level is characterized. This characteristic is given in Table 8 in a shorter form.

Table 8. Example of integration of information transfer into the manipulation dimension

DIMENSIONS OF MANIPULATION	
SUBDIMENSION - INFORMATION TRANSFER MANIPULATION	
LEVEL	CHARACTERISTICS OF THE SUBDIMENSION
0	Data is not recorded or processed, possible manual random recording in paper form. Handling technology is not interconnected and no information communication flow.
1	Manual data collection and subsequent input into the PC, data collection is regular according to the methodology. Basic offline communication of handling techniques (communication using sorted data).
2	Periodic processing of data into various information systems that are not interconnected and the data are not structured. Basic connection of handling technology, introduction of communication system (control by one program).
3	Data processing into information systems that are interconnected, local automatic data collection. Interconnection, transportation technologies and planning software. Partial automatic control of processes and technology using advanced IS.
4	Partially automated data processing in information systems that are shared across the enterprise. Coordination of transport equipment and autonomous synchronization of production and logistics processes according to current conditions and requirements.
5	Fully automated processing of intelligent data connected to cloud storage and creation of a unified data model. Mutual communication of transport equipment and data exchange in real time, so-called M2M communication based on control systems with AI.

7 DISCUSSION

The concept of Industry 4.0 provides many benefits and advantages for the company and it is clear that solving logistics processes within this concept is important. Manipulation in the form of robotic elements without added infrastructure, unlimited fixed routes, real-time localization, independent maintainability, capacity coverage of job shortages by automated solutions including increased security and elimination of errors, and human factor losses are just some of the many benefits and advantages. The implementation of the principles of Industry 4.0 is very specific, and technologically, organizationally and financially demanding for many companies. Therefore, companies must know their current level of logistics processes and evaluate the readiness of these elements for automation and digitization and determine the subsequent strategy and implementation of selected elements of Industry 4.0 in an industrial company. This is the main intention of the authors and their new evaluation tool - a proposed model for internal logistics. There is no such comprehensive tool in this area. Its main advantages are:

- calculation of the overall level of readiness of the company based on the interconnection of subdimensions,
- comparison of the main dimensions and finding the weakest link in the logistics system.

The model of readiness for internal logistics evaluation has a total of 5 dimensions and 14 sub-dimensions. Table 7 shows the evaluation for the manipulation dimension - manipulation technique subdimension. The other dimensions are processed by the same principle and the model, therefore, contains 14 tables with characteristics. It can be assumed that these 14 subdimensions will sufficiently cover the entire internal logistics and it will therefore be possible to call it a comprehensive model. At present, the research team is processing all 14 subdimensions, and to be able to apply the model to industry, it is necessary to further create an evaluation system. The evaluation will be performed based on collecting input data from the company and subsequent calculations. Input data for calculations are collected in the form of a structured interview between an external auditor and the company's employees. The structured interview consists of closed questions with multiple-choice answers. Each question is designed so that its answers can be classified into one of five levels. According to the answers, points are awarded and according to the scoring system used in the calculation phase, it is possible to obtain the final evaluation.

Respondents should have a basic knowledge of the concepts of Industry 4.0. External consultations or group sessions can therefore increase the representativeness of the questionnaire and the accuracy of the model. The answers then serve as a data input for the tool to calculate and represent the level of readiness. The resulting rating ascends from the lowest item, which is the subdimension. After evaluating the subdimensions, it is possible to obtain the evaluation of the whole dimension. And from the individual dimensions, the evaluation of the entire internal logistics is then performed. The model has mainly a diagnostic character and determines the current level of maturity, however, it is possible to obtain data on places that are so-called bottlenecks. The aim should be to increase the level for these bottlenecks. The continuation of the research team and other results will be the subject of further articles. Due to the application of the proposed model, its main attributes and their limitations are listed in Table 9.

Table 9. Restrictions on the use of the model

Attribute in the enterprise	Attribute constraints
Type of production	Series line production, flow production
Business size	Medium-sized enterprise
Industry	Automotive, engineering, electrical
Level of logistics technologies	Without limits
Information provision of logistics processes	Without limits
Company representative	Thorough knowledge of logistics processes

Just as this model is designed for internal logistics, models can also be used to assess the readiness of other areas of the business, such as the manufacturing sector, maintenance, IT departments, and more. It is possible to use one of the existing models for these areas, which has already been analysed and is sufficient, and the newly designed model will be used separately. Alternatively, it is possible to conduct research and design a new model on the same principles as the model for internal logistics. This means setting dimensions and sub-dimensions and new data for the collection of input data and gradually covering all areas of the company with a uniform evaluation.

8 CONCLUSIONS

Many companies, even on the Czech market, are proud of the fact that they are already fulfilling the principles of Industry 4.0. In most cases, however, these are only partial innovations, which in conjunction with the new concept work well as a marketing tool. Industry 4.0 is an idea rather than a specific goal, and the transition to more modern ways of managing logistics flows is an organic process. Companies should keep in mind that the new technological devices they acquire are ready for integration. In today's terminology, we talk about compatibility within the Internet of Things. In the near future, it will be important to connect everything with everything and openness. Combining areas such as production, quality, supplier logistics and production development is the right way to go. The area of internal logistics therefore has great potential within the Industry 4.0 concept, which is why the research team focused on the intersection of these two areas and is developing a tool that will assess a company's readiness for this concept. The model should be descriptive, but also prescriptive, as are some of the models that have been analysed and compared in the literature search. This was a relatively important phase, as many models were an inspiration and common ground could be used to design a new readiness model, which, however, only evaluates in detail the area of internal logistics. The aim is to create a sophisticated detailed tool for evaluating internal logistics for industrial companies regardless of their size.

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REFERENCES

[Kagermann 2013] Kagermann, H., et al. Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0 Working Group, 2013

[Sarvari 2019] Sarvari, P.A., et al. Technology roadmap for Industry 4.0. In Industry 4.0: Managing the digital transformation, Springer, 2018, pp. 95-103.

[Muhuri 2019] Muhuri, P.K. et al. Industry 4.0: A bibliometric analysis and detailed overview. Engineering applications of artificial intelligence, 2019, Vol. 78, pp. 218-235.

[Botlíková 2020] Botlíková, M. and Botlík, J. Local Extremes of Selected Industry 4.0 Indicators in the European Space - Structure for Autonomous Systems, Journal of Risk and Financial Management, 2020, Vol. 13, pp. 1-39.

[Hofmann 2017] Hofmann, E. and Rüsch, M. Industry 4.0 and the current status as well as future prospects on logistics. Computers in Industry. 2017, Vol. 89, pp. 23-34.

[Vaidya 2013] Vaidya, S., et al. Industry 4.0 - a glimpse. Procedia Manufacturing, 2018, Vol. 20, pp. 233-238.

[Gunal 2019] Gunal, M. and Karatas, M. Industry 4.0, Digitisation in Manufacturing and Simulation: A review of the literature. Simulation for Industry 4.0. Springer, 2019, pp. 19-37

[Mařík 2017] Mařík, V. Průmysl 4.0:Výzva pro Českou republiku. Praha: Management Press, 2016. ISBN 9788072614400

[Rüßmann 2015] Rüßmann, M. et al. Industry 4.0: The future of productivity and growth in manufacturing industries. Boston Consulting Group (BCG), 2015, pp.1-14.

[Barreto 2017] Barreto, L., Amaral, A., and Pereira, T. Industry 4.0 implications in logistics: an overview, 2017, Procedia Manufacturing, Vol. 13, pp. 1245-1252.

[Strandhagen 2017] Strandhagen, J.O., et al. Logistics 4.0 and emerging sustainable business models, Advances in Manufacturing, 2017, Vol. 5(4), pp. 359-369.

[Winkelhaus 2020] Winkelhaus, S. and Grosse, E.H. Logistics 4.0: A systematic review towards a new logistics system, International Journal of Production Research, 2020, Vol. 58, pp. 18-43

[Wang 2016] Wang, K. Logistics 4.0 Solution-New Challenges and Opportunities, 6th International Workshop of Advanced Manufacturing and Automation, Atlantis Press, 2016, pp. 68-74.

[Galindo 2016] Domingo Galindo, L. The challenges of logistics 4.0 for the supply chain management and the information technology. Master's thesis, NTNU, 2016.

[Glistau 2018] Glistau, E. and Coello Machado, N. I. Industry 4.0, logistics 4.0 and materials-Chances and solutions. In Materials Science Forum, 2018, Vol. 919, pp. 307-314.

[Zou 2018] Zou, O. and Zhong, R. Y. Automatic Logistics in a Smart Factory using RFID-enabled AGVs. IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM), 2018, July, pp. 822-826

[Torrecilla Salinas 2016] Torrecilla Salinas, C. J., et al. Web Engineering and Capability Maturity Model Integration: A systematic literature re-view. Information and Software Technology, 2016, pp. 92-107

[CMMI Product Team 2002] CMMI Product Team. CMMI for Software Engineering, Version 1.1, Continuous Representation CMMI-SW, V1.1, Continuous. Software Engineering Institute, Carnegie Mellon University, 2002

[Paulk 1993] Paulk, M. C., et al. Capability Maturity Model for Software, Version 1.1, The Software Engineering Institute, Carnegie Mellon University, Pittsburgh, 82 s. 1993

[Lami 2016] Lami, G., Biscoglio, I., Falcini, F. An empirical study on software testing practices in auto-motive. Spice 2016, CCIS, Springer, Cham, 2016, Vol. 609, pp. 301-315

[Amaral 2016] Amaral, A., Jorge, D. and Peças, P. Small Medium Enterprises And Industry 4.0: Current Models' Ineptitude And The Proposal Of A Methodology To Successfully Implement Industry 4.0 In Small Medium Enterprises. Procedia Manufacturing 41, January 2020, pp. 1103-1110.

[Viharos 2017] Viharos, Z. J., et al. Non-comparative, Industry 4.0 Readiness Evaluation for Manufacturing Enterprises. Technical Diagnostics in Cyber-Physical Era. Budapest, 2017

[Basl 2018] Basl, J. Companies on the way to industry 4.0 and their readiness. Journal of Systems Integration, 2018, Vol. 9, pp. 3-6.

[De Carolis 2017] De Carolis, A., et al. Maturity models and tools for enabling smart manufacturing systems: comparison and reflections for future developments. Ifip international conference on product lifecycle management, Springer, Cham, 2017, pp. 23-35.

[Schmitt 2019] Schmitt, P., Schmitt, J., Engelmann, B. Evaluation of proceedings for SMEs to conduct I 4.0 projects. Procedia CIRP. 2019, Vol. 86. pp. 257-263.

[Lichtblau 2015] Lichtblau, K., et al. INDUSTRIE 4.0 READINESS. Impuls-Stiftng, 2015, Aachen, Cologne.

[Carolis 2017] Carolis, A. D., et al. A Maturity. Model for Assessing the Digital Readiness of Manufacturing Companies. IFIP International Conference on Advances in Production Management Systems. August 2017, pp. 13-20.

[Agca 2017] Agca, O. An Industry 4 readiness assessment tool. University of Warwick, Warwick, 2017

[EDB Singapore 2018] The Singapore Smart Industry Readiness Index: Catalysing the transformation of manufacturing. Singapore Economic Development Board, 2018

[Oleśków-Szłapka 2018] Oleśków-Szłapka, J. and Stachowiak, A. The framework of Logistics 4.0 maturity model. In International Conference on Intelligent Systems in Production Engineering and Maintenance, 2018 September, Springer, pp. 771-781

[Schumacher 2016] Schumacher, A., Erol, S. and Sihn, W. A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. Procedia CIRP. 2016. Vol. 52. pp. 161-166.

[Colli 2018] Colli, M. et al. Contextualizing the outcome of a maturity assessment for Industry 4.0. IFAC-PapersOnLine. 2018. Vol. 51. pp. 1347-1352.

[Zeller 2018] Zeller, V., Hocken, C. and Stich, V. Acatech Industrie 4.0 Maturity Index – A Multidimensional Maturity Model. Advances in Production Management Systems. Smart Manufacturing for Industry 4.0, 2018, pp.105–113.

[Akdil 2017] Akdil, K.Y., Ustundag, A. and Cevikcan, E. Maturity and Readiness Model for Industry 4.0 Strategy. Springer Series in Advanced Manufacturing, 2017, pp. 61–94.

[Lee 2017] Lee, J., et al. A Smartness Assessment Framework for Smart Factories Using Analytic Network Process. Sustainability, 2017, Vol. 9(5), p.794.

[Krajcovic 2018] Krajcovic, M., et al. Intelligent Logistics for Intelligent Production Systems. Communications - Scientific Letters of the University of Zilina, 2018, 20(4), pp. 16-23.

[Sternad 2018] Sternad, M., Lerher, T. and Gajsek, B. Maturity Levels For Logistics 4.0 Based on Nrw's Industry 4.0 Maturity Model. Business Logistics in Modern Management, 2018, Vol. 18, pp. 695-708.

[Werner Lewandowska2019] Werner-Lewandowska, K. and Kosacka-Olejnik, M. Logistics maturity of the service industry – research results. Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu. 2019.

[Gokalp 2017] Gokalp, E., Sener, U., and Eren, P. E. Development of an Assessment Model for Industry 4.0: Industry 4.0-MM. In International Conference on Software Process Improvement and Capability Determination, Springer, Cham, 2017, pp. 128-142.

[Berghaus 2017] Berghaus, S. and Back, A. Stages in Digital Business Transformation: Results of an Empirical Maturity Study. Tenth Mediterranean Conference on Information Systems (MCIS), September 2016

[BCG Perspective 2017] BCG Perspective – Time to Accelerate in the Race towards Digital Manufacturing. (2017), Capgemini Digital Transformation Institute, Smart factory survey. [online], [2020-03-12] Available from: https://www.bcgperspectives.com/content/articles/lean-manufacturing-operations-time-accelerate-race-toward-industry-4/

[Mittal 2018] Mittal, S., et al. Towards a Smart Manufacturing Toolkit for SMEs. Proceedings of the 15th International Conference on Product Lifecycle Management, 2018

[Sjödin 2018] Sjödin, D.R., et al. Smart Factory Implementation and Process Innovation, Research-Technology Management, 2018, 61:5, pp. 22-31.

[Paulo 2019] Paulo, A., et al. The degree of readiness for the implementation of Industry 4.0. Computers in Industry. 2019, Vol. 113. pp. 103-125.

[Bibby 2018] Bibby, L. and Dehe, B. Defining and assessing industry 4.0 maturity levels – case of the defence sector, Production Planning & Control, 2018, 29:12, pp. 1030-1043

[Facchini 2020] Facchini, F.; et al. A. A Maturity Model for Logistics 4.0: An Empirical Analysis and a Roadmap for Future Research. Sustainability 2020, 12, 86.

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