SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2023
ORGANIZATION AND MANAGEMENT SERIES NO. 170

# PRODUCTION MANAGEMENT AS ONE OF THE DIMENSIONS OF THE INDUSTRY 4.0 IMPLEMENTATION

Anna MICHNA[1*], Joanna KRUSZEWSKA[2]

[1] Silesian University of Technology, Faculty of Organization and Management; amichna@polsl.pl,
ORCID: 0000-0002-4099-2943
[2] Silesian University of Technology, Faculty of Organization and Management; jkruszewska@polsl.pl,
ORCID: 0000-0001-6335-1455
* Correspondence author

**Objective:** In the context of the Fourth Industrial Revolution (Industry 4.0), one of the more frequently discussed topics in the literature is the issue of maturity and readiness to implement Industry 4.0 solutions. The purpose of this article is to collect the dimensions of the implementation of modern technological solutions and to present the developed research tool for the functional area of the enterprise, which is "production management". The presented results are part of a broader research.
**Methodology:** The research methods consist of a multiple and extensive literature review of maturity models and models of readiness of organizations to implement the concept of Industry 4.0. Based on the review of literature sources, a set of functional areas and dimensions of implementation was collected. Using this data, a proposal for a research tool was developed to systematize the levels of sophistication of the dimensions in specific functional areas of the organization.
**Conclusions:** The result of the study is a proposal for a research tool for the "production management" area, which will be used to conduct the planned pilot study. This element is the next step in the development of the final research tool verifying the dimensions of Industry 4.0 implementation in the presented functional areas of manufacturing enterprises.
**Limitations/indications:** Functional areas in manufacturing organizations may vary depending on the specifics of the enterprise. Likewise, the dimensions of Industry 4.0 implementation gathered from literature studies do not represent a closed set. Further studies detailing these aspects are advisable. It is also necessary to carry out a pilot study, based on which it will be possible to correct or confirm the effectiveness of the tool.
**Practical implications:** The developed survey tool will provide the opportunity to conduct a comprehensive survey in manufacturing enterprises and at the same time can be used when performing self-assessment of the organization at the time of making decisions related to the implementation of modern technologies.
**Originality/substantive value:** The developed research tool will quickly and effectively allow decision-makers in enterprises to identify the current situation of their organizations, determine the target state and identify competency, technical, and organizational gaps. As part of their own research, it will allow the authors to conduct a pilot study in manufacturing enterprises.

**Keywords:** Industry 4.0, dimensions of Industry 4.0 implementation, maturity, readiness.

**Category:** Results of literature findings.

## Introduction

Changing political, legal, social, environmental, economic and technological conditions directly affect the way organizations are managed. Dynamics in technological development, combined with the guidelines of Agenda 20230 (A/RES/70/1 Transforming Our World: The 2030 Agenda for Sustainable Development, 2030) for sustainable development presents companies with new challenges. As defined by (Stock, Seliger, 2016) Industry 4.0 is a stage just in the direction of sustainable industrial value creation and its main goal is to connect the real physical world with the digital factory and thus create a Smart Factory (Grabowska, 2021). The Smart Factory provides flexible and adaptive production processes, problem solving and immediate responses to changes and complexity in planning processes.

This paper aims to present and discuss one of the dimensions of the implementation of technological solutions included in the broader issue of Industry 4.0, namely "production management." This study is a continuation of previous literature studies that dealt with the implementation of Industry 4.0 in manufacturing organizations (Michna et al., 2021; Michna, Kruszewska, 2020, 2021, 2022a, 2022b, 2022c) and to address the research gap on tools tailored to the specifics of small and medium-sized organizations, the vast majority of which are still at initial levels of maturity/readiness to implement Industry 4.0 technology solutions (Amaral, Peças, 2021; Schuh et al., 2021). The result of the analysis presented here is the next step in the development of the final research tool to verify the overarching research hypothesis: "It is possible to rank the identified implementation barriers and drivers of Industry 4.0 implementation in terms of the strength of impact on the various dimensions of Industry 4.0 implementation in small and medium-sized manufacturing companies in the automotive industry".

The research discussed in this dissertation was carried out in accordance with the scheme presented in Figure 1, which also includes the summaries used within the framework of this study. The dissertation begins with the definition of functional areas in manufacturing organizations, developed on the basis of requirements collected in the international standard for quality management systems – PN-EN ISO 9001 issued in 2015. Literature research in the subject area of Industry 4.0, models of maturity and readiness for the implementation of modern technological solutions, resulted in the development of a map of the dimensions of implementation of Industry 4.0. Subsequently, the dimensions of implementation were allocated to individual functional areas of the enterprise, which is shown in Figure 2. The area of production management in technical and organizational terms was selected for detailed discussion. In this aspect, the literature was reexamined, this time with a special focus on the issues of organizational maturity related to the production area. The levels of maturity in the implementation of the various dimensions in the production management area were presented as a proposed research tool. Its design is based on the *VDMA Industry 4.0 Toolbox* solution

(Anderl, 2016; Rauen et al., 2016; Chong et al., 2018; Wang et al., 2018; Mohammad et al., 2019). Its main advantage is to visualize the steps – the levels of advancement of the organization in the implementation of a dimension in a specific area. For example: levels of advancement from 1–5, of the dimension "standardization" in the functional area "production management."

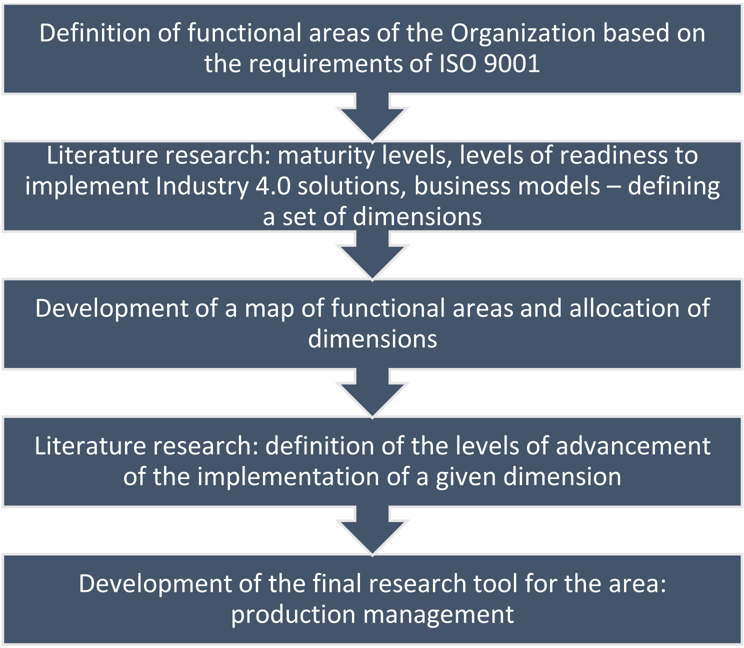


**Figure 1.** Study plan diagram. Source: Own elaboration.

## Dimensions of implementation of Industry 4.0 in functional areas

The requirements for the operation of the organization are collected in the international standard PN-EN ISO 9001:2015 (ISO 9001, 2015). Starting from the location of the organization in the social, economic, legal, environmental, and technological space, through the establishment of the organization's structure, its processes, resources, responsibilities and authority, to operational activities, i.e. production or service delivery, logistics, change management and continuous improvement. Considering the standard's requirement to define the organization's internal processes, manufacturing companies use similar process divisions into: management processes (business management, human resources, quality management system, safety, environment, energy, etc.); core processes (sales, marketing, design, product development, production, logistics, customer service); and support processes (maintenance, IT, purchasing, quality control, finance and accounting). Figure 2 shows the most common processes in manufacturing organizations, which at the same time constitute the functional areas of companies. The nomenclature of the areas used and the division of responsibilities within these areas depends on the specifics, size, and internal decisions of individual enterprises.

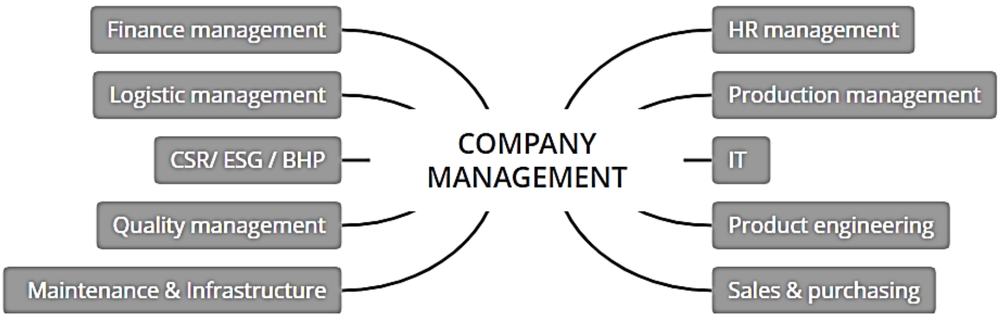


**Figure 2.** Processes – organizational areas in manufacturing enterprises.

Source: Own elaboration based on (Michna, Kruszewska, 2022c).

The "organization management" process is responsible for the development of business strategy, policies, goals, leadership, performance and development of the company. The "personnel management" process covers all aspects of employees: recruitment, development, training as well as termination. The "OHS" (health and safety) process is responsible for maintaining internal processes so that they are safe for all employees, while the "CSR - ESG" (*CSR – Corporate Social Responsibility, ESG – Environment, Social, Governance*) process focuses the organization's attention on aspects broader than just health and safety and namely elements related to the company's performance and its impact on the environment and society. The "financial management" or "finance and accounting" process deals with budgets, costs, income, assets, current accounts, etc., while the "purchasing" process is responsible for nominating and monitoring suppliers, purchasing components and materials and "sales" is responsible for acquiring new projects and new customers and, of course, selling products and services. The "IT" area includes all services related to IT equipment, installations, cyber security, applications, IT and communications connections and systems. The process most often referred to as "engineering or product design" but also as "product development" or "research and development" includes in its scope product creation, research, functionality verification and product innovation. Production technology and process development itself are usually allocated in the "production", "production management" or "technology" process. The "logistics management" process, on the other hand, is responsible for internal and external material flows, warehousing and shipping. "Quality management" has as its responsibility the supervision of quality systems that comply with industry standards or norms, planning and quality assurance of products and services, while the "maintenance" process deals with all infrastructure, machinery, and tools.

Literature research on maturity models of Industry 4.0 and models of readiness to implement the concept (Michna, Kruszewska, 2022c) resulted in a set of dimensions of Industry 4.0 implementation, which, when assigned to individual areas, form the map shown in Figure 3.

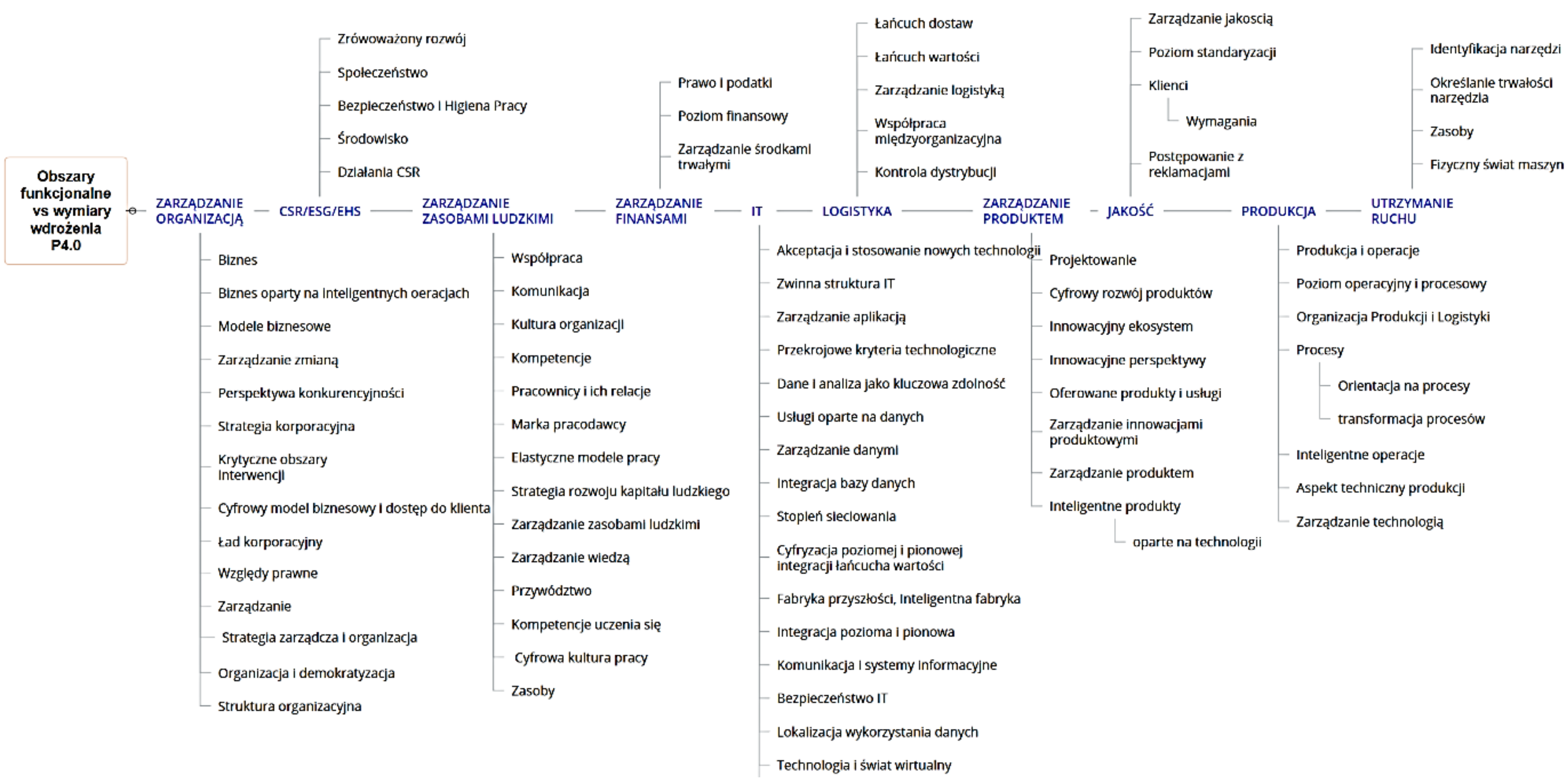


**Figure 3.** Map of dimensions of Industry 4.0 implementation by functional areas of the organization.
Source: Own elaboration based on (Michna, Kruszewska, 2022c).

In the functional area – "production management", the literature distinguishes such dimensions as production and operations, operational level and processes, production and logistics organization, process orientation, process transformation, intelligent operations, technical aspect of production, technology management. The literature research in terms of the individual requirements for a particular dimension detailed the names and scope of the selected dimensions the result of which is shown in Table 1.

**Table 1.**
*Dimensions from literature sources and their adaptation*

| Dimensions – literature sources | Dimensions – adjusted description |
|---|---|
| Production and operations, Process level Production and logistics organization | Production management systems |
| Operational level | Data |
| Process orientation | Standardization, Data |
| Process transformation | M2M/Man2M communication (Machine-to-Machine & Man-to-Machine) |
| Technological aspect of production | Automation |

Source: Own elaboration.

## Production management as a dimension of Industry 4.0 implementation

Production management is a concept that combines many aspects, e.g., process management, personnel management, product management, technological aspect (including capabilities and limitations of manufacturing processes and machinery and equipment) and organizational aspect (norms, standards, customer and internal process requirements, visualization tools, work organization, methodologies such as lean management or continuous improvement). The element that binds all these aspects together is data. Data that is necessary for the correct development and planning of processes, data related to the status of the process, the status of the product, its quality, the status of machinery and equipment, their working efficiency, failure rate, etc. Obtaining accurate and real information about the state of the process is very important in the management and development of production systems (Rácz-Szabó et al., 2020). Data allows optimization and improvement of processes, facilitating making decisions and defining improvement actions. These actions include the implementation of Industry 4.0 solutions.

The first of the dimensions discussed in this study – "automation" with its level of implementation and use in the enterprise supports more efficient production, affects the reduction of waste, reduces resources and achieves repeatability of manufacturing processes (Zoubek et al., 2021). Starting with the initial automation of individual manufacturing processes or machining cells (Mittal et al., 2018), through linking machines into system infrastructures including their full control through automation (Agca et al., 2016) all the way to the phenomenon that is the "lights-out factory" (Zoubek et al., 2021) or a factory in which processes can be carried out with the lights off thanks to automation and robotization. Table 2 shows the collected aspects of automation broken down from the basic level of implementation – 1 to the most advanced level – 5. The scope that goes into each level of sophistication was collected through literature research. The content of each level was linguistically adapted, capturing the translation from English, improving sentence style and optimization enabling future respondents to more easily understand the issue at hand.

**Table 2.**
*Literature sources for the automation dimension*

| AREA: Production management; DIMENSION: Automation | | | |
|---|---|---|---|
| **#** | **Source** | **Source description** | **Adjusted description** |
| 1 | (Mittal et al., 2018) | "Single-station automated cells" | 1. None or little implementation of automation of production processes – single automated workstations/machining nests.<br>2. Machines are not/cannot be controlled or managed through automation. |
| | (Zoubek et al., 2021) | "Lack of implementation in production processes" | |
| | (Agca et al., 2016) | "Machines cannot be controlled through automation" | |
| 2 | (Mittal et al., 2018) | "Automated assembly systems" | 1. Basic level of automation of production processes with required participation of workers, e.g., automated assembly systems.<br>2. Partial connection of production equipment (machines, production lines) with information systems – basic digitization. |
| | (Zoubek et al., 2021) | "Partial connection of production equipment (machines, production lines) with information systems – basic digitization.<br>Basic automation of production processes with the participation of workers" | |
| | (Agca et al., 2016) | "Few machines can be controlled through automation" | |
| 3 | (Mittal et al., 2018) | "Flexible production system" | 1. Some machines and system infrastructure can be controlled through automation. Automated machines and production lines with human collaboration. Communication conducted online.<br>2. Flexible production system. |
| | (Zoubek et al., 2021) | "Automated machines and production lines with human collaboration. Communication conducted online" | |
| | (Agca et al., 2016) | "Some machines and system infrastructure can be controlled through automation" | |
| 4 | (Mittal et al., 2018) | "Computer-integrated production system" | 1. Most machines and system infrastructure can be controlled through automation. Use of robots to replace workers – process supervision still required.<br>2. Computer-integrated production system. Machines and production lines autonomously connected. |
| | (Zoubek et al., 2021) | "Use of robots to replace workers – process supervision still required. Machines and production lines autonomously connected" | |
| | (Agca et al., 2016) | "Most machines and system infrastructure can be controlled through automation" | |
| 5 | (Mittal et al., 2018) | "Reconfigurable production system" | 1. Machines and systems can be completely controlled through automation. Highest form of autonomous manufacturing company – fully robotic and autonomous machines; implementation of *"lights-out factory"*.<br>2. Reconfigurable production system. |
| | (Zoubek et al., 2021) | "Highest form of autonomous manufacturing company – fully robotic and autonomous machines; implementation of *"lights-out factory"* | |
| | (Agca et al., 2016) | "Machines and systems can be completely controlled through automation" | |

Source: Own elaboration.

The effectiveness of organizations making digital transformation also depends on parallel management improvement, which is related to production management, but also to the management of the entire organization. Investing only in modern technologies without improving management can lead to the opposite of the intended results (Kryukov et al., 2022). Considering the possibilities within production management systems, we have a whole set of tools: from ERP (*Enterprise Resource Planning*) systems – enabling the management of production information at a strategic and financial level, through MES (*Manufacturing Execution System*) systems – systems for managing and monitoring production processes in real time, PPC (*Production Planning and Control*) systems – a tool that enables production planning and monitoring to ensure productivity and efficiency, up to the full compatibility of these systems and common communication and all this to ensure cost minimization and increase efficiency (Chong et al., 2018; Kryukov et al., 2022; Mohammad et al., 2019; Rauch et al., 2020).

Table 3 shows the set of individual levels of sophistication within Production Management Systems.

**Table 3.**
*Literature sources for the production management systems*

| **AREA: production management; DIMENSION: production management systems** | | | |
|---|---|---|---|
| **#** | **Source** | **Source description** | **Adjusted description** |
| 1 | (Rauch et al., 2020) | “No ERP-class system” | 1. IT systems are not used for the implementation of production processes or their basic tools are used: computer hardware, MS Office level software. No ERP-class system.<br>2. Lack of connection of production with other units of the organization. |
| | (Kryukov et al., 2022) | “IT systems are not used for the implementation of production processes or their basic IT tools are used: computer hardware, MS Office level software” | |
| | (Anderl, 2016; Rauen et al., 2016; Chong et al., 2018; Wang et al., 2018; Mohammad et al., 2019) | “Lack of networking of production with other business units” | |
| 2 | (Rauch et al., 2020) | “ERP system implemented” | 1. Systems and services that exclude the presence of paper media are used to implement the production process. ERP-class system implemented – planning system.<br>2. Exchange of information with other organizational units is performed via mail/telecommunications. |
| | (Kryukov et al., 2022) | “Systems and services that exclude the presence of paper media are used to implement the process” | |
| | (Anderl, 2016; Rauen et al., 2016; Chong et al., 2018; Wang et al., 2018; Mohammad et al., 2019) | “Exchange of information via mail/telecommunications” | |

Cont. table 3.

| | | | |
|---|---|---|---|
| 3 | (Rauch et al., 2020) | "ERP and PPC system. Production planning and control system used to plan material requirements" | 1. An automated system tailored to the company's processes and standards is used to implement the production process. Automated management systems are used. ERP and PPC production planning and control systems have been implemented.<br>2. Information is exchanged with other organizational units through the use of systems, using uniform data and established rules for their exchange. |
| | (Kryukov et al., 2022) | "This process is executed through an automated business management system. The automated system is tailored to the company's process. The implementation of the process using an automated system is reflected in the company's standards" | |
| | (Anderl, 2016; Rauen et al., 2016; Chong et al., 2018; Wang et al., 2018; Mohammad et al., 2019) | "Uniform data formats and rules for their exchange" | |
| 4 | (Rauch et al., 2020) | "MES or similar system implemented but not integrated with ERP" | 1. An MES or similar system is used to implement the production process. However, it is not integrated with ERP. Data analysis is based on large data sets, reports are generated automatically and recommendations are available in real time.<br>2. Information exchange with other organizational units is carried out through the system, using uniform data and using interdepartmental data servers. |
| | (Kryukov et al., 2022) | "Automated process services are used to evaluate process implementation results. Activity analysis is based on big data analysis technologies that automatically generate reports and recommendations in real time. Changes to the automated system are planned" | |
| | (Anderl, 2016; Rauen et al., 2016; Chong et al., 2018; Wang et al., 2018; Mohammad et al., 2019) | "Uniform data formats and interdepartmental data servers" | |
| 5 | (Rauch et al., 2020) | "ERP and MES are integrated and communicate with each other" | 1. An MES system fully integrated with ERP is used to implement the production process. Integration with external data sources of suppliers and buyers. Use of artificial intelligence systems for forecasting, diagnostics, and recommendations<br>2. Information exchange with other organizational units is carried out through fully networked and inter-branch IT solutions. |
| | (Kryukov et al., 2022) | "The efficiency of the company's process is greatly enhanced by automating it. Changing a company's processes is done by changing its automated implementations. Integration with external data sources of suppliers and buyers. Use of artificial intelligence systems for forecasting, diagnostics, and recommendations" | |
| | (Anderl, 2016; Rauen et al., 2016; Chong et al., 2018; Wang et al., 2018; Mohammad et al., 2019) | "Cross-divisional fully networked IT solutions" | |

Source: Own elaboration.

In the area of manufacturing, the maturity of Industry 4.0 should be understood as full integration, in which not only all production equipment (sensors, machines, robots, conveyors, etc.) are connected and automatically exchange data and information with each other, but will also become self-aware and intelligent enough to predict events, control and manage the entire production system (Müller, 2019; Stawiarska et al., 2021). The generation of data, its further processing, storage, visualization, access, and its use in different areas of the organization (Chong et al., 2018; Colli et al., 2019; Grufman, Lyons, 2020) constitute another dimension shown in Table 4.

**Table 4.**
*Literature sources for the data dimension*

| AREA: production management; DIMENSION: data | | | |
|---|---|---|---|
| **#** | **Source** | **Source description** | **Adjusted description** |
| 1 | (Stawiarska et al., 2021) | "Data from the components that make up the production system are not generated and processed" | 1. The elements that make up the production system do not generate data – thus, data is not processed. |
| | (Colli et al., 2019) | "Lack of presence of digital data generating assets in the organization" | |
| | (Grufman, Lyons, 2020) | "No data for further use" | |
| | (Anderl, 2016; Rauen et al., 2016; Chong et al., 2018; Wang et al., 2018; Mohammad et al., 2019) | "Lack of data processing" | |
| 2 | (Stawiarska et al., 2021) | "Data from production systems are exclusively generated and stored" | 1. The components that make up the production system exclusively generate and store data. Interfaces exist to access and visualize data for anyone who needs it.<br>2. Data shall be stored for documentation purposes, visualized and used as needed. |
| | (Colli et al., 2019) | "Digital processes are in place and working because assets generate digital data".<br>"Interfaces exist to access and visualize data for anyone who needs it" | |
| | (Grufman, Lyons, 2020) | "Data is used for a few select purposes (greater transparency, etc.)" | |
| | (Anderl, 2016; Rauen et al., 2016; Chong et al., 2018; Wang et al., 2018; Mohammad et al., 2019) | "Data storage for record-keeping purposes" | |
| 3 | (Stawiarska et al., 2021) | "Data from production systems are analyzed to monitor production processes" | 1. Data from production systems are generated, processed, and analyzed. Tools exist to process the data, correlate and analyze it, and communicate the results to the user.<br>2. Data is analyzed and used mainly for monitoring. "Some data is used to optimize production processes (maintenance, predictive actions, etc.)". |
| | (Colli et al., 2019) | "Tools exist to process the data, correlate and analyze the data and communicate the results to the user" | |
| | (Grufman, Lyons, 2020) | "Some data is used for process optimization (predictive maintenance, etc.)" | |
| | (Anderl, 2016; Rauen et al., 2016; Chong et al., 2018; Wang et al., 2018; Mohammad et al., 2019) | "Analyzing data to monitor the process" | |
| 4 | (Stawiarska et al., 2021) | "Data from production systems are analyzed and evaluated to plan and control production processes" | 1. Data from production systems are generated, processed, analyzed and evaluated to plan and control production processes. There are resources/tools that can operate autonomously according to the information received after the analytical process.<br>2. Data is used in several areas to optimize, plan and control production processes. |
| | (Colli et al., 2019) | "There are assets or tools that can operate autonomously according to the information received after the analytical process" | |
| | (Grufman, Lyons, 2020) | "Data is used in several areas for optimization" | |
| | (Anderl, 2016; Rauen et al., 2016; Chong et al., 2018; Wang et al., 2018; Mohammad et al., 2019) | "Evaluation for process planning/control" | |

Cont. table 4.

| | | | |
|---|---|---|---|
| 5 | (Stawiarska et al., 2021) | "Production systems are automatically planned and controlled" | 1. Production systems are automatically planned and controlled. "Resources deployed throughout the supply chain can interact and reconfigure themselves to optimize performance"<br>2. Data is used for comprehensive process optimization. |
| | (Colli et al., 2019) | "Resources deployed throughout the supply chain can interact and reconfigure themselves to optimize performance" | |
| | (Grufman, Lyons, 2020) | "Data is used for comprehensive process optimization" | |
| | (Anderl, 2016; Rauen et al., 2016; Chong et al., 2018; Wang et al., 2018; Mohammad et al., 2019) | "Automatic scheduling/process control" | |

Source: Own elaboration.

Table 5 contains a set of elements related to M2M (*Machine to Machine*) machine-to-machine and man-to-machine (Man2M) communication. Such components as infrastructure, machine integration, PLCs (*Programmable Logic Controller*), user interfaces, data processing capability, visualization and use of augmented reality, networking, Internet, industrial Ethernet interfaces that is, data communication standards in industrial automation that allow various devices to be connected over an Ethernet network (Stawiarska et al., 2021), field bus interfaces or data communication standards used to connect devices on a single bus (Mittal et al., 2018; Mohammad et al., 2019), interaction and cooperation between different systems within a single open ecosystem (open system interconnections) are aspects that need to be considered in the M2M or a Man2M communication dimension (Grufman, Lyons, 2020).

**Table 5.**
*Literature sources for the M2M communication dimension*

| AREA: production management; DIMENSION: M2M communication | | | |
|---|---|---|---|
| **#** | **Source** | **Source description** | **Adjusted description** |
| 1 | (Grufman, Lyons, 2020) | "The infrastructure of machines and systems cannot be controlled by IT and lack of integration (M2M)".<br>"No exchange of information between the user and the machine" | 1. Machine-to-Machine communication No communication. There is no automatic communication between machines and production equipment. Infrastructure of machines and systems cannot be controlled by IT, no integration (M2M), Control by PLC.<br>2. Man-to-Machine communication No exchange of information between the user and the machine. No data exchange. |
| | (Mittal et al., 2018; Mohammad et al., 2019) | "No communication".<br>"No exchange of information between the user and the machine" | |
| | (Stawiarska et al., 2021) | "There is no automatic communication between machines and production equipment".<br>"There is no exchange of information or data in man-to-machine interaction" | |
| | (Amaral, Peças, 2021) | "PLC-controlled sensors and integrators." | |

Cont. table 5.

| | | | |
|---|---|---|---|
| 2 | (Grufman, Lyons, 2020) | "Some machines can be controlled by IT, are co-operative or have M2M communication capabilities" | 1. Machine-to-Machine communication. PLCs are used, Field Bus Interfaces – connection of devices on a single bus. Devices (sensors, controllers, and IT systems) exchange information and data between each other. Some machines can be controlled by IT, are co-operative or have communication capability. Data processing capability.<br>2. Man-to-Machine communication. Use of local user interface. Only local exchange of data and information in man-to-machine interaction (e.g., only at a given production site). |
| | (Mittal et al., 2018; Mohammad et al., 2019) | "Field Bus Interfaces."<br>"Use of local user interface" | |
| | (Stawiarska et al., 2021) | "Only local exchange of data and information in man-to-machine interaction (e.g., only at a given production site)".<br>"Machines and equipment are equipped with PLCs" | |
| | (Amaral, Peças, 2021) | "Data processing capability" | |
| 3 | (Grufman, Lyons, 2020) | "The infrastructure of machines and systems can be controlled through IT and is partially integrated" | 1. Machine-to-Machine communication. The infrastructure of machines and systems can be controlled through IT and is partially integrated. The devices communicate over an industrial Ethernet network. Machines can exchange information.<br>2. Man-to-Machine communication. Monitoring and control of production processes can be carried out centrally and locally. |
| | (Mittal et al., 2018; Mohammad et al., 2019) | "Industrial Ethernet interfaces."<br>"Centralized/decentralized production, monitoring/control" | |
| | (Stawiarska et al., 2021) | "The devices communicate over an industrial Ethernet network."<br>"Monitoring and control of production processes can be carried out centrally and locally" | |
| | (Amaral, Peças, 2021) | "Machines can exchange information" | |
| 4 | (Grufman, Lyons, 2020) | "Machine can be completely controlled by IT, is partially integrated (M2M) or co-operative" | 1. Machine-to-Machine communication. The devices have Internet access, can be completely controlled by IT, are partially integrated or co-operative. Open-system interconnections (no need for modification or integration of systems).<br>2. Man-to-Machine communication. In man-to-machine interaction, mobile devices are used to exchange data and information – mobile user interface. |
| | (Mittal et al., 2018; Mohammad et al., 2019) | "Machines have Internet access."<br>"Man2M – Using the mobile user interface" | |
| | (Stawiarska et al., 2021) | "Machines and devices have Internet access".<br>"Mobile devices are used to exchange data and information in man-to-machine interaction" | |
| | (Amaral, Peças, 2021) | "Open system interconnections" | |
| 5 | (Grufman, Lyons, 2020) | "Machines and systems can be controlled almost entirely by IT and are fully integrated (M2M)" | 1. Machine-to-Machine communication Machines and systems can be controlled almost entirely by IT, are fully integrated and communicate with each other through network services and M2M software. Use of systems to control open systems.<br>2. Man-to-Machine communication. Assistive software, augmented reality, etc., are used to exchange data and information. |
| | (Mittal et al., 2018; Mohammad et al., 2019) | "Internet service (M2M software)".<br>"Man2M – augmented and assisted reality" | |
| | (Stawiarska et al., 2021) | "Machines and devices communicate with each other through network services, Machine to Machine (M2M) software".<br>"Man-to-machine interaction uses assistive software, augmented reality, etc., to exchange data and information" | |
| | (Amaral, Peças, 2021) | "Open systems control system" | |

Source: Own elaboration.

The last dimension selected for this study is "Standardization" – Table 6. This dimension includes issues related to the Lean Management concept, quality management and maintenance management. These three issues combine the requirements of maintaining work standards, meeting organizational and customer requirements and continuous process improvement. Concepts and tools such as MRO (*maintenance, repairs, and operations*) or, in short, a collection of various activities related to the upkeep and maintenance of machinery and equipment, as well as their repair and improvement, to ensure smooth and efficient operation (Zoubek et al., 2021), whether CMMS (*Computerized Maintenance Management System)* or, on the other hand, QMS (*Quality Management System*) (Kumar et al., 2020) along with a full range of standardized processes, just as the broad area of Lean Management (Maasouman, Demirli, 2015) are a representation of the elements included in the sophistication within the latter dimension.

**Table 6.**
*Literature sources for the Standardization dimension. Source:* Own elaboration.

| AREA: production management; DIMENSION: standardization | | | |
|---|---|---|---|
| **#** | **Source** | **Source description** | **Adjusted description** |
| 1 | (Zoubek et al., 2021) | "Lack of MRO implementations (maintenance, repairs, and operations)".<br>"Basic monitoring. Minimization of unnecessary movement and ease of transportation. Proper (including use of natural) lighting and ventilation." | 1. UR – Basic monitoring of machinery and equipment, no MRO (maintenance, repairs, and operations) implementations.<br>2. Lack of Lean Management initiatives.<br>3. Quality 1.0 Self-Monitoring. |
| | (Maasouman, Demirli, 2015) | "Lack of Lean initiatives" | |
| | (Caballero et al., 2008) | "Information quality (IQ) management objectives have not been defined" | |
| | (Kumar et al., 2020) | "Quality 1.0 Self-Monitoring" | |
| 2 | (Zoubek et al., 2021) | "Small CMMS implementation, maintenance processes focused on functionality. A paperless maintenance management system" | 1. Small CMMS implementation, maintenance processes focused on functionality. A paperless maintenance management system.<br>2. Lean Management principles are understood by the Organization.<br>3. Quality 2.0. Inspection/control/ assurance/standards. Repeatability of conducting internal processes. |
| | (Maasouman, Demirli, 2015) | "Lean initiatives have resulted in an understanding of Lean principles" | |
| | (Caballero et al., 2008) | "The information management system (IMP) has been defined and planned. The process is therefore repeatable" | |
| | (Kumar et al., 2020) | "Quality 2.0 Inspection/control/ assurance/military standards" | |
| 3 | (Zoubek et al., 2021) | "MRO implemented. Mainly through the use of CMMS and other business information systems" | 1. MRO principles are implemented; CMMS or other business information systems are used.<br>2. Lean initiatives have led to the implementation of Lean Management principles.<br>3. Quality – management systems have been implemented. |
| | (Maasouman & Demirli, 2015) | "Lean initiatives have resulted in an implementation of lean principles" | |
| | (Caballero et al., 2008) | "IMP's integrated information management system is defined and aligned with IQ requirements.<br>As a result, the process can be managed in accordance with the organizational policy on IQ". | |

Cont. table 6.

| | | | |
|---|---|---|---|
| 4 | (Zoubek et al., 2021) | "Level 3 + Implementation of artificial intelligence (AI), use of online sensors, dashboards" | 1. Artificial intelligence, online sensors - Internet of Things - are being used in maintenance operations.<br>2. Lean initiatives lead to continuous improvement in the production area and to improve the lean tools and principles used.<br>3. Quality 3.0 Software is used to manage quality improvement and quality planning. Implemented management systems function and are constantly improved. |
| | (Maasouman, Demirli, 2015) | "Lean initiatives have resulted in the improvement of lean principles" | |
| | (Caballero et al., 2008) | "Information management processes are integrated, and plans for obtaining them are developed and automated. Thus, IMP can obtain repeatable and reliable data" | |
| | (Kumar et al., 2020) | "Quality 3.0 Software for quality management, improvement and planning" | |
| 5 | (Zoubek et al., 2021) | "Completely implemented in MRO. Big data and predictive maintenance as catalysts for performance improvement" | 1. Completely implemented MRO. CMMS systems are used. Big data analytics are used for predictive action. Continuous efficiency improvements.<br>2. Lean initiatives lead to improvements in the production area and the consolidation of lean principles. Lean Management principles are built into the Organization Management System.<br>3. "Quality 4.0 – Continuous quality through real-time data and IoT." |
| | (Maasouman, Demirli, 2015) | "Lean initiatives have resulted in the stability of lean principles" | |
| | (Caballero et al., 2008) | "IMP optimization is managed quantitatively, and measures are used to improve its performance. Thus, the process is subject to continuous improvement" | |
| | (Kumar et al., 2020) | "Quality 4.0 Continuous quality through real-time data and IoT" | |

The different levels in the tables above have been developed in such a way that it is possible to build a research tool. The target matrix is based on the "Toolbox" concept (Anderl, 2016; Rauen et al., 2016; Wang et al., 2018; Chong et al., 2018; Mohammad et al., 2019). Its design makes it possible to depict different elements and stages of development organized in a sequence from low level to high sophistication within a given dimension. The strength of this tool is the easy identification of progress and competence within the organization according to the selected areas and their dimensions (Anderl, 2016; Wang et al., 2018). Figure 4 shows an example of the "Toolbox' for the "business model" area and the "quality improvement" dimension (Wang et al., 2018). In this case, Level 1 is manual quality control, Level 2 is automatic quality control, Level 3 is real-time control through connection to monitoring sensors, Level 4 implies a knowledge-based process for detecting error patterns, and Level 5 is automatic intervention in the process. By rearranging the information in such a clear and obvious way, one can quickly recognize the severity of an issue.

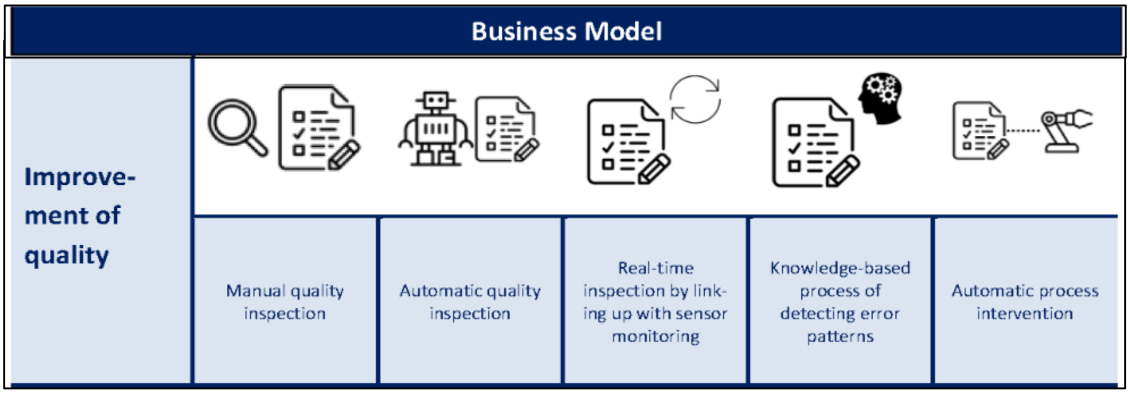


**Figure 4.** Example of Toolbox for a business model.

Source: Y. Wang, T. Tran, R. Anderl, Toolbox Approach for the Development of New Business Models in Industrie 4.0. WCECS 2018, II.

Based on all of the above data and the information collected, a matrix of levels of sophistication of dimensions within the "production management" area was developed. Here, Levels 1 through 5 also determine the sequence of sophistication within an issue. Tables 7-9 will present the final matrices along with the dimensions: automation, production management systems, data, M2M communication, standardization; and the levels developed based on the literature research conducted.

**Table 7.**
*Level matrix: area – production management, dimensions – automation and production management systems*

| Area | Dimension | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 |
|---|---|---|---|---|---|---|
| PRODUCTION | AUTOMATIZATION | 1. Lack of process automatization or little implementation of automation at the production area - single automated workstations / machining cells.<br><br>2. Machines are not / cannot be controlled through automation. | 1. Basic degree of automation of production processes with required participation of employees, e.g. automated assembly systems.<br><br>2. Partial connection of production equipment (machines, production lines) with information systems - basic digitization. | 1. Some machines and system infrastructure can be controlled through automation. Automated machines and production lines with human cooperation. Communication carried out online.<br><br>2. Flexible production system. | 1. Most machines and system infrastructure can be controlled through automation. Use of robots to replace employees - process supervision still required.<br><br>2. Computer-integrated production system. Machines and production lines are autonomously connected. | 1. Machines and systems can be completely controlled through automation. The highest form of autonomous manufacturing company - fully robotic and autonomous machines; implementation of a "lights-out factory."<br><br>2. Reconfigurable production system. |
| PRODUCTION | PRODUCTION MANAGEMENT SYSTEM | 1. IT systems are not used for the implementation of production processes or their basic tools are used: computer hardware, MS Office level software. Lack of ERP-class systems.<br><br>2. No connection of production with other units of the organization. | 1. Systems and services that exclude the presence of paper media are used to implement the production process. An ERP - planning system has been implemented.<br><br>2. Information exchange with other organizational units is carried out by mail / telecommunications. | 1. An automated system tailored to the company's processes and standards is used to implement the production process. Automated management systems are used. ERP and PPC - production planning and control systems have been implemented.<br><br>2. Information exchange with other business units is carried out using the systems, using uniform data and established rules for their exchange. | 1. An MES or similar system is used to implement the manufacturing process. However, it is not integrated with ERP. Data analysis is based on large data sets, reports are generated automatically and recommendations are available in real time.<br><br>2. Information exchange with other business units is done through the system, using uniform data and using interdepartmental data servers. | 1. An MES system fully integrated with ERP is used to implement the manufacturing process. Integration with external data sources of suppliers and customers. Use of artificial intelligence systems for forecasting, diagnostics and recommendations.<br><br>2. Information exchange with other business units is carried out through fully networked and inter-branch IT solutions. |

Source: Own elaboration.

**Table 8.**

*Level matrix: area – production management, dimensions – data and M2M communication*

| Area | Dimension | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 |
|---|---|---|---|---|---|---|
| PRODUCTION | DATA | 1. The elements that make up the production system do not generate data - thus data is not processed. | 1. The components that make up a production system exclusively generate and store data. There are interfaces to access and visualize the data for anyone who needs it.<br><br>2. Data is stored for documentation purposes, visualized and used when needed. | 1. Data from production systems is generated, processed and analyzed. Tools exist to process the data, correlate and analyze it, and communicate the results to the user.<br><br>2. Data is analyzed and used mainly for monitoring purposes. Some data is used to optimize production processes (maintenance, predictive actions, etc.). | 1. Data from production systems are generated, processed, analyzed and evaluated to plan and control production processes.<br>There are resources/tools that can operate autonomously according to the information received after the analytical process.<br><br>2. Data used in several areas to optimize, plan and control production processes. | 1. Production systems are automatically planned and controlled. "Resources deployed throughout the supply chain can interact and reconfigure themselves to optimize performance.<br><br>2. Data is used for end-to-end process optimization. |
| PRODUCTION | COMMUNICATION M2M | 1. Machine-to-machine communication. Lack of communication. There is no automatic communication between machines and production equipment. Infrastructure of machines and systems cannot be controlled by IT, No integration (M2M), Control by PLC.<br><br>2. Human-machine communication Lack of information exchange between user and machine. Lack of data exchange. | 1. Machine-to-Machine Communication. PLCs are used, Field Bus Interfaces-connection of all devices on a single bus. Devices (sensors, controllers and IT systems) exchange information and data between each other. Some machines can be controlled by IT, are co-operative or have communication capability. Data processing capability.<br>2. Human-Machine Communication. Use of local user interface. Only local exchange of data and information in human-machine interaction (e.g., only at a particular production site). | 1. Machine-to-Machine Communication. The infrastructure of machines and systems can be controlled via IT and is partially integrated. Machines communicate via an industrial Ethernet network. Machines can exchange information.<br><br>2. Human-Machine Communication. Monitoring and control of production processes can be carried out centrally and locally. | 1. Machine-to-Machine Communication. Devices have Internet access, can be completely controlled by IT, are partially integrated or co-operative. Open-system interconnections (without the need for modification or integration of systems).<br><br>2. Human-Machine Communication. Human-machine interaction uses mobile devices to exchange data and information - mobile user interface. | 1. Machine-to-Machine Communication Machines and systems can be controlled almost entirely by IT, are fully integrated and communicate with each other through network services, M2M software. System for controlling Open systems.<br><br>2. Human-Machine Communication. Assistive software, augmented reality, etc. are used to exchange data and information. |

Source: Own elaboration.

**Table 9.**

*Level matrix: area – production management, dimensions – standardization*

| Area | Dimension | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 |
|---|---|---|---|---|---|---|
| PRODUCTION | STADARDIZATION | 1. UR - Basic monitoring of machinery and equipment, lack of MRO (maintenance, repair and operations) implementations.<br><br>2. Lack of Lean Management initiatives.<br><br>3. Quality 1.0 - Self-Monitoring, | 1. Small CMMS implementation, maintenance processes focused on functionality. Paperless maintenance management system.<br><br>2. Lean Management principles are understood by the Organization.<br>3. Quality 2.0 Inspection / control / assurance / standards. Repeatability of running internal processes. | 1. MRO principles are implemented; CMMS or other business information systems are used.<br><br>2. Lean initiatives have led to the implementation of Lean Management principles.<br><br>3. Quality - management systems have been implemented. | 1. Artificial intelligence, online sensors - the Internet of Things - are being used in maintenance activities.<br><br>2. Lean initiatives lead to continuous improvement in the production area and improvement of the lean tools and principles used.<br><br>3. Quality 3.0 Software is used to manage quality improvement and quality planning. The implemented management systems are functioning and being improved. | 1. MRO has been fully implemented. CMMS systems are being used. Big data analytics are used for predictive action. Continuous improvement in efficiency.<br><br>2. Lean initiatives are leading to improvements in the production area and the consolidation of lean principles. Lean Management principles are embedded in the Organization Management System.<br><br>3. Quality 4.0 - Continuous quality through real-time data and IoT- Internet of Things. |

Source: Own elaboration.

## Summary

Industry 4.0 solutions are intended to optimize and streamline processes, give the ability to manage them in real time and on the basis of real and available data, so that, as a result, production processes can be realized faster, production batches can be adapted more flexibly to changing customer requirements and the economic situation of the environment (Wang et al., 2018). Changes concerning the production area in terms of modern technological solutions are inevitable and ubiquitous. However, the variation depending on the size of the organization and the business sector means that the access, capabilities and use of Industry 4.0 solutions are not homogeneous (Amaral, Peças, 2021). Designed, based on detailed literature research, the tool illustrates the elements and stages of implementation of each dimension within the “Production Management” area. Designed for use in small and medium-sized enterprises, it fits into the aforementioned research gap. A further elaboration of the levels of implementation of Industry 4.0 solutions in the other functional areas of the organization listed above, along with their implementation dimensions, will provide the opportunity to conduct a comprehensive study. This tool can also be successfully used in the future when performing a self-assessment of the organization at the time of making decisions related to the implementation of modern technologies, while allowing the generation of new ideas. Given the limitations of this tool (number and selected functional areas, and selected dimensions), it is necessary to carry out a pilot study on the basis of which guidelines will be developed for its possible correction and improvement.

## References

1. Agca, O., Gibson, J., Godsell, J., Ignatius, J., Davies, C., Wyn, Xu, O. (2016). *An Industry 4 readiness assessment tool*. WMG The University of Warwick. https://warwick.ac.uk/fac/sci/wmg/research/scip/reports/final_version_of_i4_report_for_use_on_websites.pdf.
2. Amaral, A., Peças, P. (2021). A Framework for Assessing Manufacturing SMEs Industry 4.0 Maturity. *Applied Sciences*, *11*(13), Art. 13. https://doi.org/10.3390/app11136127.
3. Anderl, R. (2016). Ind*ustrie 4.0—Digital Transformation in Product Engineering and Production.* 21st International Seminar on High Technology—Smart Products and Smart Production.
4. *A/RES/70/1 Transforming our world: The 2030 Agenda for Sustainable Development*. (2030).
5. Caballero, I., Caro, A., Calero, C., Piattini, M. (2008). IQM3: Information Quality Management Maturity Model. *Journal of Universal Computer Science*, *14*(22), 3658-3685.

6. Chong, Z.Q., Low, C.Y., Mohammad, U., Rahman, R.A., Shaari, M.S.B. (2018). Conception of Logistics Management System for Smart Factory. *International Journal of Engineering & Technology*, *7*(4.27), Art. 4.27. https://doi.org/10.14419/ijet.v7i4.27.22499.
7. Colli, M., Berger, U., Bockholt, M., Madsen, O., Møller, C., Wæhrens, B.V. (2019). A maturity assessment approach for conceiving context-specific roadmaps in the Industry 4.0 era. *Annual Reviews in Control*, *48*, 165-177. https://doi.org/10.1016/j.arcontrol. 2019.06.001.
8. Grabowska, S. (2021). *Model Biznesu 4.0. Architektura, tworzenie wartości, ocena konkurencyjności i efektywności.* TNOiK.
9. Grufman, N., Lyons, S. (2020). *Exploring industry 4.0. A readiness assessment for SMEs.* Stockholm University. https://doi.org/10.13140/RG.2.2.12170.08647.
10. Kryukov, V., Shakhgeldyan, K., Kiykova, E., Kiykova, D., Saychuk, D. (2022). Assessment of transport enterprise readiness for digital transformation. *Transportation Research Procedia*, *63*, 2710-2718. https://doi.org/10.1016/j.trpro.2022.06.313.
11. Kumar, M.P., Sahithi, P., Revanth, S.S. (2020). Industry of quality (IoQ) – An industry 4.0 perspective. *International Journal of Applied Research*, *6*(4), 109-114.
12. Maasouman, M.A., Demirli, K. (2015). Assessment of Lean Maturity Level in Manufacturing Cells. *IFAC-PapersOnLine*, *48*(3), 1876-1881. https://doi.org/10.1016/ j.ifacol.2015.06.360
13. Michna, A., Kmieciak, R., Kruszewska, J. (2021). Ind*ustry 4.0 Implementation in automotive sector: Driving forces, barriers and competencies. Pilot empirical study.* Proceedings of the 38th International Business Information Management Association (IBMIA), pp. 9444-9450.
14. Michna, A., Kruszewska, J. (2020). *Industry 4.0 solution implementation factors: Driving forces, barriers and chances. Planned research of SME.* Proceedings of the 36th International Business Information Management Association (IBMIA), pp. 13924-13927.
15. Michna, A., Kruszewska, J. (2021). *Driving Forces, Barriers and Competencies in Industry 4.0 Implementation.* Proceedings of the 37th International Business Information Management Association (IBMIA), pp. 11112-11117.
16. Michna, A., Kruszewska, J. (2022a). Study on key competences for the implementation of Industry 4.0 solutions. *Zeszyty Naukowe Politechniki Śląskiej. Organizacja i Zarządzanie*, *161*. https://doi.org/10.29119/1641-3466.2022.161.10.
17. Michna, A., Kruszewska, J. (2022b). Determining the Level of Use of the Industry 4.0 Solutions in the COVID-19 Pandemic Era: Results of Empirical Research. *Sustainability*, *14*(14), 8844. https://doi.org/10.3390/su14148844.
18. Michna, A., Kruszewska, J. (2022c). *Dimensions of the Industry 4.0 implementation in manufacturing industry: Literature review.* Proceedings of the 40th International Business Information Management Association Conference (IBIMA).

19. Mittal, S., Khan, M.A., Romero, D., Wuest, T. (2018). A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs). *Journal of Manufacturing Systems*, *49*, 194-214. https://doi.org/10.1016/j.jmsy.2018.10.005.
20. Mohammad, U., Low, C.Y., Rahman, R.A., Johar, M.A., Koh, C.T., Dumitrescu, R., Rabe, M., Asmar, L., Kamaruddin, S., Berhad, S. (2019). Smart Factory Reference Model for Training on Industry 4.0. *Journal of Mechanical Engineering*, *16*(2), 129-144.
21. Müller, J.M. (2019). Business model innovation in small- and medium-sized enterprises: Strategies for industry 4.0 providers and users. *Journal of Manufacturing Technology Management*, *30*(8), 1127-1142. https://doi.org/10.1108/JMTM-01-2018-0008.
22. *PN-EN ISO 9001:2015* (2015). ISO. https://www.iso.org/standard/62085.html.
23. Rácz-Szabó, A., Ruppert, T., Bántay, L., Löcklin, A., Jakab, L., Abonyi, J. (2020). Real-Time Locating System in Production Management. *Sensors*, *20*(23), Art. 23. https://doi.org/10.3390/s20236766.
24. Rauch, E., Unterhofer, M., Rojas, R.A., Gualtieri, L., Woschank, M., Matt, D.T. (2020). A Maturity Level-Based Assessment Tool to Enhance the Implementation of Industry 4.0 in Small and Medium-Sized Enterprises. *Sustainability*, *12*(9), Art. 9. https://doi.org/10.3390/su12093559.
25. Rauen, H., Anderl, R., Fleischer, J. (2016). *Guideline Industrie 4.0. Guiding principles for the implementation of Industrie 4.0 in small and medium sized businesses.* https://www.plattform-i40.de/IP/Redaktion/EN/Downloads/Publikation/vdma-guideline-industrie-40.html.
26. Schuh, G., Scheuer, T., Nick, G., Szaller, Á., Várgedő, T. (2021). A two-step digitalization level assessment approach for manufacturing companies. *Procedia Manufacturing*, *54*, 25-30. https://doi.org/10.1016/j.promfg.2021.07.005.
27. Stawiarska, E., Szwajca, D., Matusek, M., Wolniak, R. (2021). Diagnosis of the Maturity Level of Implementing Industry 4.0 Solutions in Selected Functional Areas of Management of Automotive Companies in Poland. *Sustainability*, *13*(9), Art. 9. https://doi.org/10.3390/su13094867.
28. Stock, T., Seliger, G. (2016). Opportunities of Sustainable Manufacturing in Industry 4.0. *Procedia CIRP*, *40*, 536-541. https://doi.org/10.1016/j.procir.2016.01.129.
29. Wang, Y., Tran, T., Anderl, R. (2018). Toolbox Approach for the Development of New Business Models in Industrie 4.0. *Proceedings of the World Congress on Engineering and Computer Science WCECS*, *II*.
30. Zoubek, M., Poor, P., Broum, T., Basl, J., Simon, M. (2021). Industry 4.0 Maturity Model Assessing Environmental Attributes of Manufacturing Company. *Applied Sciences*, *11*(11), Art. 11. https://doi.org/10.3390/app11115151.