TRENDS IN USE OF ADVANCED MANUFACTURING TECHNOLOGIES IN SLOVENIAN MANUFACTURING COMPANIES

Iztok Palčič[1] [ORCID 0000-0001-5981-0209]

[1]*University of Maribor, Faculty of Mechanical Engineering, Maribor, Slovenia*

Abstract: *This paper deals with the use of advanced manufacturing technologies (AMT) and information technologies (IT) in Slovenian manufacturing companies in the light of Industry 4.0. The main objective of the paper is to determine the adoption of specific AMT and IT, such as digital factory technologies, 3D manufacturing technologies and use of specific types of robots. A special focus is on the use of artificial intelligence. Results are based on a sample of 141 Slovenian manufacturing companies, whose data were obtained through the latest 2022 European Manufacturing Survey edition. Additionally, we use data from previous research rounds. The results are presented with the use of descriptive statistics. Results show that the use of specific technologies in Slovenian manufacturing companies is quite diverse and that several technologies have obviously reached its peak.*

Key words: manufacturing company, advanced manufacturing technology, Industry 4.0, European manufacturing survey, Slovenia

1 INTRODUCTION

Industry 4.0 can be briefly defined as the digitalization of manufacturing and services. Commonly the general understanding of industry 4.0 concept is fully automated physical systems, but it should be considered as also automated and smart decision systems, not only automated physical systems (Elibal and Özceylan, 2021). Industry 4.0 is marked by highly developed automation and digitization processes and by the use of electronics and information technologies (IT) in manufacturing and services (Yang, 2017). Digitalization refers to "the manifold sociotechnical phenomena and processes of adopting and using (digital) technologies in broader individual, organizational, and societal contexts (Legner et al., 2017). The adoption of digital technologies influences almost all areas of modern firms, including manufacturing/production processes (Plekhanov et al., 2022).

In manufacturing companies besides IT, we must consider also other advanced manufacturing technologies (AMT), such as robots and additive manufacturing technologies. There are many representatives of AMT and IT and it is a fact that the dispersion of these technologies heavily depends on industry and company size. It is also true that technologies are very context related and are not suitable for all manufacturing companies. To determine the dispersion of different IT and AMT, we have analysed several technologies from the "digital factory" area as well as from "automation/robots" and "additive manufacturing technologies" area that have a potential and the need to find their way in all manufacturing environments. Therefore, our research presents the diffusion of 16 selected AMT and IT that are characteristic for the Industry 4.0 era in the Slovenian manufacturing industry. Besides analysing diffusion of AMT and IT this paper also presents a possible Industry 4.0 readiness index and assess Industry 4.0 readiness of Slovenian manufacturing companies.

This paper is organized as follows: first, we will introduce the concept of Industry 4.0 readiness and maturity models in general and later Industry 4.0 readiness index that we used in our research. The methodological section explains the characteristics of the European Manufacturing Survey (EMS). After that, we present the use of selected technologies in Slovenian manufacturing companies and the results, obtained with the use of Industry 4.0 readiness model. Finally, a concluding discussion is provided for the findings, where some managerial implications, research limitation and directions for future research are given.

2 INDUSTRY 4.0 READINESS & MATURITY MODELS

2.1 Industry 4.0 Readiness models in general

As the industry 4.0 concept came to the scene, both academics and practitioners are challenging to identify the current maturity and readiness of organizations for the industry 4.0 concepts (Elibal and Özceylan, 2021). In order to perform better, industry and academia have been making continuous attempts to develop and re-develop self-assessment models that can evaluate the Industry 4.0 readiness of organizations (Hizam-Hanafiah et la., 2020). Identification of these Industry 4.0 readiness models is also significantly needed as it will enable companies to measure precedents and antecedents in the digital transformation process which can then lead to organizational transformation (Canetta et al., 2018).

Industry 4.0 readiness model tries to represent how ready an enterprise is to implement advanced technologies and concepts. Some authors define readiness model as "the degree to which organizations are able to take advantage of Industry 4.0 technologies" (Hizam-Hanafiah et la., 2020) while others define it as "an instrument to conceptualize and measure the starting point and allow for initializing the development process" (Schumacher et al., 2016). In order to successfully master Industry 4.0 readiness, academic and industry researchers have developed a variety of Industry 4.0 readiness models in the recent years.

Schumacher et al. (2016) have developed maturity model to assess the Industry 4.0 readiness and maturity of manufacturing companies. Their main goal was to extend the dominating technology focus by including organizational aspects. They defined 9 dimensions and assigned 62 items to them for assessing Industry 4.0 readiness and maturity. The dimensions "Products", "Customers", "Operations" and "Technology" have been created to assess the basic enablers. Additionally, the dimensions "Strategy", "Leadership", Governance, "Culture" and "People" allow for including organizational aspects into the assessment.

De Carolis et al. (DeCarolis et al., 2017) have developed maturity assessment method to measure the digital readiness of manufacturing firms. Different dimensions are used to assess 5 areas in which manufacturing key processes can be grouped: 1) design and engineering, 2) production management, 3) quality management, 4) maintenance management and 5) logistics management. Canetta et al. (2018) have proposed a digitalization readiness model to assess the state of a company journey towards Industry 4.0 considering five dimensions: "Strategy", "Processes", "Technologies", "Products & Services" and "People". Pachinni et al. (2019) proposed a model, that employs a structure based on the Society of Automotive Engineers (SAE) J4000 standard for measuring the implementation of lean manufacturing in a company; the model is duly modified to encompass Industry 4.0 principles and concepts. The proposed model comprises eight technology enablers that are the most relevant based on existing literatures: big data, 'Internet of Things' (IoT), cloud computing, autonomous robots, additive manufacturing, cyber physical systems, augmented reality, and artificial intelligence.

As we pointed out there are many different readiness (and maturity) Industry 4.0 assessment models that cover many different areas. In our research, we focus on "Technology" area. We include several representatives of IT technologies from the model proposed by Pachinni et al. (2019). We present an Industry 4.0 readiness index, developed by Fraunhofer Institute for Systems and Innovation Research – ISI (Lerch et al., 2016), who is a coordinator of the EMS project. The model was applied to Slovenian manufacturing industry.

2.2 Industry 4.0 Readiness Index

The proposed Industry 4.0 readiness index was developed by Fraunhofer ISI (Lerch et al., 2016) to analyse data collected within our research: EMS. The logic of the Fraunhofer Industry 4.0 readiness index is presented in Fig. 1 and it is based on the selected Industry 4.0 enabling technologies. Since the different technologies are highly process and operation-dependent and come from different technology fields, a simple counting of the technologies used is not sufficient for an Industry 4.0 readiness index. Therefore, these AMT are divided into three technology fields: Digital management systems, Wireless human-machine communication and Cyber-physical system (CPS)-related processes. While the first two technology fields cover IT-related processes (Industry 4.0 basic technologies) and still have a clear distance from Industry 4.0, technology field CPS already contains the first approaches to networked/digital production and can therefore be classified as Industry 4.0 closer than the other two technology fields (Lerch et al., 2016).

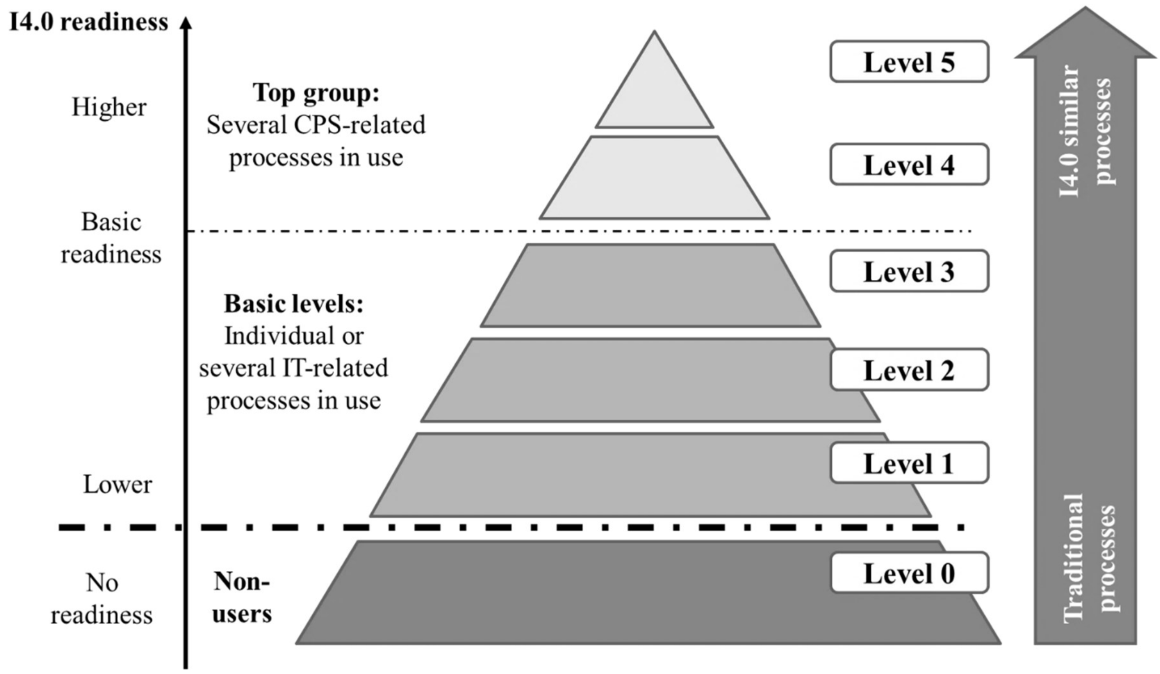

Figure 1: Industry 4.0 readiness index (Lerch et al., 2016)

Using this grouping, the companies can be classified as Industry 4.0-close companies, which, on the one hand, use and combine several technology fields in production and, on the other hand, use several of the CPS-related processes in their production. Accordingly, Industry 4.0 readiness index results with the following main groups and levels:

Non-users who are not (yet) ready for Industry 4.0:

- Level 0: Companies that do not use any of the Industry 4.0 enabling technologies and tend to still rely on traditional production processes.

Basic levels, as the basis on the way to Industry 4.0, with little readiness:

- Level 1 (beginners): Companies that use IT-related processes in one of the three technology fields.
- Level 2 (advanced beginners): Companies that use IT-related processes in two of the three technology fields.
- Level 3 (advanced users): Companies that are active in all three technology fields and use both IT-related processes and CPS-related processes.

Top group, as a pioneer on the way to Industry 4.0, with a slightly higher readiness:

- Level 4: Companies that are active in all technology fields and use at least two technologies of CPS-related processes.
- Level 5: Companies that are active in all technology fields and use at least three technologies of the CPS-related processes.

With each level, the Industry 4.0 readiness status increases or the distance to networked production decreases. While there is no readiness for Industry 4.0 in level 0, companies in levels 1 to 5 have a basic readiness. Companies that already use IT-related processes (levels 1 and 2), however, have a greater Industry 4.0 distance than companies in levels 3 to 5 that are already implementing the first elements of networked production. However, even at levels 4 and 5 it cannot be assumed that the threshold to Industry 4.0 has actually been breached. Rather, only the distance to networked production has narrowed. With the help of this Industry 4.0 readiness index, the change from traditional production to production close to Industry 4.0 can be mapped. Companies with a higher level have already made the transition more strongly than companies in the lower levels (Lerch et al., 2016).

Fig. 2 presents all three technology fields in Industry 4.0 readiness index and AMT from our research:

- Digital management systems: The first technology field is formed by software systems for production planning and scheduling (ERP) and the product lifecycle management systems. These are classified as the basic technologies of IT and digitization and are thus assigned to IT-related processes.
- Wireless human-machine communication: In the second technology field, the digital visualization is summarized with the mobile devices. This field is also assigned to the I4.0 basic technologies and thus to IT-related processes.

- Cyber-physical system (CPS)-related processes: The third technology field takes into account the near real-time production control system, the automation of logistics and the digital data exchange with suppliers and customers. These technologies already had production elements in cyber-physical systems and are therefore considered to be among the advanced I4.0 technologies.
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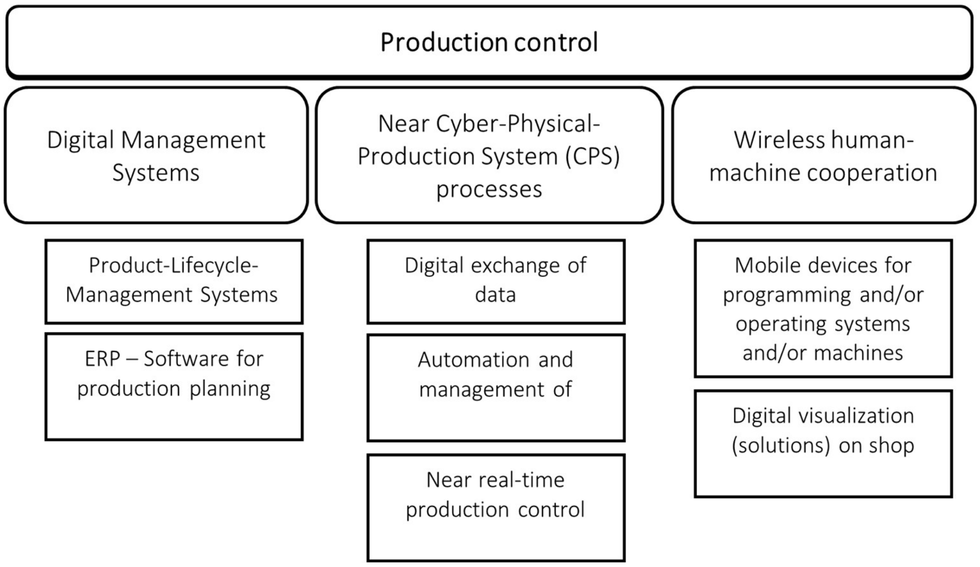

Figure 2: Industry 4.0 readiness index with selected AMT (Lerch et al., 2016)

3 EUROPEAN MANUFACTURING SURVEY

The research data was collected using the EMS, coordinated by the Fraunhofer Institute for Systems and Innovation Research – ISI, the largest European survey of manufacturing activities. The survey's questions deal with manufacturing strategies, application of innovative organizational and technological concepts in production, cooperation issues, production offshoring and backshoring, servitisation, and questions of personnel deployment and qualification. In addition, data on performance indicators such as productivity, flexibility, quality and returns is collected. In our last EMS research round we added questions on digital elements of products, new business models, artificial intelligence, circular economy etc. The survey takes place every three years. In most countries, EMS is organized as a paper-based survey at company level (the core questionnaire has six pages). The persons contacted to fill in the questionnaires are the production manager or the CEO of the manufacturing companies. The responding companies present a cross-section of the main manufacturing industries. Included are producers of rubber and plastics, metal works, mechanical engineering, electrical engineering, textile and others. The survey is conducted among manufacturing companies (NACE Revision 2 codes from 13 to 32) having at least 20 employees. The main objectives of the EMS project are to find out more about the use of production and information technologies, new organizational approaches in manufacturing and the implementation of best management practices.

Our research is based on EMS data from a Slovenian subsample from the year 2022 round. We sent 950 questionnaires and received 146 responses – a 15,4% response rate. For the purpose of our presented study, we have excluded companies from the textile industry (NACE 13, 14 and 15) and included 141 responses from other industries into the analysis. The response rate is almost 16%. In our 2022 subsample, manufacturing companies from NACE divisions 22, 25 and 28 are represented most widely with around 32% of companies from NACE 25, around 18% from NACE 28, and around 16% from the NACE 22 division. We classified manufacturing companies in three size classed based on the number of employees. The largest share of respondents is from medium sized companies (around 49%), followed by small companies (31%) and large companies (20%). We also classified manufacturing companies into suppliers (system supplier or supplier of parts or components) and Original Equipment Manufacturers (OEM): 52% were suppliers and 48% OEMs.

4 RESULTS AND DISCUSSION

4.1 Adoption of AMT in Slovenian manufacturing companies

In our last EMS 2022 research round, we have analysed the use of 21 AMT and ICT. Technologies were divided into six groups:

- Production control (7 technologies);
- Automation and robots (4 technologies);
- Additive Manufacturing Technologies (2 technologies);
- Simulation Tools and Data Analysis (3 technologies);
- Energy efficiency technologies (3 technologies);
- Waste recycling technologies (2 technologies).

In this paper, we are focusing on Industry 4.0 specific IT and AMT from the Production control, Automation and robots, Additive manufacturing technologies and Simulation Tools and Data Analysis (we are skipping energy efficient and waste recycling technologies). Fig. 3 presents a structural part of a question from EMS 2022 that deals with the diffusion of technologies and represents a core question for all our analysis.

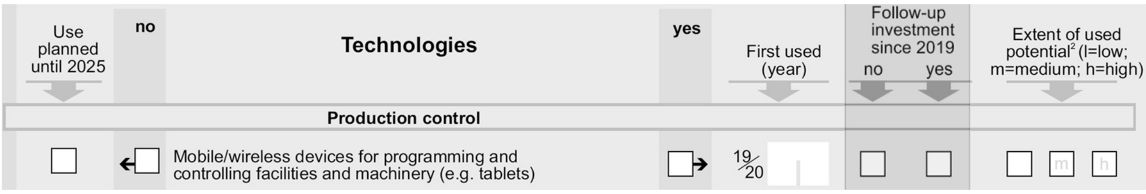

Figure 3: Question on the use of technologies in EMS 2022

Analysis shows (Table 1) that digital solutions to provide drawings, work schedules or work instructions directly on the shop floor and software for production planning and scheduling (e.g. the ERP or APS systems) are the most frequently used technologies, with instalment in around two thirds of Slovenian manufacturing companies. Mobile/wireless devices for programming and controlling machinery and/or facilities and Digital Exchange of product/process data with suppliers / customers (Electronic Data Interchange EDI) from "Production control" group are also catching up with instalments in almost 50% of Slovenian manufacturing companies. From the IT we can also observe frequent use of software for product design simulation, while software for simulating production processes (e.g. digital twins) are still rarely implemented.

We observed 4 types of robots. Besides industrial robots for manufacturing and handling processes we included additional subgroup of robots, namely: mobile industrial robots (e.g. AGVs) and collaborating robots/cobots. The former two robot types have been a part of manufacturing companies for a long time, while the latter robot types are gaining in their importance. When we looked at the use of industrial robots for manufacturing and handling processes together, we found that at least one type of robots is present in 64% of companies, making industrial robots the most widely used technology from our list next to ERPs and digital solutions on the shop floors.

Additive technologies have been a part of our research for several rounds. We observe two types of these technologies: 3D printing technologies for prototyping and 3D printing technologies for manufacturing. If we combine both types of additive manufacturing technologies, we can observe that at least one of them is used in around 45% of companies.

Figure 4 presents the use of selected technologies in the period from 2015-2018-2022. Firstly, we can clearly observe that the adoption share of majority of selected IT and AMT has increased in the period from 2015 until 2018. The only exceptions are ERP systems and 3D technologies for manufacturing. The former already have a very high adoption frequency with around 65% through the whole observed period.

Table 1: AMT adoption in Slovenian manufacturing companies

AMT	Share [%]
Production Control	
Mobile/wireless devices for programming and controlling machinery and/or facilities	47,5%
Digital solutions to provide drawings, work schedules or work instructions directly on the shop floor	64,5%
Software for production planning and scheduling (e.g. ERP or APS system)	63,8%
Techniques for automation and management of internal logistics (e.g. Warehouse management systems, RFID)	27,7%
Digital Exchange of product/process data with suppliers / customers (Electronic Data Interchange EDI)	44,0%
Product-Lifecycle-Management-Systems (PLM) or Product/Process Data Management	17,7%
Near real-time production control system (e.g. Systems of centralized operating and machine data acquisition, MES)	33,3%
Automation and robots	
Industrial robots for manufacturing processes (e.g. welding, painting, cutting)	52,5%
Industrial robots for handling processes (e.g. depositing, inserting, sorting, packing processes)	38,3%
Mobile industrial robots (autonomously moving around the shopfloor)	5,7%
Collaborating robots/Cobots (free of fences)	9,9%
Additive manufacturing technologies	
3D printing technologies for prototyping (prototypes, demonstration models, 0 series)	39,0%
3D printing technologies for manufacturing of products, components and forms, tools, etc.	23,4%
Simulation Tools and Data Analysis	
Software for product design simulation (e.g., product performance or parts reliability)	44,0%
Software for simulating production processes e.g. on process, line, factory level, or for supply chain	14,9%

The increase of IT and AMT use in the period from 2018 until 2022 in general is not so evident as for the previous period. Some technologies are (at least) stagnating in their use, while some received a major boost, especially mobile/wireless devices for programming and controlling machinery and/or facilities. Digital solutions to provide drawings, work schedules or work instructions directly on the shop floor are also showing a steady increase in use.

We can observe an increase in the use of industrial robots manufacturing and handling processes in the period from 2015 to 2018. But if look the last period from 2018 to 2022 it seems their use is stagnating. In 20 years since we follow the use of industrial robots in Slovenia, we observed that in the period from 2003 until 2009 the use of industrial robots has doubled, but after that there was only approximately 15% of additional growth (in terms of looking the percentage of manufacturing companies that use at least one type of industrial robot).

If we look at the 3D technologies and companies that use at least of two types, we can observe a substantial increase of use in the period from 2018 until 2022. According to EMS 2018 results these technologies were used in one third of the companies, in 2022 already in almost 45% of Slovenian manufacturing companies.

In the last 5 years we are witnessing a lot of conversation on the use of artificial intelligence (AI) in every aspect of our lives. The same applies for manufacturing companies, where the applications / software with self-learning functionality are already showing their potential. In our research we asked manufacturing companies if they use specific software solutions in different areas (Table 2). Additionally, we have asked if this software solutions already include self-learning algorithms / AI functionality. As we can see from Table 2 the share of companies that use software for specific areas quite differs (column 2). In general, around 20 to 30% of companies that use software solution for specific area also includes self-learning algorithms / AI functionality in these software solutions (column 3). The fourth column presents the general share of Slovenian manufacturing companies that use AI-supported software. It is seen that this percentage is from 5 to 12%.

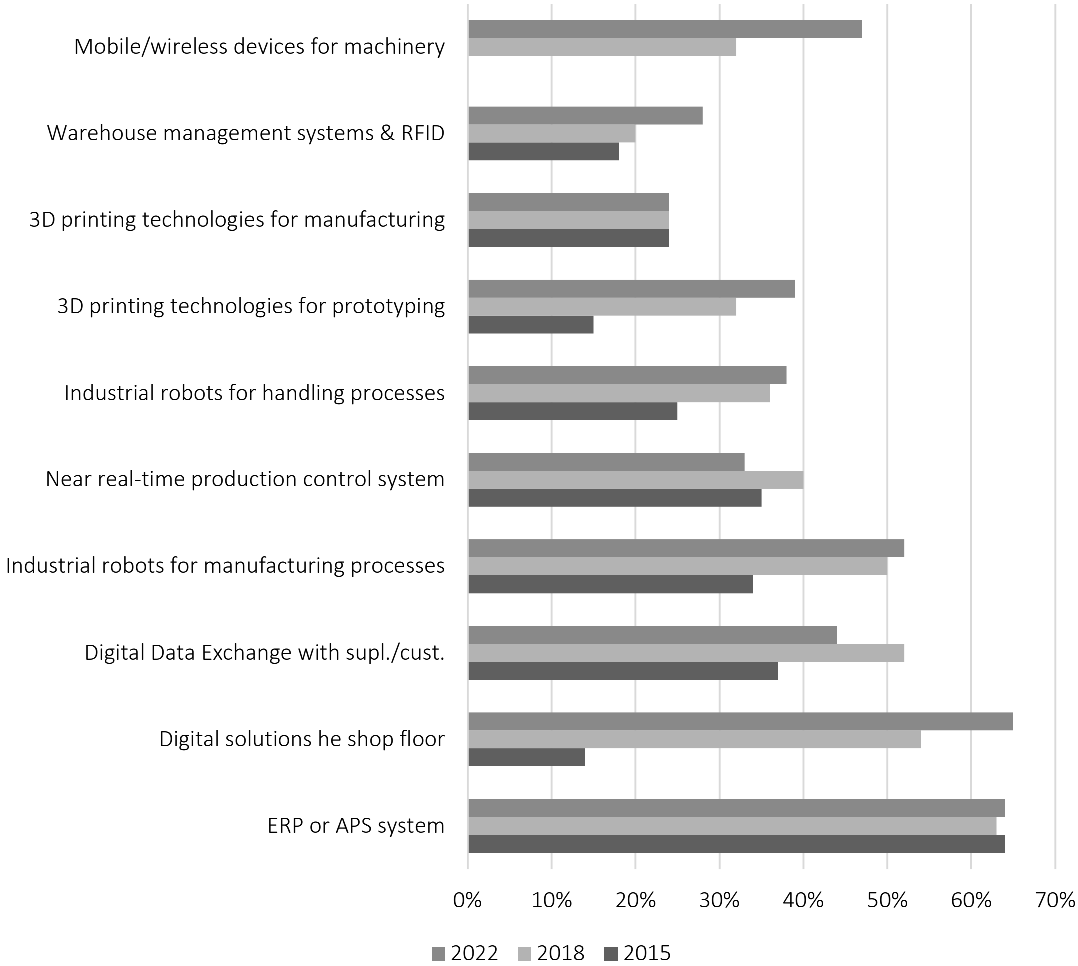

Figure 4: Trends in using AMT in Slovenian manufacturing companies

Table 2: Use of specific software solutions in Slovenian manufacturing companies

Using specific software solutions in the area of ...	Share [%]	Share with AI who use SW [%]	Share with AI in general [%]
Management of production processes (e.g. process monitoring)	61,7%	12,6%	7,8%
Quality control (e.g. defect detection)	43,3%	27,9%	12,1%
Maintenance of machinery and equipment (e.g. condition monitoring)	36,9%	21,2%	7,8%
Management of internal logistics (e.g. warehouse, transport)	30,5%	18,6%	5,7%
Energy management	23,4%	24,2%	5,7%
Improvement or innovation of production processes	26,2%	29,7%	7,8%

In EMS 2018 we added one general question on AI use and its first installations. Four years ago, only 5% of the observed population of manufacturing companies used AI in their processes. As we can see there was a substantial growth of share of manufacturing companies that use specific solutions based on self-learning algorithms / AI. If we combine all 6 possible AI-based software types, there is 20% of Slovenian manufacturing companies using at least one of these 6 types.

4.2 Industry 4.0 readiness index in Slovenian manufacturing companies

Fig. 5 depicts the distribution of all six described Industry 4.0 readiness levels for Slovenin manufacturing companies. Around 14% of all companies have so far not implemented any AMT or IT in production. Around 57% of all companies already have IT-related processes in their production and form the basic levels.

However, this group covers a big share of companies (nearly two thirds). This basic users group includes the group of beginners who only use technologies from one field (almost 18%; level 1), the advanced beginners who operate in two technology fields (almost 24%; level 2), but also the already advanced companies that are combining technologies from all three technology fields (over 16%; level 3). In the two highest levels 4 and 5, this top group consist of a total of 28,4% of all companies. About every fourth company is consequently active in all three technology fields, and not only uses IT-related processes, but also several CPS-related processes simultaneously. Levels 4 and 5 have very similar share of companies.

A look at Slovenian manufacturing sector shows that there is still a certain share of companies that heavily relies on traditional production processes (non-users). The main group of Slovenian manufacturing companies has slowly started to use IT-related processes, but there is a big difference between beginners and advanced users. The former are clearly closer to the non-users in terms of the type of production processes, the advanced companies are slowly preparing to enter the top group. The top group is not only active in each of the three technology fields, but also uses several CPS-related processes. There is a certain readiness to digitize their production, where the level 5 companies (14,9%) in particular seem to be preparing for Industry 4.0 related production or are already trying to implement it.

Fig. 6 presents comparison between Industry 4.0 readiness levels for Slovenian manufacturing companies based on data from EMS 2018 and EMS 2022 data. We can see a small shift of companies into higher levels (3, 4 and 5), and a small decline in lower level (0, 1, and 2), but the differences are rather small.

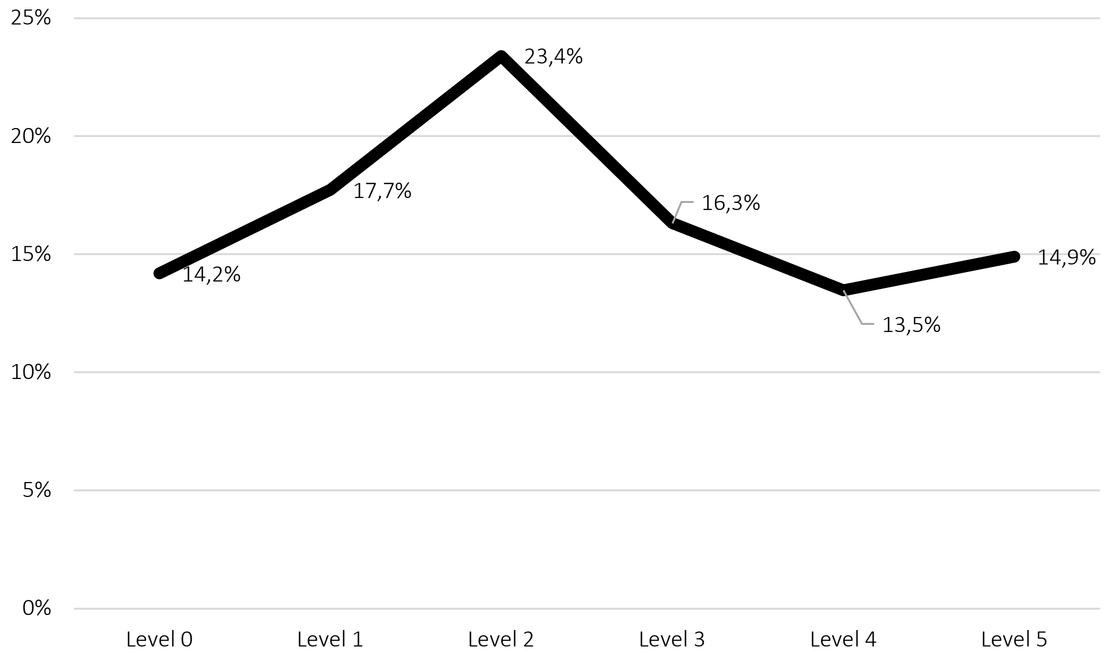

Figure 5: Industry 4.0 readiness index in Slovenian manufacturing companies (EMS 2022)

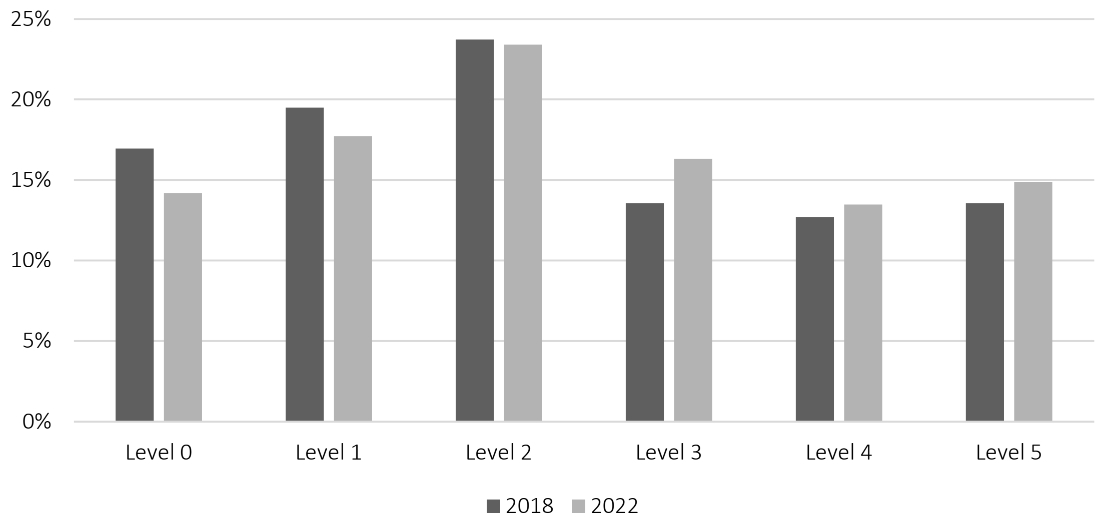

Figure 6: Comparison of Industry 4.0 readiness index in Slovenian manufacturing companies in EMS 2018 and EMS 2022

5 CONCLUSIONS

Our results show that the use of IT and AMT in Slovenian manufacturing companies is very diverse and context related. Our main goal of this paper was to compare the use of selected IT and AMT through the last 4 years. In general, we have observed a small increase in use of included technologies, but there are also technologies where their use obviously achieved its peak. The Industry 4.0 readiness levels for Slovenian manufacturing companies also points on the fact that the observed period did not bring a huge shift in using IT and AMT.

As is the case with all research, some issues must be taken into account when considering the reliability, significance, and general use of the obtained results. First, the data from Slovenia contains 141 companies in the EMS 2022 round. Although the sample is not small, further research should go towards the direction of a larger sample of more countries. We will also make more in depth analysis regarding the use of IT and AMT where we will consider company size, technological intensity of the industry they belong to, their status as the final producer for consumers or business customers (OEM) or supplier. We will also look into the relationship between introduced IT and AMT and specific characteristics, such as product complexity, production type and ability to introduce new products.

This research also has practical and managerial implications. Our results on the adoption of IT and AMT indicate the current state of technology implementation in Slovenian manufacturing companies, which can serve managers as a roadmap for future investments. Similar with Industry 4.0 readiness index managers can on one hand get familiar with one of the possible models to measure company readiness for Industry 4.0 and on the other hand compare their company to Slovenian average Industry 4.0 readiness.

6 ACKNOWLEDGMENTS

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