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"A LITERATURE REVIEW OF INDUSTRY 4.0 MATURITY MODELS AND LEVELS IN DIFFERENT COUNTRIES"

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A LITERATURE REVIEW OF INDUSTRY 4.0 MATURITY MODELS AND LEVELS IN DIFFERENT COUNTRIES

Content

1. Introduction

Industry 4.0 can be briefly defined as the digitalization of manufacturing and services. [6] Our lives, customs, products, and companies are being strongly influenced by new technologies and new business models transformed by the 21st century. Increasing use of new technologies such as artificial intelligence, advanced robotics, Internet of Things. Self-driving cars, 3D printing, and nanotechnology are designing a new world. [1] These changes are critical to the need to adapt to this era of new technologies (also known as digital transformation, which stands for "the adoption of business processes and practices to help organizations compete effectively in an increasingly digital world" [4]. The global digital economy should reach $23 trillion by 2025 and is expected to grow at a rate 2.5 times faster than the rest of the global economy in other sectors over the next few years [16]. It is estimated that the digital economy accounts for approximately 5% the of global GDP and 3% of global employment [10].

Technology domains are factors that determine the competitive position of countries and companies. Germany, the world's fourth-largest economy, has defined advanced technology as a clear strategic innovation to become a world leader, consolidating its position as an industrial and export leader. Innovative solutions are defined as factors that drive prosperity and maintain the quality of life of its population. [11] China officially proposed the Smart Manufacturing 2025 Strategy in 2015. The strategy aims to solve the problem of low manufacturing levels in China. It can help to accelerate the pace of innovation and reshaping of the domestic manufacturing industry, promote the deep integration of various manufacturing industries and the internet, and promote the intelligent construction of manufacturing cons. [9]

To remain competitive and seek growth in its industry, it must position itself in the face of this new reality of digital transformation. And a good way for this is to focus on reference leading countries in the technological race. [10]

Against this background, I am curious about the development of digital Industry 4.0 in different countries. How mature are these countries in digital manufacturing development? Which countries have differences? whether this difference is obvious? and whether it is consistent with our expected value.

Therefore, this thesis aims to conduct a systematic literature review of the industry 4.0 maturity level to obtain a clear and whole view of the current maturity level in different countries. Identifying characteristics of the thesis, making a main information comparison, creating several main tables of maturity dimensions and maturity level, and comparing the maturity level result in 13 countries have been aimed to give readers a clear view of the development level in maturity degree in 13 countries and guide future development studies.

There is one main question of this study:

Q: What is the maturity level in different countries?

The structure of this thesis is as follows. Section 2 describes the methodology of the literature review and outlines findings and gaps in current review articles about industry 4.0 maturity. Section 3 gives information about the main references review for the industry 4.0 maturity level. Sections 4 and 5 present the quantitative and qualitative analysis results. Section 6 gives information about the review results and challenges for further research studies. Finally, the conclusion has been made in Section 7.

2. Methodology

To conduct an appropriate literature review, a methodology must be defined. In this section, the method of the literature review will be introduced. Procedures for data collection and analysis will be briefly described.

The next step is determining search terms and inclusion-exclusion criteria for the review.

2.1 Data collection

Conducting a review phase starts with identifying research studies and this identification starts with the definition of search terms. To gather more articles about maturity levels in different countries, expressions such as “readiness” and “assessment” are also used to identify industry 4.0. The below list shows the search terms for the review.

Search terms
“Digitalization”, “Industry 4.0”, “manufacturing”, “maturity”, “maturity model”, “industrial”, “industrial companies”, “readiness”, “assessment”, “smart factory”, “maturity level”, “self-assessment”, “maturity index”, “readiness index”, “assessment index”, “readiness level”. Literature search has been conducted on Scopus and google scholar with the query shown in the given list.

Search query
(TITLE-ABS-KEY (“digitalization”) OR TITLE-ABS-KEY (“digital” AND “transformation”) OR TITLE-ABS-KEY (“industry 4.0”) AND TITLE-ABS-KEY (“maturity” AND “ model”) AND TITLE-ABS-KEY (“manufacturing”) OR TITLE-ABS-KEY (“industrial” AND “companies”) AND NOT SRCTITLE (“computer” AND “sciences”) AND NOT TITLE-ABS-KEY (“engineering”) AND TITLE-ABS-KEY (“readiness”) AND TITLE-ABS-KEY (“assessment”))

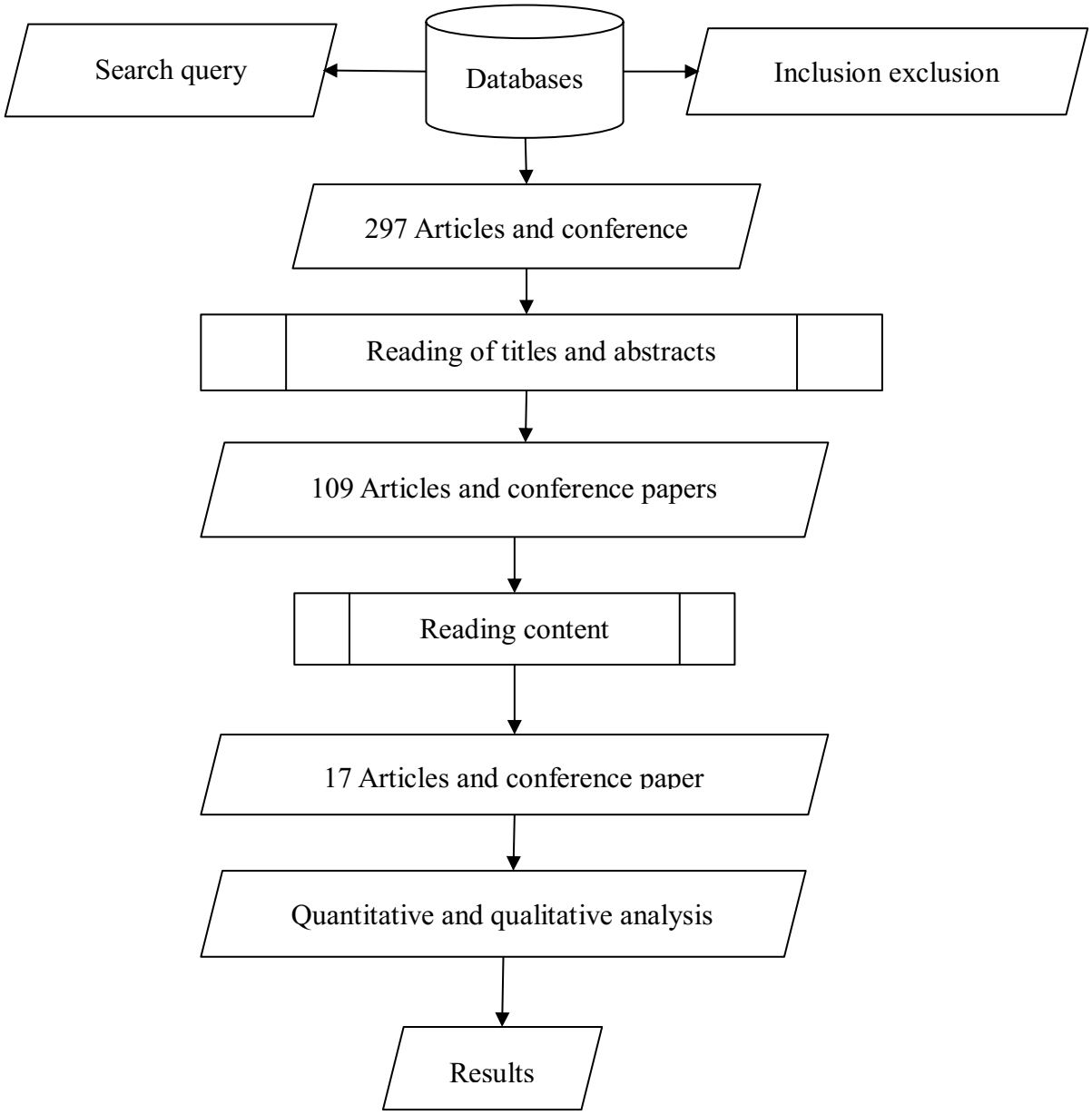
Dealing with the manufacturing concept is the main inclusion criterion for this review. Search terms mentioned in the data above are searched in titles, abstracts, and keywords of the publications. The language of publications is limited to English. Database search has been conducted until Nov 2022, which means articles until this date have been reviewed.

The process of the conducted literature review is shown in Fig. 1 and 297 articles/conference papers are found. By reading titles and abstracts, it has been seen that 109 review papers are related to the industry 4.0 maturity degree. Then the next step is to read the content of the article to determine whether the article measures the maturity of the country at the national level.

2.2 Data analysis

As mentioned in Section 1, identifying characteristics of the reviewed industry 4.0 maturity level at the national level is a key question of this thesis. To answer this question, a qualitative and quantitative analysis has been conducted through 17 articles. In Fig. 1, Quantitative and qualitative analysis of the reviewed literature are the keys to the data analysis.

Figure 1. Schema of literature review



3. Findings from the review articles

After reviewing 109 articles' content, I gathered 17 main references which show the industry's 4.0 maturity level in 13 countries. They are Colombia, Kazakhstan, Indonesia, Malaysia, Taiwan, Germany, Brazil, China, Serbia, Hungary, Turkey, Poland, Portugal, and Italy. According to different enterprise scales, the articles applied several types of industry 4.0 manufacturing maturity models in their countries. After analyzing different sample data, each article came up with different results on the degree of digitization in industry 4.0.

The main contents of these documents are as follows:

The study of Ávila-Bohórquez J.H (2022) is the first article found in the literature search which validated 23 enterprises in Bogotá, the capital city of Colombia, contributing a quarter to Colombia's GDP and about 20% of employment. Because Latin America still does not have a culture of applying the elements of Industry 4.0. Therefore, this document serves as a basis for SMEs in Latin America to establish a baseline measurement for the application of Industry 4.0 elements in companies. In the meanwhile, this article shows the preliminary result of the maturity level in Bogotá.

Dikhanbayeva D (2022) aims to study one of the promising but not investigated sectors of Kazakhstan textiles. Textiles took the main share (60%) in Kazakhstan's light industry and is considered one of the well-growing sectors. It is oriented to SMEs in that sector, as SMEs present almost 97% of all businesses in the country. And this study analyzed the current status of industry companies via the developed maturity assessment model to investigate their digitization state, identify common strengths and weaknesses, draw out the possibilities that digital technologies may bring to the sector, and conclude with recommendations to improve the sector.

The reference Arie Rahmadi (2020) reviewed the textiles industry in Indonesia. According to Ramanathan (2018), for the four clusters of ASEAN nations to enter the Industry 4.0 ecosystem, the Government of Indonesia should connect the frameworks of Industry 4.0 and circular economy principles in theory, practice, policy initiatives, and research programs. Therefore, it is important to evaluate the Industry 4.0 readiness profile at the level of the firm and the sector. Thus, this article conducts the maturity level in the textiles industry in Indonesia.

Christian Stark (2022) builds an Industry 4.0 maturity questionnaire and applies it to Malaysia's medical device manufacturing industry. The questionnaire suited the acatech Industrie 4.0 maturity index model's multifaceted requirements. The study contains 54 answers with a 2.91 industry maturity level and is set to enter the visibility stage.

The article by Lin T.-C (2021) focuses on Taiwanese enterprises using data collected from 165 valid questionnaires and subjected to a cluster analysis and addressed the gap between maturity

models and project management by designing an effective assessment framework for smart transformation. Enterprises can use this model to examine the maturity level of their transformation and assess the scope for improvement in their project strategies and implementation barriers. The results reveal that most enterprises' smart transformation is at an immature or medium-maturity level, and is therefore amenable to further improvement.

Luciano Raizer Moura (2020) presents a comparative analysis of the maturity level in industry 4.0, of Brazilian and German companies which used the VDMA (German Mechanical Engineering Industry Association) model. The study shows that Brazilian companies have the same level of maturity of German companies in readiness for Industry 4.0 on average, but there is a significant difference that 5.6% of German companies are at the advanced level in Industry 4.0.

The study Jingyi Hu (2019) studies the maturity model of intelligent manufacturing based on the current situation in China from three aspects: maturity level, capability factor, and maturity requirements. According to the analysis results by the self-evaluation platform of China Electronics Standardization Institute, the maturity of intelligent manufacturing capabilities of most manufacturing companies in China still has a lot of room to improve.

Vidosav D. Majstorović (2020) presents a model for assessing the maturity and readiness of manufacturing organizations to operate and implement Project I4.0 in Serbia, which obtained 49 responses in SEMs enterprises.

The article by Gábor Nick (2019) assesses the industry 4.0 readiness of companies in Hungary with 99 questions. Based on the answers given by Hungarian organizations, the use of this data has not yet been integrated into manufacturing and production processes.

Oğuz Emir (2020) adopting these new industrial challenges in Small and Medium Sized Enterprises, and responding to them quickly is vital when it is considered that they have 99.8% of the enterprise share of Turkey. 1040 companies participated in the conducted e-survey. The average industrialization level is calculated as 2.43, and it is observed that each manufacturing sector has close levels around the average score except for food manufacturing with 2.27(total of 5).

The reference Bogdan Nogalski1 (2020) obtains objective information on the maturity of enterprises from the perspective of the implementation stage of the idea of Industry 4.0. The research was conducted among Polish producers of the agricultural machinery sector. The basic research was carried out on a sample of 71 enterprises representing Poland's agricultural machinery sector.

Bozena Gajdzik (2022) presents the steel market enterprises' maturity for functioning in Industry 4.0. The model is based on the assessment of key technologies or pillars of the new

industrial concept. The proposed assessment includes five levels of investment maturity under the conditions of the fourth industrial revolution. The research was carried out with 79 selected steel enterprises for the pilot study. Based on the research, it was established that the segment of enterprises in the Polish steel market is at the third level of maturity in the five-level scale of the model.

The research Isabel Castelo-Branco (2022) presents an Industry 4.0 measurement model that is applied to a sample of Portuguese companies from several economic sectors beyond manufacturing.

Fabiana Pirola (2019) proposes a comprehensive assessment model suitable for evaluating small- and medium-size enterprises' digital readiness levels in Italy, discusses the results of an assessment of 20 manufacturing SMEs using the proposed model, and highlights priorities needed to undertake a successful journey towards Industry 4.0.

Luiz Felipe Pierin Ramos's (2021) studies with 9 companies from different industrial sectors of southern Brazil conducted and pointed out that two evaluation models provide data that outline the real situation of organizations from different and complementary perspectives.

The study by Alessia M.R (2021) given the challenges that Industry 4.0 poses, proposes a comprehensive assessment model suitable for evaluating small and medium-sized enterprises' digital readiness levels, discuss the results of an assessment of 20 manufacturing SMEs using the proposed model and highlight priorities needed to undertake a successful journey towards Industry 4.0. Starting with a literature review about maturity and readiness-assessment models for Industry 4.0, the study's model has been built and validated through two pilot case studies, with the final model used in an extensive case studies research with 20 enterprises.

Daniel Bittighofer (2018) offers insight into a pilot study concerning the readiness level of companies in terms of Industry 4.0. The companies were classified according to enterprise size from small to big and rated in different dimensions. A survey method was chosen and realized through personal interviews or conference calls. For the study, 24 German enterprises were interviewed. As an overall result, it can be determined that level two (intermediate) was the highest average level that has been achieved relating to the enterprise size. The highest rating was reached in the field of big data. However, it has to be noted that there is a large potential for German companies to reach a higher readiness level in terms of Industry 4.0.

Investigative literature about industry 4.0 maturity model application and maturity level reviews show the current reviews are sufficient in these few years. However, the number of literature surveys in different countries is unevenly distributed, and even many developed countries do not have corresponding articles which also can be proved by the study by Marta Flamini (2022). This study observed a large diffusion of Assessment campaigns in Europe and

Asia but not in the U.S., with the Top 5 countries being Malaysia, Poland, Italy, Germany, and Slovakia. [7]

Findings from the review articles which constitute motivation for this final thesis of a university program can be summarized as follow:

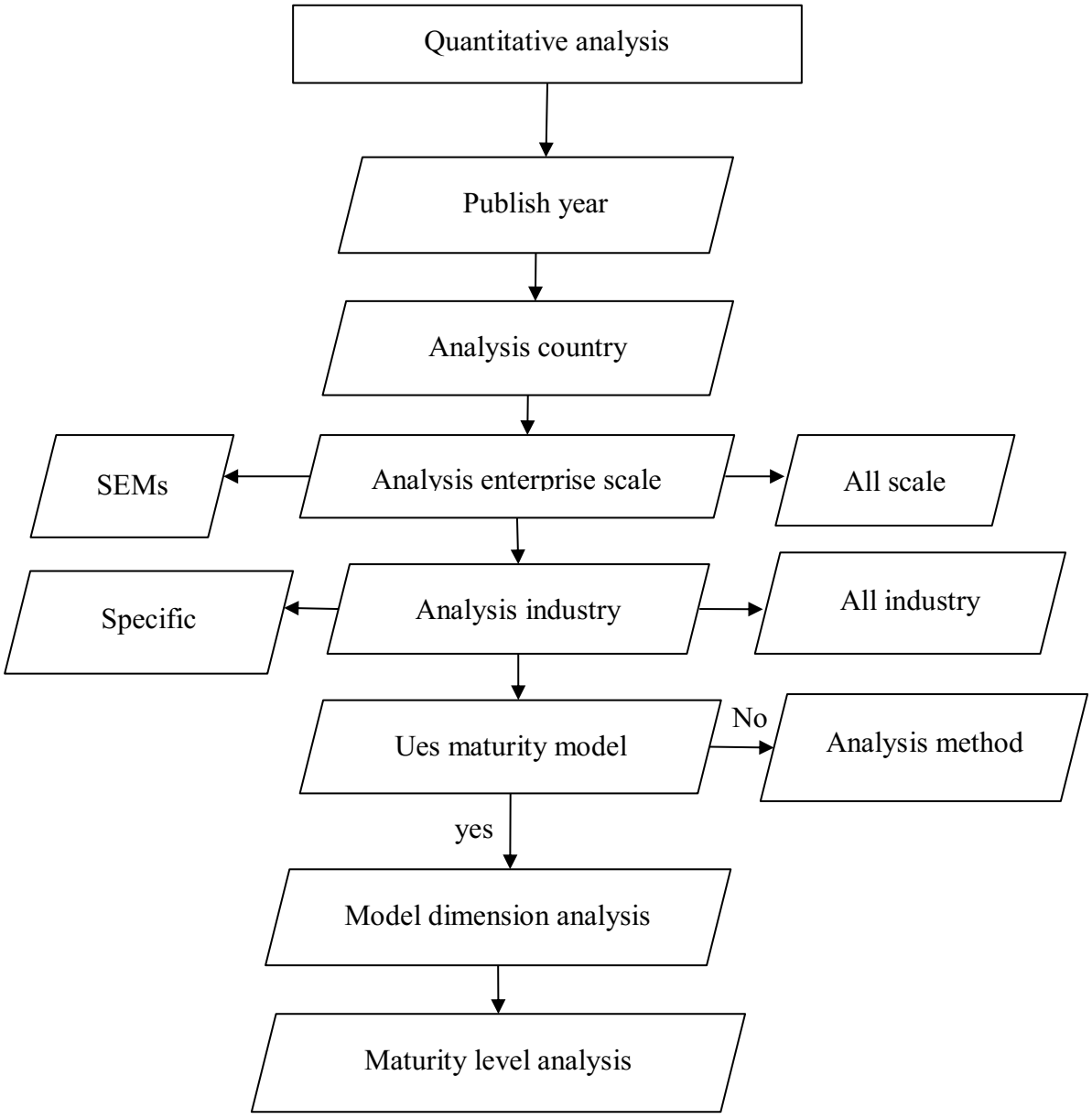
- Most articles use the maturity model and maturity level to evaluate the industry 4.0 maturity level in their country, and only a few use questions or macro indicators to measure the level of maturity.
- Most references use questionnaires as research survey to measure the maturity level in their country and get precise results.
- There are several different maturity models applied to evaluate the maturity level but the results are very similar.
- Some studies evaluate the maturity level in a very specific field, like textile, and steel manufacturing, which also overlaps in other countries.
- Some articles weigh the maturity level in all scale enterprises, and some assess in SMEs companies.
- Some articles aim to build better maturity models that can be applied more suitably, and effectively.

After reading all the important references, it can be found that the purpose of these articles is not always to measure the degree of digitization development of the country, and the purpose of some articles is to draw another appropriate maturity model based on case analysis, helping companies in a specific country to use the maturity model Simpler, quicker and more effective. As the article said, digital measurement is fraught with difficulties. However, it does not affect the measurement and comparison of the level of development of these countries under industry 4.0 digitalization, because the figures are displayed with the subdivided size of the sample and the type of enterprise. This final thesis of a university program will help readers understand the maturity level in these countries with different situations. And it can give readers an initial concept, and enable readers, scholars, and entrepreneurs to find the most appropriate articles and models which can be adopted in their own companies.

4. Quantitative analysis of the reviewed literature

In 17 documents, there are many different dimensions, so quantitative analysis is used to summarize and sum up all the dimensions, to make analysis convenient and create a clear view for the reader. The steps of quantitative analysis are shown in Fig. 2.

Figure 2. Quantitative analysis dimensions



Reviewed literature showed that the maturity level in different countries is attracting researchers' attention. As can be seen in Fig. 3, academic publications about industry 4.0 maturity level in countries show a big increase from 2019 to 2022 when compared with 2016 to 2018. And publications of the maturity level in countries grow more steadily.

Figure 3. Publish time in 17 main references

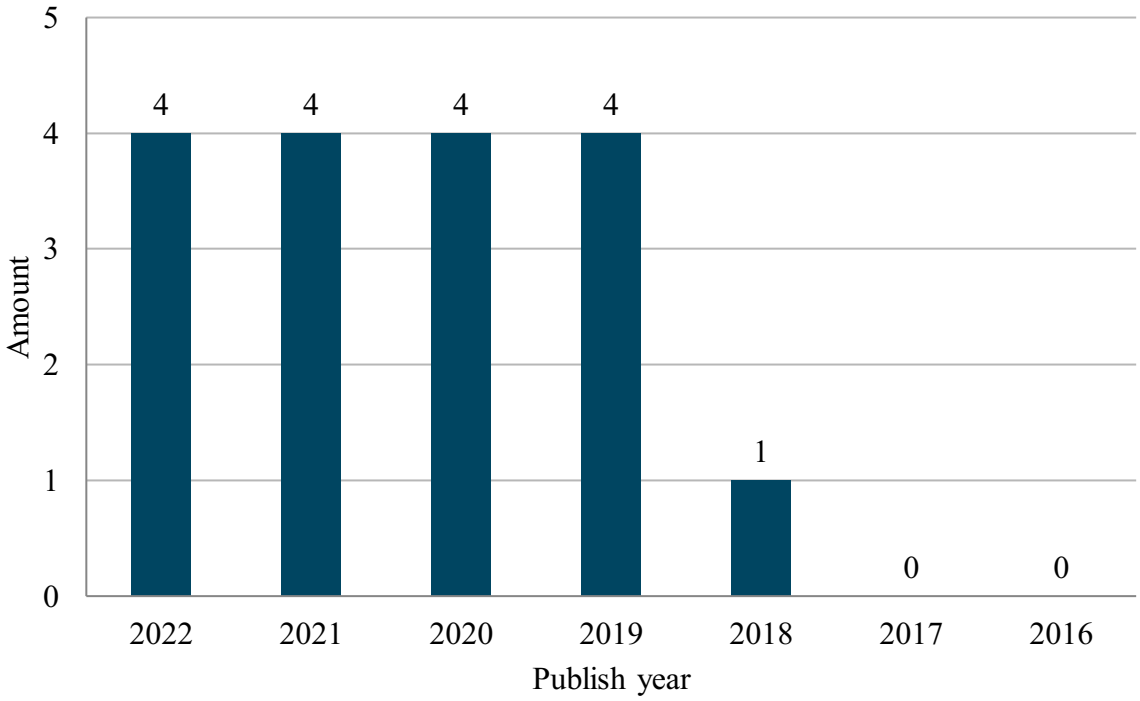


Fig.4 shows which country of the publications they wrote and discussed among 17 references. Out of 17 countries, Germany, China, Poland, Italy, and Brazil has the same amount of literature at 2. Other countries only have 1 reference. In Fig.5, among 13 countries, 4 countries belong to developed countries. Instead, 9 publications analysed the maturity level in developing countries.

Figure 4. Distribution of 17 documents in 13 countries

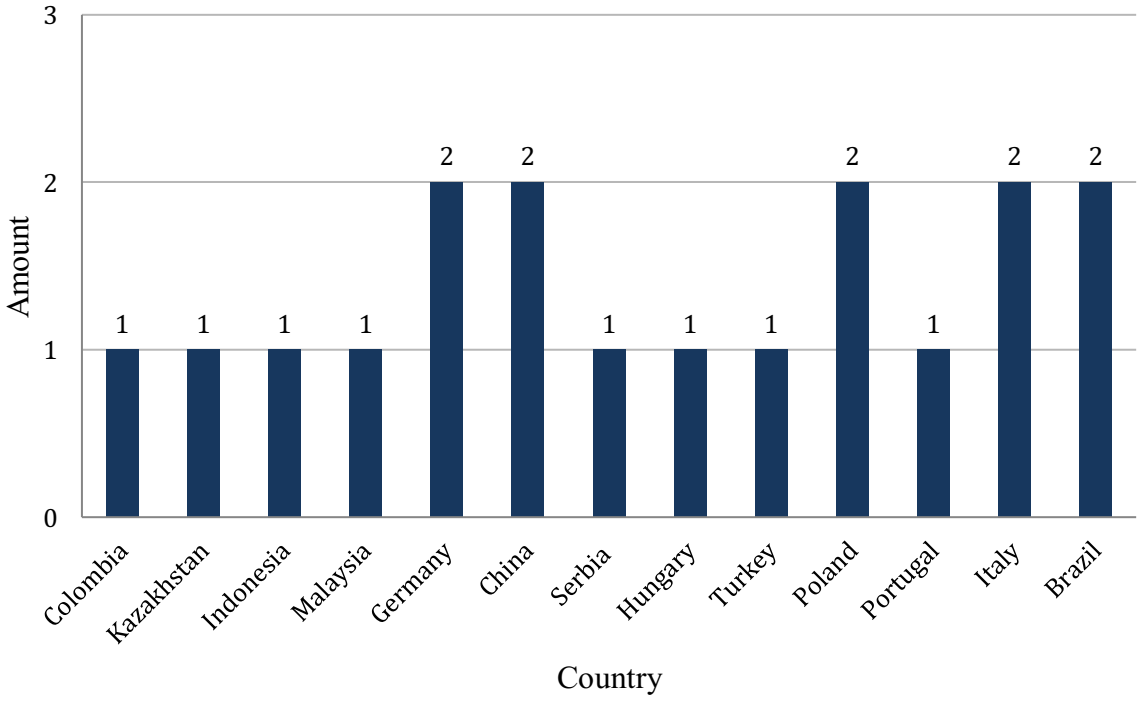
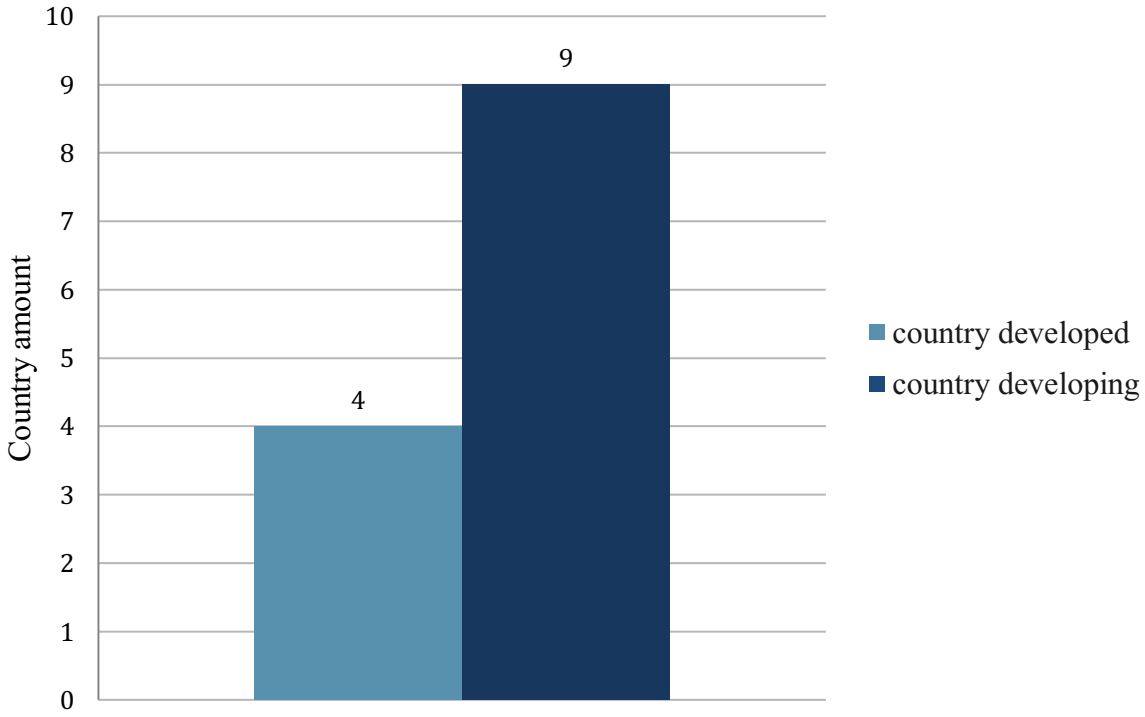


Figure 5. The 13 countries distributed in developed and developing countries



According to Fig.6, 11 references measure the maturity level of the country in all company scales, 6 articles are especially focused on small and medium Enterprise.

Fig.7 shows the industry scope that the publications are describing. And 11 articles are focusing on all scope industries in manufacturing, and 5 publications especially focused on specific industries, such as Textile, medical devices, manufacturers operating in the agricultural machinery sector, and Steel Manufacturing. And 1 article is focusing on all scope industries which is not limited in manufacturing industry.

After the classification of these characteristics, these publications mainly focus on all manufacturing industries and all scale enterprises which is a good signal to show comprehensive results of the maturity level in their countries.

Among these 17 publications, the dimension level distribution shows in Fig.8. And as can be seen that 4 dimensions of the maturity model are the most common ones.

As seen in the findings of Fig.8, this is the maturity level application among 17 publications, 5 maturity levels is the most commonly utilized dimension. Then 3, 4, and 6 maturity level are hard to be employed.

Figure 6. The company scale's distribution among 17 references

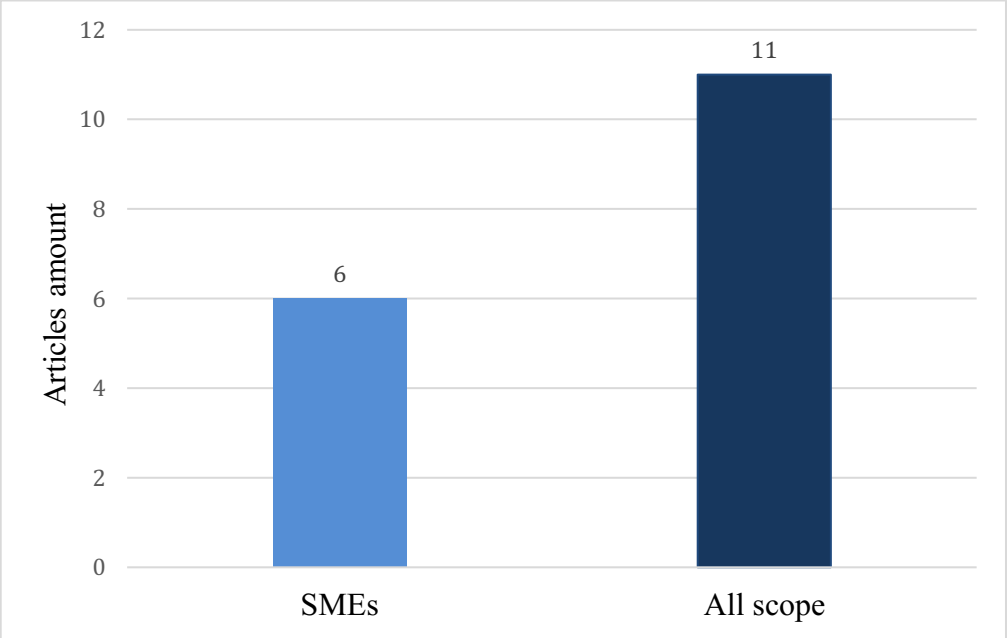


Figure 7. The company industry distribution among 17 references

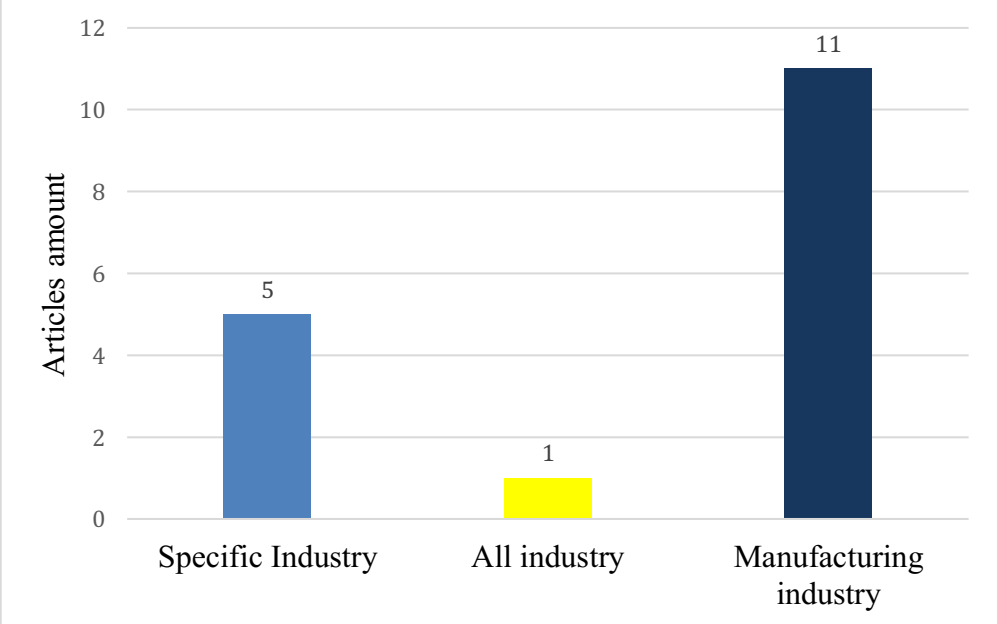
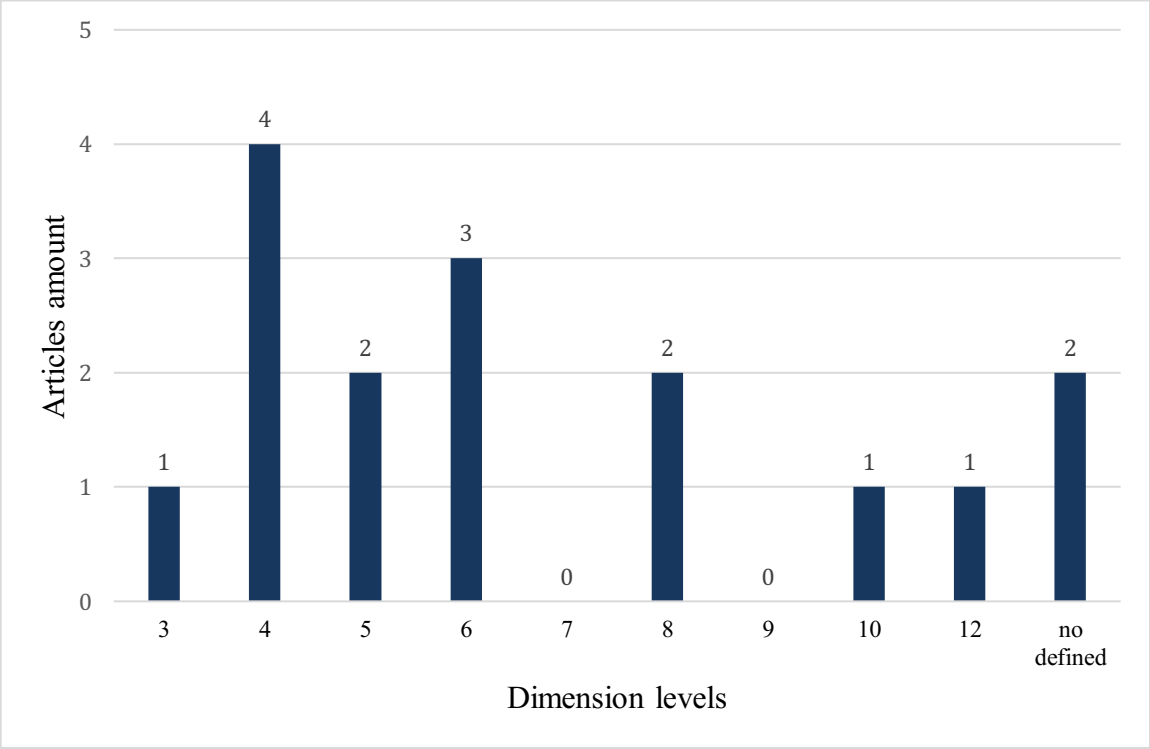


Figure 8. the maturity dimensions distribution among 17 references



In conclusion, quantitative analysis can help us summarize all the messy data so that the final results can be compared.

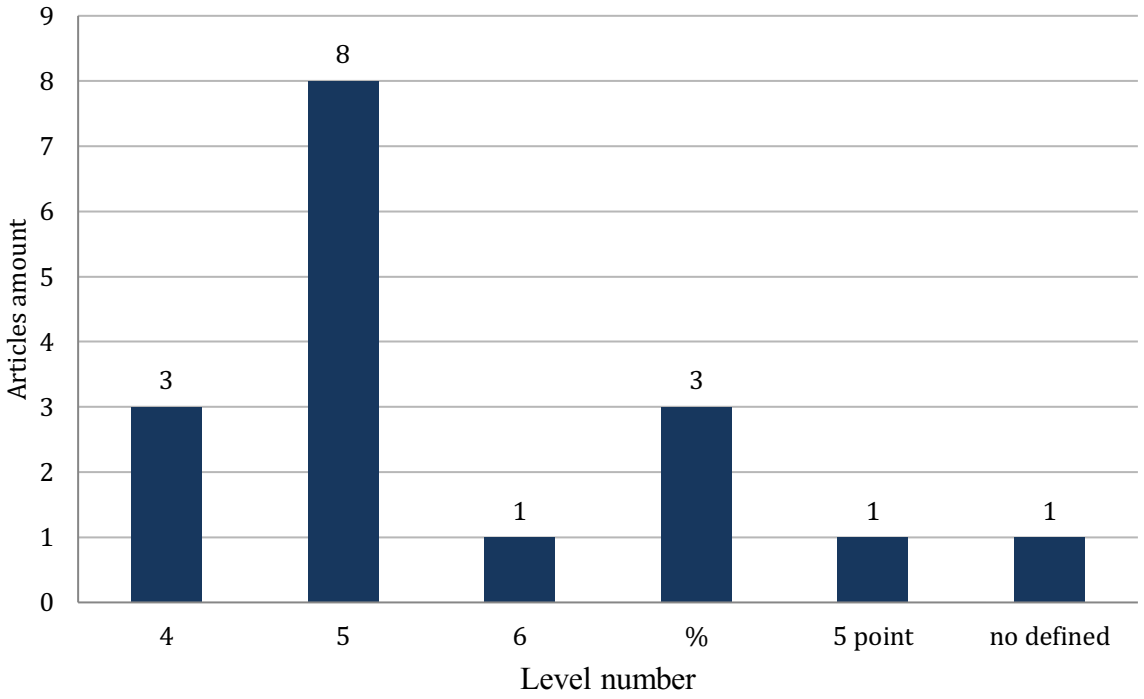
The summary of the publication time of the documents, most of them were published in the last two years, so the documents are very new and can represent the current level of manufacturing digital development in these countries.

The quantitative statistics of national data, as the data of developed countries and developing countries, it can be seen that the contribution of developing countries in the literature is very rich, it can be seen that scholars are also very interested in the topic of digital development in the manufacturing industry and have devoted themselves to research. At the same time, developing countries attach great importance to the digital development of the manufacturing industry.

Statistical analysis of enterprise size and manufacturing type can facilitate our group comparison in the chapter on results.

The last one is about the quantitative analysis of levels and dimensions, which can help us make the resulting data comparative.

Figure 9. The maturity level distribution among 17 references



5. Qualitative analysis of the reviewed literature

Kitchenham (2004) indicates three main reasons for systematic literature review; to summarize existing evidence concerning treatment or technology, to identify any gaps in current research studies to suggest areas for future investigations, and to provide a framework for new research activities. In light of these statements of Kitchenham (2004), qualitative analysis has been conducted to identify the current status of the industry 4.0 maturity level at the national level. The qualitative analysis presents the findings in tabular form, which can reduce the reading burden for the readers. The main work of this study is to summarize the reviewed literature as simply and directly as possible to provide clear perspectives for future researchers.

Qualitative analysis has been constructed into two main taxonomies. The first taxonomy is about the main information analysis of 17 references, which intends to give a clear view of all the publications. The second taxonomy is about applied models and dimension details. The general structure of the qualitative taxonomy is shown in Fig. 10. All the taxonomies are helping to compare the maturity level result in the end.

As seen in Fig. 10, structural taxonomy includes 2 branches; articles' main information and academics' applied models and dimensions. The main effort of this review is to analyze the dimensions of the applied model and give the whole view of all the references.

5.1 Main information analysis

As seen in Table 1, the main information analysis classifies the information of the articles into 9 characteristics. There are titles, authors, published time, country, scope, industry, use MM or not, model name and level. In this taxonomy way, it gives a clear view of all the information, and it gives the reader a whole view of the important information they needed. And it is very clear to see that articles focus on which industry, uses MM or not, the applied model name and the level, and also the survey method. And it will be efficient to see which reference can be compared with others or not.

The definitions of these are characteristics explained below.

The title is the name of the reference. Country means the analysis country in the articles. Scope means the enterprise scope, which includes scopes, of the big, medium, and small enterprises, SMEs means small and medium enterprises. The industry represents the scope of the manufacturing industry, including the manufacturing industry and some specific industries like textiles. It should be noted here that all industry means includes all not only manufacturing, so in this case, but is also to clean the data which meets the requirements of the manufacturing industry. The applied MM means the reference adopted maturity model or not, and it is acceptable that the articles does not to use the maturity model and it uses another way to describe the maturity level in their country. Then the important information is the maturity

model, it can be seen that some articles applied the same model like IMPULS, which explains in table 2, the most common applied models descriptions. And the maturity level is included in the analysis, which means how many levels are applied in the model. Therefore, Table 1 is easy to see which country the article is focusing on, and it brings convenience to the readers to check the articles at once.

Table 3 describes the model dimensions in the article, dimension is very important for the maturity model, because the maturity degree needs to be evaluated by different dimensions, so in this table, we can have a clear view of all dimensions detail and can see the difference of dimensions in each article.

After collecting all the dimensions in articles, Table 4 summarizes the same meaning but using different name's dimensions together, and counts the usage times of all dimensions, thus obtaining a list of the most commonly used dimensions, and at the same time gives a conceptual explanation of these dimensions in table 5.

And Table 6 describes the level in maturity model. The maturity level constitutes the data against which the final results are compared, so status is quite important. The maturity levels include the number of levels and descriptions in each level. Because in different models, the division and definition of levels are different, so this attribute is summarized in Table 6.

Table 7 shows the capacity of sample data in different articles. There are certain different capabilities to collect data in each article, and this may be one of the reasons to cause the discrepancy in the results, so the sample capacity needs to be displayed in here, so that when the comparison results are inconsistent, the difference in sample size may be one of the reason.

Last but not the least, survey methods are shown in table 7, which means in which way to get the result from the survey, and a questionnaire is very common.

Figure 10. Qualitative analysis steps

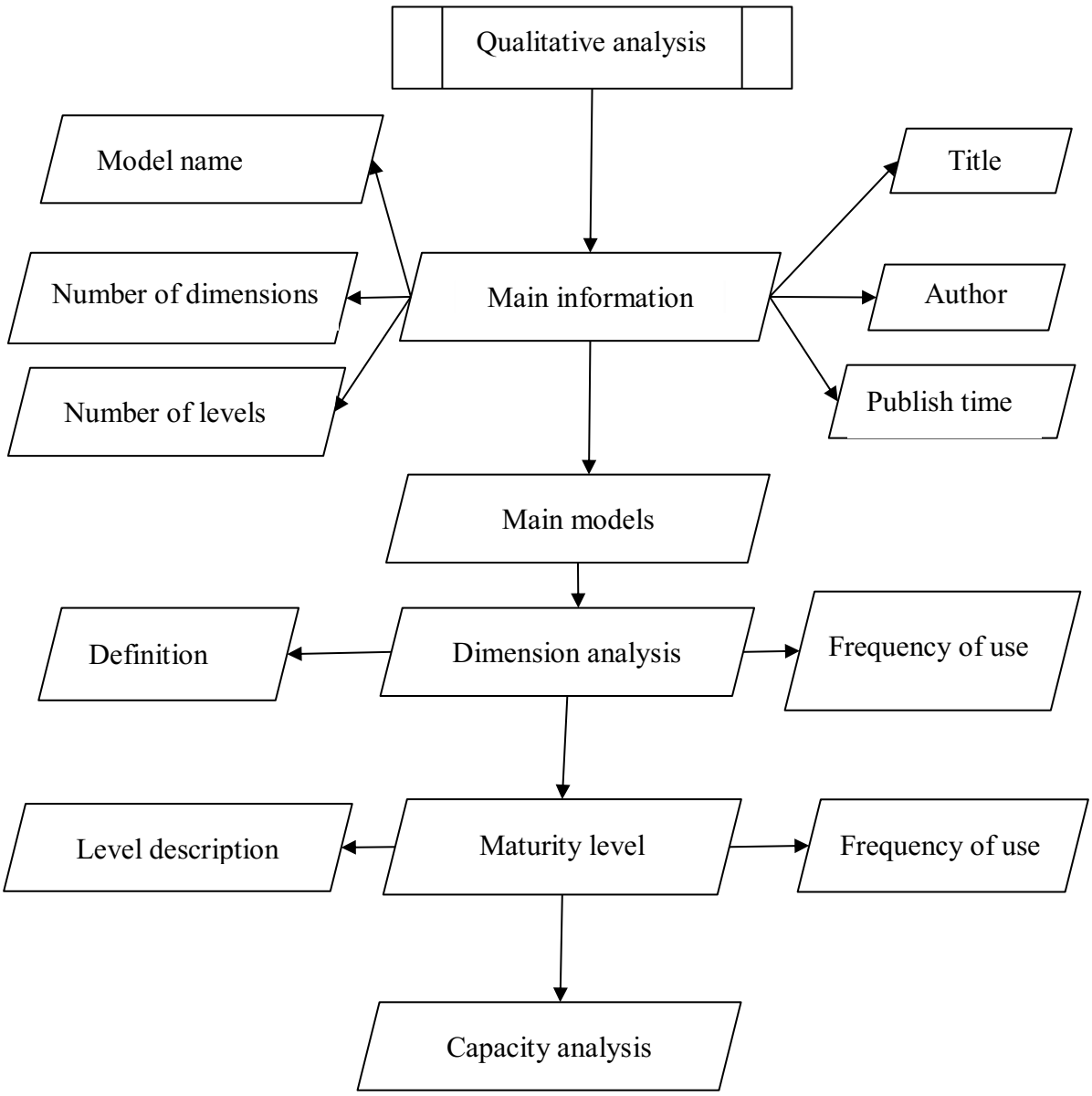


Table 1. Main information analysis

Title	Authors	Published time	Country	Scope	Industry	Applied model	Model name	Level
Proposal and Validation of an Industry 4.0 Maturity Model for SME	Ávila-Bohórquez J.H (2022)	2022	Colombia	SMEs	Manufacturing	yes	Reference: Schumacher et al. (2016)	5
Analysis of Textile Manufacturing SMEs in Kazakhstan for Industry 4.0	Dikhanbayeva D (2022)	2022	Kazakhstan	SMEs	Textile	yes	COMMA 4.0	5
Transition Trends and Readiness of Indonesia – Textile and Electronic Sectors	Arie Rahmadi (2020)	2020	Indonesia	All	Textile	yes	Industry 4.0 readiness in manufacturing	5
Industry 4.0 Maturity Assessment in a Medical Devices Manufacturing Industry	Christian Stark (2022)	2022	Malaysia	All	Medical devices	yes	Acatech	6

Project-based maturity assessment model for smart transformation in Taiwanese enterprises	Lin T.-C (2021)	2021	Taiwan	All	Manufacturing	yes	project-based maturity model (modified from Lin et al. Singapore EDB).	5
maturity assessment in industry 4.0 - a comparative analysis of Brazilian and German companies	Luciano Raizer Moura A (2020)	2020	Germany & Brazil	All	Manufacturing	yes	IMPULS	5
Research and Application of Capability Maturity Model for Chinese Intelligent Manufacturing	Jingyi Hu a (2019)	2019	China	All	Manufacturing	yes	Capability Maturity Model	5

Assessing industry 4.0 readiness in manufacturing companies from Serbia	Vidosav D. Majstorović (2020)	2020	Serbia	SMEs	Manufacturing	yes	IMPULS as a reference	4
Industry 4.0 readiness in Hungary: model, and the first results in connection to data application	GáborNick (2019)	2019	Hungary	All	All	yes	IMPULS 2015	%
A Comparative Sectoral Analysis of Industry 4.0 Readiness Levels of Turkish SMEs	Dikhanbaye va D (2021)	2021	Turkey	SMEs	Manufacturing	no	no mentioned	4

INDUSTRY 4.0 DESIDERATA AS MICRO FOUNDATIONS IN THE ASSESSMENT OF COMPANIES' MATURITY – CASE STUDY	Bogdan Nogalski1 (2020)	2020	Poland	All	manufacturers operating in the agricultural machinery sector	no	no mentioned	5 points
Frameworks of the Maturity Model for Industry 4.0 with Assessment of Maturity Levels on the Example of the Segment of Steel Enterprises in Poland	Bozena Gajdzik (2022)	2022	Poland	All	Steel Manufacturing	yes	based on pillars (key technologies) of the next industrial concept	5
Measuring the fourth industrial revolution through the Industry 4.0 lens: The relevance of resources, capabilities and the value chain	Isabel Castelo-Brancoa (2019)	2019	Portugal	All	Manufacturing	yes	none; according to expert interviews	%

Digital readiness assessment of Italian SMEs: a case-study research	Fabiana Pirola (2019)	2019	Italy	SMEs	Manufacturing	yes	DRL 4.0	5
An Analysis of Maturity Models and Current State Assessment of Organizations for Industry 4.0 Implementation	Luiz Felipe Pierin Ramosa (2021)	2021	southern Brazil	All	Manufacturing	yes	Assessment I4.0 &Readiness I4.0	%
A survey study on Industry 4.0 readiness level of Italian small and medium enterprise	Alessia M.R. Tortora(a) (2021)	2021	Italy	SMEs	Manufacturing	no	no	no
State of Industry 4.0 Across German Companies	Daniel Bittighofer (2018)	2018	Germany	All	Manufacturing	yes	no mentioned	5

Table 2. Explanation of common models

Model name	Explanation
IMPULS	The IMPULS model was selected as the base on which to build the new, adapted model. In fact, it is one of the most cited MMs in the scientific and academic literature related to Industry 4.0 MMs and readiness models since its publication in 2015. IMPULS is aimed mainly at the manufacturing and engineering industry. A scope of activity where the MT-SMEs are included. IMPULS is scientifically well grounded which facilitates its adaptation to standardization. In fact, IMPULS was the best-adapted MM to the ISO 15504 standard (though not fully fitted) (when seven identified MMs were analyzed by comparing their characteristics of scope, purpose, completeness, clarity, and objectivity.
COMMA 4.0	COMMA 4.0 is a research model developed for the analysis of manufacturing enterprises in developing economies and takes into account the characteristics of SMEs. The model includes the following five main dimensions chosen based on an extensive literature study and analysis of local manufacturing industries: Strategy and Organization, Workforce Development, Smart Factory, Smart Processes, and Smart Products and Services. The model assesses the enterprises based on five maturity stages starting from level 1 (Entrant) to level 5 (Expert). To notify the weights of the developed model dimensions and indicators, the Analytic Hierarchy Processes (AHP) method was employed. AHP is a structured technique that allowed to identify the weights of dimensions and maturity items using eigenvectors with a panel of researchers and interviewed practitioners. Each of the respondents compares the relative importance of each pair of items using a specially designed questionnaire. In addition, one of the main values of the model is that it is equipped with an expert system, which automatically estimates the level of maturity of the company, identifies drivers and weaknesses, and generates certain recommendations upon the received score. The model is empirically grounded and validated by pilot tests conducted by developers. The model was checked and approved by the Institutional Research Ethics Committee (IREC).

Acatech	The acatech Industrie 4.0 maturity index model (the acatech model) is co-developed by multiple research institutes (RWTH Aachen, TU Darmstadt, and Paderborn University), industrial partners (PTC, Infosys, and TÜV SÜD), and the National Academy of Science and Engineering Germany to identify individual and customized recommendations for the Industry 4.0 (I4.0) transformation. This maturity index model provides a structured technique for measuring a company's present degree of digital transformation by reviewing the underlying concepts and core principles of I4.0. The information is essential for developing a road map for gradual digital transformation. The acatech model's concept of maturity level is more intuitive, making it significantly simpler for the industry to comprehend. The acatech model serves as the basis for the survey questions.
SIMMI 4.0	The model focused on the IT area. Suitable for more technical notes involving the IT area - Not applicable because the full questionnaire is not accessible. [16]
DRL 4.0	Digital Readiness Level 4.0 (DRL 4.0), which is specifically designed for SMEs to assess their current DRLs, i.e., their current positions concerning the digital transformation process. The proposed DRL 4.0 model aims to overcome existing models' general limitations, providing a tool for SMEs that want to assess their readiness before undertaking the transformation towards Smart Manufacturing. Since Industry 4.0 is a broad concept entailing several aspects, this model focuses on both technology implementation and strategic and operational levels. Second, insights drawn from the assessment of 20 manufacturing SMEs' digital readiness through DRL 4.0 are discussed, highlighting the principal priorities for successfully undertaking the journey towards Industry 4.0. In doing so, we aim to accelerate the adoption rate for innovations required for the digitalization of the industry by providing robust knowledge of the current context and the potentialities implied. [15]
Schumacher et al. (2016)	Studies by Schumacher et al. (2016, 2019) are important milestones for industry 4.0 maturity modeling. The first study in 2006 is one of the first academic publications, which extend existing practitioners' models. They

	claimed that each dimension should have different priorities and assign weights to dimensions by expert interviews. Also, they indicated that for the model's accuracy, all the respondents should have a basic understanding of industry 4.0 concepts and the questionnaire should be conducted by group sessions or external consulting. They targeted manufacturing companies that are producing physical goods in house. They indicated that determining a company specific approach as future work and the study in 2019 proposed a method to overcome this issue. Besides proposing a company-specific modeling approach, the study of 2019 proposes a structural procedure which includes roadmapping according to company specific needs.

Table 3. Model dimensions analysis

Authors	Country	Model name	Dimension Level	Dimensions Details
Ávila-Bohórquez J.H (2022)	Colombia	Reference: Schumacher et al. (2016)	8	1 Service 2 Operations 3 Quality 4 Products 5 Documented information- Big Data 6 Leadership and strategy 7 Communication 8 Culture and people
Dikhanbayeva D (2022)	Kazakhstan	COMMA 4.0	5	1 Strategy and Organization 2 Workforce Development 3 Smart Factory 4 Smart Processes 5 Smart Products and Service

Arie Rahmadi (2020)	Indonesia	Industry 4.0 readiness in manufactu ring	8	1 Strategy and Organization 2 Plant and Equipment 3 Information Technology Systems and Data Management 4 Human Resources 5 Product Definition 6 Managing Operations- Resource Consumption and Energy Management 7 Managing Operations- Quality Management 8 Managing Operations- Supply Chain Management
Christian Stark (2022)	Malaysia	Acatech	4	1 Resources 2 Information System 3 Organization Structures 4 Corporate Culture
Lin T.-C (2021)	Taiwan	Project-based maturity model	4	1 Organization Intelligence 2 Transformation Project 3 Equipment Intelligence 4 Process Intelligence
Luciano Raizer Moura A (2020)	Germany & Brazil	IMPULS	6	1 Strategy And Organization 2 Smart Factory 3 Smart Operations 4 Smart Products 5 Data-driven Services 6 Employees
Jingyi Hu a (2019)	China	Capability Maturity Model	4	1 Personnel 2 Technology 3 Resource 4 Manufacturing

Vidosav D. Majstorović (2020)	Serbia	IMPULS	10	1 Strategy 2 Culture of Organization 3 Leadership 4 Customers 5 Suppliers 6 Products 7 Technology 8 People 9 I4.0 Framework 10 Governance
GáborNicka (2019)	Hungary	IMPULS	6	1 Strategy and Organization 2 Smart Factory 3 Intelligent Process 4 Smart Products 5 Services Based on Product Data 6 Employees
Dikhanbayeva D (2021)	Turkey	No mentioned	3	1 Manufacturing sectors 2 Process 3 Technologies
Bogdan Nogalski1 (2020)	Poland	No mentioned	6	1 Maturity level in terms of Technology 4.0 2 Maturity level in the field of applied management concepts 3 Maturity level in the scope of applied tools 4 Maturity level in the field of “Knowledge 4.0” desiderata 5 Maturity level in the field of “Ecological competences” 6 Maturity level in the field of “Relations 4.0”
Bozena Gajdzik	Poland	Based on pillars	12	1 Automation of production using single machines (P_1)

(2022)		(Key technologies) of the next industrial concept		2 Automation of production using interacting machines in production nests (P_2) 3 Automation and robotization of full production lines (P_3), automation of warehouse 4 Processes—the stage of partially or fully automated warehouses (P_4) 5 Multi-tasking production lines controlled automatically with machine learning (ML) (P_5) 6 Internet and mobile technologies (ICTs) in customer services, including EDI, e-invoicing system (P_6) 7 TPM—equipment with sensors generating data about efficiency of machines in real time (P_7) 8 Development and compatibility of production support information systems: CAx, MRP, MES (P_8) 9 Business network and chain integration with the system end-to-end engineering (P_9) 10 extension of databases (Big Data) and process visualization (P_10) 11 Access to cloud services and the Industrial Internet of Things IIoT (P_11) 12 Development of block chain in the steel sector and distribution of

				steel products (product protection, cybersecurity in chain, etc. (P_12)
Isabel Castelo-Brancoa (2019)	Portugal	None; according to expert interviews	4	1 IT strategy and cybersecurity 2 Enablers 3 Smart factory, 4 Value proposition and customer experience
Fabiana Pirola (2019)	Italy	DRL 4.0	5	1 Strategy 2 People 3 Processes 4 Technology, Integration
Luiz Felipe Pierin Ramosa (2021)	southern Brazil	Assessment I4.0 & Readiness I4.0	8	1 Innovation Culture 2 Strategy and Leadership 3 Smart Factory 4 Agile and Modular Management 5 Governance and Processes 6 Digital Infrastructure 7 Smart Logistics 8 Smart Product and Services
Alessia M.R. Tortora(a) (2021)	Italy	no	no dimension	23 questions
Daniel Bittighofer (2018)	Germany	no mentioned	6	1 Product Development Process 2 Steering and Control 3 Manufacturing and Operation 4 Smart Services 5 Process Organization 6 Big Data

After reviewing tables 2 and 3, here conduct a summary of the dimension details. First of all, all the articles did not apply the same model, in other words, the dimensions of the maturity model are different from each other. Secondly, there are some similarities between the dimensions themselves. And it is obvious that some features show more than one time, and be

utilized very frequently. To know which characteristics are the most common ones to adopt, it is necessary to add them up and show them in a figure. Therefore, there comes out table 4 (Bozena Gajdzik (2022) and Alessia M.R. Tortora(a) (2021) does not count in this table because of specific dimensions and questions).

As can be seen in table 4, all the dimensions are classified into different groups. And if the dimensions have the same name or different names with analogous meaning, they will group. Then the consequence shows up below. Obviously, Technology is the first feature that is mentioned the most in the model applied, and 11 maturity models used of this characteristic. Hence, Technology became Top 1 among 29 characteristics. Strategy is the second feature which is adopted 9 times out of 17 articles. Process and Factory becomes the top 3 among 29 characteristics which are employed 8 times. After that, Product have 7 applied times in the maturity model of the references and become the fourth ranking in the table. And in the meantime, here is the basic explanation of each dimension in table 5.

Table 4. Dimension using frequency distribution

Ranking	Dimensions				
Top.1 Technology	Information Technology Systems and Data management	Information system	Technology	Big Data	Technology
	Equipment Intelligence	Technology 4.0	Technology	Big Data	IT strategy and cybersecurity
	Technologies				
Top.2 Strategy	Leadership and strategy	Strategy and organization	IT strategy and cybersecurity	Strategy	Strategy and Leadership
	Strategy and organization	Strategy and organization	Strategy and organization	Strategy	
Top.3 Process	Smart Processes	Intelligent Process	Process	Product Development Process	Governance and Processes
	process intelligence	Process Organization	Process		
Top.3 Factory	Manufacturing	Smart Factory	Smart factory	Smart factory	Smart factory
	Manufacturing and Operation	Manufactur-ing sectors	Smart Factory		

Top.4 Products	Products	Smart Products and Services	Product definition	Smart products	smart products
	Smart Product and Services	Products			
Top.5 Organiza-tion	Strategy and organization	organization intelligence	Strategy and Organisation	Strategy and Organizati on	Strategy and organization
	Organization structures				
Top.5 Services	Smart Services	Services based on product data	Smart Products and Services	Service	Data-driven services
	Smart Product and Services				
Top.6 Govern-ance	Governance and Processes	Management concepts	Governance	Agile and Modular Manage-ment	
Top.6 People	Culture and people	Personnel	People	People	
Top.6 Culture	Innovation Culture	Culture of organization	Culture and people	Corporate culture	
Top.7 Leadership	Leadership and strategy	Leadership	Strategy and Leadership		
Top.7 Operations	Manufacturing and Operation	Smart operations	Operations		
Top.7 Employees	Workforce Development	Employees	Employees		
Top.7 Equipment	Plant and Equipment	Applied tools	Digital Infrastructure		
Top.7 resources	Resources	managing operations-resource consumption and energy management	Resource		
Top.8 Customers	Customers	Value proposition and customer experience			

Top.8 Logistics	Supply chain management	Smart Logistics			
Top.8 Quality	Quality	Quality management			
Top.9 I4.0 framework	I4.0 framework				
Top.9 Communication	Communica-tion				
Top.9 Transformation project	Transforma-tion project				
Top.9 Suppliers	Suppliers				
Top.9 Knowledge 4.0	Knowledge 4.0				
Top.9 Ecological competences	Ecological competences				
Top.9 Relations 4.0	Relations 4.0				
Top.9 Enablers	Enablers				
Top.9 Integration	Integration				
Top.9 Steering and Control	Steering and Control				
Top.9 Human resources	Human resources				

Table 5. Dimensions Interpretation

Dimension	Interpretation
Technology	Existence of modern ICT, utilization of advanced machines, etc.
Strategy	Implementation of the I4.0 roadmap, needed resources, design business model, etc.
Products	Digitalization of the product, product integration in other systems
Operation	Decentralization of processes, modeling, and simulation, application of CAD, CAE, CAM, virtual and augmented reality, human-machine interfaces, robotization, and utilization of machine-to-machine communication.
Organization	Concepts/technologies for organizational and management-oriented processes.
Smart factory	A concept that refers to a modern factory paradigm that has arisen as a result of the fourth industrial revolution. Mechanization, industrialization, and automation are the predecessors of the first three major developmental processes that are known as revolutions.
Process	Analyses how internal processes are managed from a digitalization point of view and how data are collected, shared, and managed inside the company.
People	Analyses people skills and how the know-how is managed inside the company.
Culture	Knowledge sharing, Open-innovation and cross-company collaboration, Value of ICT in the company.
Service	Customers' data utilization, response to petitions, claims, and complaints through different digital media, and interaction with customer/Enterprise (sales/services/designs/process).
Governance	Applies to I4.0 management paradigms such as the aging

	population, resource-effective and clean urban manufacturing, mass customization, growing demand heterogeneity, shorter product life cycle, competitive supply chain, unpredictable economies, and cost-containment pressure.
Leadership	Commitments and competencies of leaders, Project leadership, etc.
Logistics	Use of digital technologies in the supply chain is referred to as Logistics 4.0. The different facets of end-to-end logistics and supply chain management are discussed by Logistics 4.0.
Customers	Customer database, digitalization of sales/services, Social networks, etc.
Employees	Analyzing the skills of employees in various areas and by the company's efforts to acquire new skills.
Equipment	Digital Infrastructure
I4.0 framework	Basic elements of I4.0, cloud technology etc.
Quality	Safety protocols related to complying with the quality parameters, devices for detecting errors in the process and in the product.
Communication	Validation of the significant changes in the ways in which the enterprise handles the communications both within the companies and towards the stakeholders.
Transformation project	transformation projects must aim at developing new organizational capacities and skills to maintain competitiveness.
Suppliers	Database of suppliers, digitalization of order and acceptance etc.
Knowledge 4.0 desiderata	Level of competences held by employees.
Ecological competences	Development strategy including eco-innovation in the corporate objectives bundle.

Relations 4.0	Activities aimed at deepening or building relations with customers and suppliers.
Enablers	The necessary pre-conditions required to extract the maximum potential of Industry 4.0 technologies, practices and processes.
Integration	Analyses the digitalization level and the integration with other actors of the value chain.
Human resources	Human resources
Steering and Control	Steering and control defines the way an enterprise steers and controls its processes, information and material flows.

Table 6. Level description

Country	Model	Level Amount	Level description
Colombia	Reference: Schumacher et al. (2016)	5	Level 1: it represents the level to which the surveyed companies have not yet concretely generated any activity or application of elements of industry 4.0 Level 2: it represents the level to which the surveyed companies have started strategic activities of research and analytical studies, as well as pilots to include and appropriate technology. Level 3: it represents the level to which the surveyed companies have partially applied technologies to their processes. Level 4: it represents the level to which the surveyed companies have highly applied technologies to their processes. Level 5: it represents the surveyed companies that have implemented different elements and have achieved the scope that is covered by the industry 4.0.

Kazakhstan	COMMA 4.0	5	Level 1 Entrant: There exists an understanding of the need to transform to I4.0, however, no proactive steps are taken. Level 2 beginner Level 3 learner Level 4 integrator Level 5 expert
Indonesia	Industry 4.0 readiness in manufacturing	5	Level0 outsiders Level1 beginners Level2 Potentialists Level3 Expert front runners Level4 leaders
Malaysia	Acatech	6	1 Computerization, 2 Connectivity, 3 Visibility, 4 Transparency, 5 Predictiveness, 6 Adaptivity
Taiwan	Project-based maturity model	5	Level 1 Initiated (Immature), Level 2 Performed(Immature), Level 3 Managed (Med-mature), Level 4 Optimized (Med-mature), Level 5 Implemented(Mature)
Germany& Brazil	IMPULS	5	Level 0 Outsider Level 1 Beginner [new commers] Level 2 Intermediate [learners] Level 3 Experienced Level 4 Expert Level 5 Top performer [leaders]
China	Capability Maturity Model	5	Level 1 Planning level Level 2 Specification level Level 3Integration level Level 4 Optimization level Level 5 Leading level

Serbia	IMPULS	4	Level 1 Beginners, an organization gets acquainted with I4.0 Level 2 An established project, the defined vision and strategy for I4.0 Level 3 Roadmap, Good practice for I4.0 is established Level 4 All the industry 4.0 elements for an organization have been implemented. The organization is working on the Platform for I4.0
Hungary	IMPULS	%	Use % to evaulate
Turkey	No mentioned	4	Definitions and requirements of levels Industry 1.0 Level: The operations are realized manually. There is no electrical system introduced to the processes. Industry 2.0 Level : Some systematic implementations are introduced to the system. Electricity is used instead of manpower. Personal computers, simple software and Internet are present in the company, but not integrated with each other and not for managing the processes. Industry 3.0 Level: All operations are realized in a systematic manner. Automation and sensors are used in the operations, but they are not in collaboration with each other. There are systems for data collection, but the data are not used for online decisions. The infrastructure of the company is ready for the full transformation. Industry 4.0 Level: The company is in the adaptation phase. The internal operations and those with the stakeholders are realized in an integrated manner via digitalization. Most of

			the technological drivers such as big data, augmented reality, horizontal and vertical integration etc. are implemented in the system.
Poland	No mentioned	5 points	1 is low, 5 is high
Poland	Based on pillars (key technologies) of the next industrial concept	5	5 level on a five-point scale—a Likert scale scoring system from 1 to 5 1 — a very low level of maturity, 2 — low, 3 — medium, 4 — high, 5 — very high.
Portugal	None; according to expert interviews	%	Use % to evaulate
Italy	DRL 4.0	5	five-point Likert scale
southern Brazil	Assessment I4.0 & Readiness I4.0	%	Readiness I4.0: Classification Traditional: very low, low, average Readiness Model: Absence, Existence, Survival Assessment I4.0: %
Italy	No	no	no mentioned
Germany	No mentioned	5	level 0 - outsider to level 5 - top performer

Table 7. Capacity of the survey

Authors	Country	Survey Method	Capacity
Ávila-Bohórquez J.H (2022)	Colombia	The questionnaire is based on questions (index of maturity) targeting managers, specialists around manufacturing or technology of the enterprises.	23 enterprises are taken as reference; out of this chosen companies, the 63.6% corresponds to the classification of medium-sized enterprises and 36.4% to small enterprises.
Dikhanbayeva D (2022)	Kazakhstan	The respondents' replies were recorded by a team member.	Located in 14 different cities of Kazakhstan, as a result, from 105 shortlisted firms, 27 responses were collected.
Arie Rahmadi (2020)	Indonesia	Interviews with two textile industry experts	Two textile experts
Christian Stark (2022)	Malaysia	Questionnaire Survey	54 responders, They have either a high level of relevant expertise or institutional authority (process responsibility and power of decision).
Lin T.-C (2021)	Taiwan	Questionnaire among senior executives, operation managers, and project managers from the IT, engineering, or manufacturing fields.	Collected from 165 Taiwan-based enterprises, and the respondents were asked to rate questionnaire items on a five-point Likert scale
Luciano Raizer Moura A (2020)	Germany & Brazil	Questionnaire	Applied in 289 small, medium, and large German industries.

Jingyi Hu a (2019)	China	Questionnaire	With 4,235 participating enterprises, including 2,037 valid data.
Vidosav D. Majstorović (2020)	Serbia	2 questionnaire	Both questionnaires were distributed to 106 SMEs from the manufacturing sector, and 49 responses were obtained
GáborNick a (2019)	Hungary	Questionnaire	No mentioned
Dikhanbayeva D (2021)	Turkey	Questionnaire	It is seen that the average industrialization level for the 1040 companies is 2.43. It is seen that the SMEs are still not achieving the Industry 4.0 level, and yet they are behind the 3.0 level.
Bogdan Nogalski 1 (2020)	Poland	Questionnaire	71 company
Bozena Gajdzik (2022)	Poland	Questionnaire	79 company
Isabel Castelo-Brancoa (2019)	Portugal	Questionnaire	23 results

Fabiana Pirola (2019)	Italy	Questionnaire	A critical phase during case-study research is choosing the sampling method (Miles and Huberman, 1994). The overall research involved 22 SMEs localised in the Bergamo province in Lombardy, Northern Italy, where more than 99 per cent of companies are SMEs.
Luiz Felipe Pierin Ramosa (2021)	southern Brazil	Questionnaire	The evaluation was carried out in 9 companies from different sectors. Managers from 39 companies from different sectors, sizes, and service levels were interviewed.
Alessia M.R. Tortora(a) (2021)	Italy	Survey	No mentioned
Daniel Bittighofer (2018)	Germany	Personal interviews or conference calls	in small (one enterprise), medium-sized (six enterprises), and large enterprises (17 enterprises). seven sectors automotive, automation, electronics, manufacturing, mechanical engineering, medical engineering, and process industry. In the wider study, a convenience sample of 6 French and 24 German employees was interviewed.

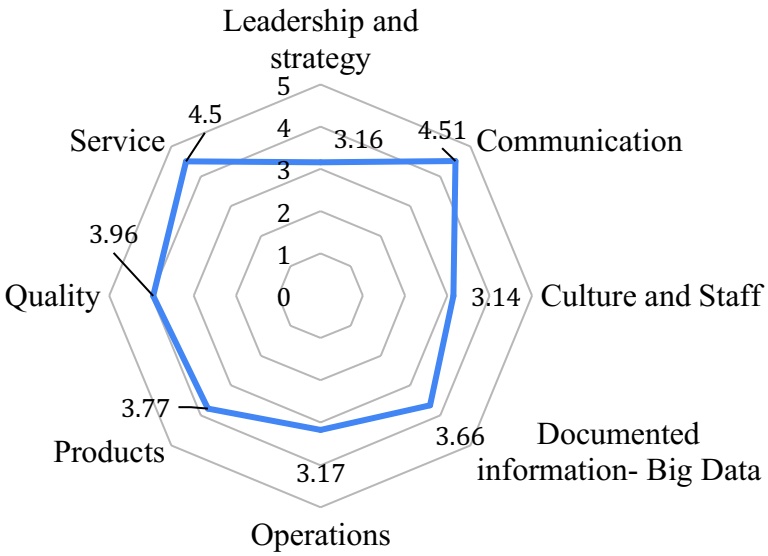
6. Results

This sector describes the maturity level assessment results in different types of charts, like radar chart, pie chart, and bar chart. It needs to be emphasized that the data of some articles have been converted into radar charts or column charts for display.

6.1 The maturity level results are displayed by each country

6.1.1 The SMEs companies' maturity level in Colombia's Bogotá city

Figure 11. Average maturity level in 23 surveyed enterprises



Here is the maturity level result in Bogotá, Colombia, and it should be emphasized that the survey object only concentrated on SMEs companies in Bogotá city which is the capital of Colombia. 63.6% of medium-sized enterprises and 36.4% of small enterprises composed the survey.

The scores of each dimension are Service (4.5), leadership and strategy (3.16), communication (4.51), Quality (3,96), Product (3.77), operations (3.17), culture and staff (3.14), documented information (big data) (3.66). To make a unified comparison in the next sector, where the average score of all the dimensions without considering different weights is 3.73.

Considering Colombia is a developing country, this score is quite high. Because the result is limited by Bogotá city and focuses on SEMs companies.

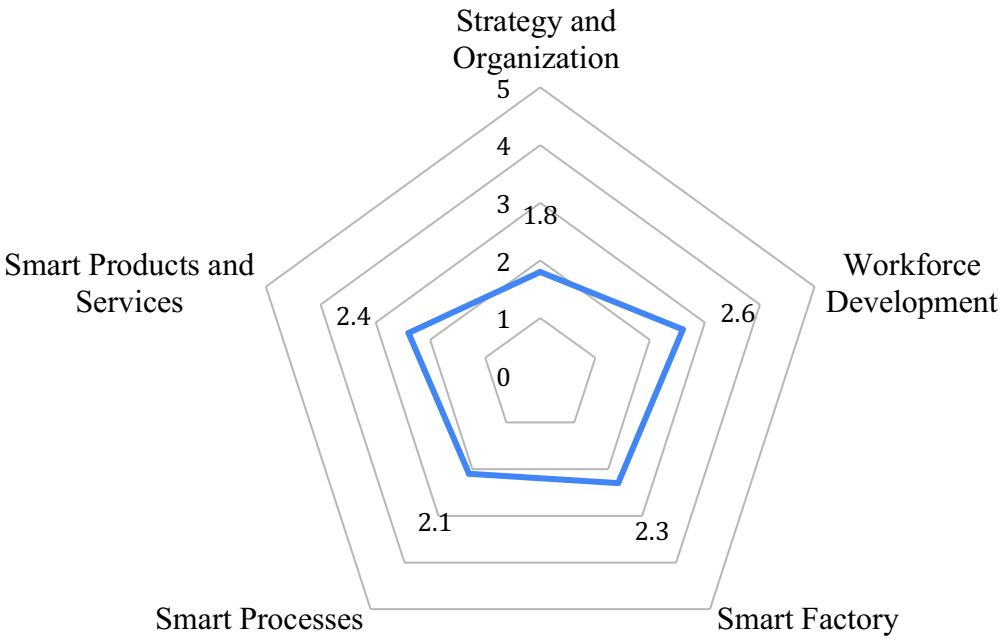
According to the level description, level 3 represents the level to which the surveyed companies have partially applied technologies to their processes. Level 4 represents the level to which the surveyed companies have highly applied technologies to their processes. It can be observed in the Culture and Staff, Leadership and strategy, and Operations dimensions, which are placed

within a Level of Maturity bordering Level 3. It can be said then that these companies have partially applied technologies to their processes.

As the writer said, the model presented can served as a basis for SMEs to establish a baseline measurement of the application of Industry 4.0 elements in in Latin America companies. Therefore, in this article, it is appropriate to adopt this article's model and assessment process in Latin America SMEs companies.

6.1.2 The maturity level in Textile industry SMEs Kazakhstan company

Figure 12. Average maturity level in 27 surveyed enterprises



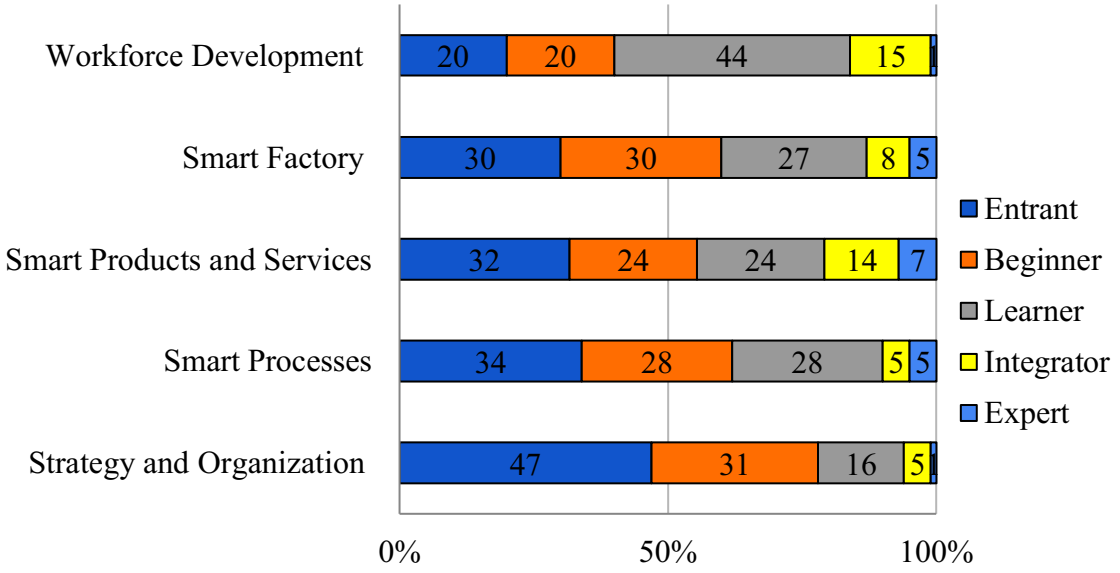
Average maturity level in 27 surveyed enterprises

This article creates a complete picture of the readiness of SMEs in the textile sector of Kazakhstan through a developed comprehensive maturity assessment model (COMMA 4.0) for the implementation of I4.0. Additionally, SMEs are essential in the textile sector of Kazakhstan as it consists of 94.3% of small enterprises, 3.7% of medium, and 2% of large enterprises. The sample data were chosen within the textile sector companies located in 14 different cities. As a result, from 105 shortlisted firms, 27 responses were collected.

As all dimension data can be seen on a single radar chart in Fig.12. The score of the Strategy and organization dimension is 1.8. The score of products and Services is 2.4. The score of the workforce developer is 2.6. The score of smart processes is 2.1. The score of the smart factory is 2.3. For 5 dimensions, the average score is 2.24 without considering different proportions.

All participating companies represent SMEs, then compare data with level description, 4 dimensions are in level 2, only one dimension is 1,8. And the average maturity level received equals 2.23, which corresponds to a beginner level.

Figure 13. Maturity levels of textile companies by model dimensions



This article provides more data in Fig.13 which presents the maturity levels of textile companies by dimensions. It can be stated that in terms of strategy and organization prospects within the textile industry of Kazakhstan, there exists an understanding of the need to transform to I4.0, however, no proactive steps are taken as 47% of firms correspond to an entrant, and 31% to a beginner level.

A higher maturity level for the workforce development dimension can be explained by a high acceptance level of changes among employees which corresponds to almost a learner level, which is level 3.

Components of the smart factory dimension show results stretched onto three levels of maturity, entrant (30%), beginner (30%), and learner (27%) maturity levels.

In the smart processes dimension, textile companies on average are also in the entrant (34%), beginner (28%), and learner (28%) stages.

In the smart products and services case, results mostly belong to the entrant level (32%), then equally to the beginner (24%) and learner (24%).

Summarizing all points, the textile industry can firmly be described as a beginner in the I4.0 journey since the maturity level for almost 60% of components is located between level 1 and level 2.

6.1.3 The maturity level in Indonesian Textile companies

Table 8. Industry 4.0 readiness survey results for the Indonesian Textile industry

Rating classification	Actual obtained value	Maximum value	Readiness Classification	Rating
Industry 4.0 readiness	48	132	Potentialists	0.36(36%)
Industry 4.0 readiness for the circular economy	15	56	circular economy beginners	0.27(27%)
Circular economy-adjusted industry 4.0 readiness rating				0.097

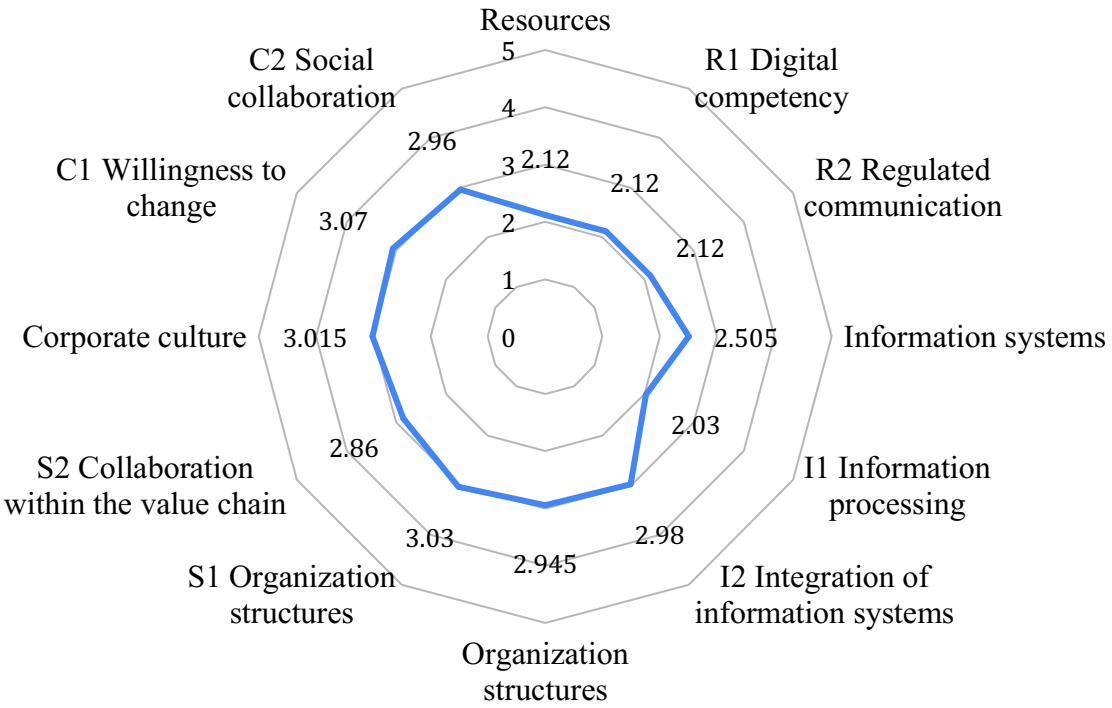
Figure 14. average maturity level by 2 experts' survey

In this article, two figures are demonstrating the maturity level of the Indonesian textile industry. In table 8, the actual obtained value in Industry 4.0 readiness is 48, Rating of 0.36 (36%), has scored as "potentialiste", which corresponds to level 2. In Fig. 14, there is a big gap between actual obtained values and maximum values. As a result, these two figures tell that the

textile digital development in manufacturing is still at a beginner level, with a 0.36 score (full 1 score).

6.1.4 The maturity level of medical devices industry companies in Malaysia

Figure 15. Average maturity level under 54 responders



The I4.0 maturity evaluation with content based on the Acatech model has been successfully implemented in the medical device manufacturing business using a questionnaire survey in Malaysia. Multiple questions were used to assess the level of maturity concerning eight guiding principles and 27 competencies. And 54 respondents answered 29 of the questionnaire's questions.

More specifically, the score of resources is 2.12, R1 Digital competency of resources, with a score of 2.12, and R2 Regulated communication, with a score of 2.12. The score of information systems is 2.5, I1 Information processing, with a score of 2.03, and I2 Integration of information systems with a score of 2.9. The organization structures score is 2.945, the S1 Organization structures a score of 3.03, and S2 Collaboration within the value chain with a score of 2.86. Corporate culture is 3.015, C1's Willingness to change score is 3.07, and C2's Social collaboration gets 2.96 scores.

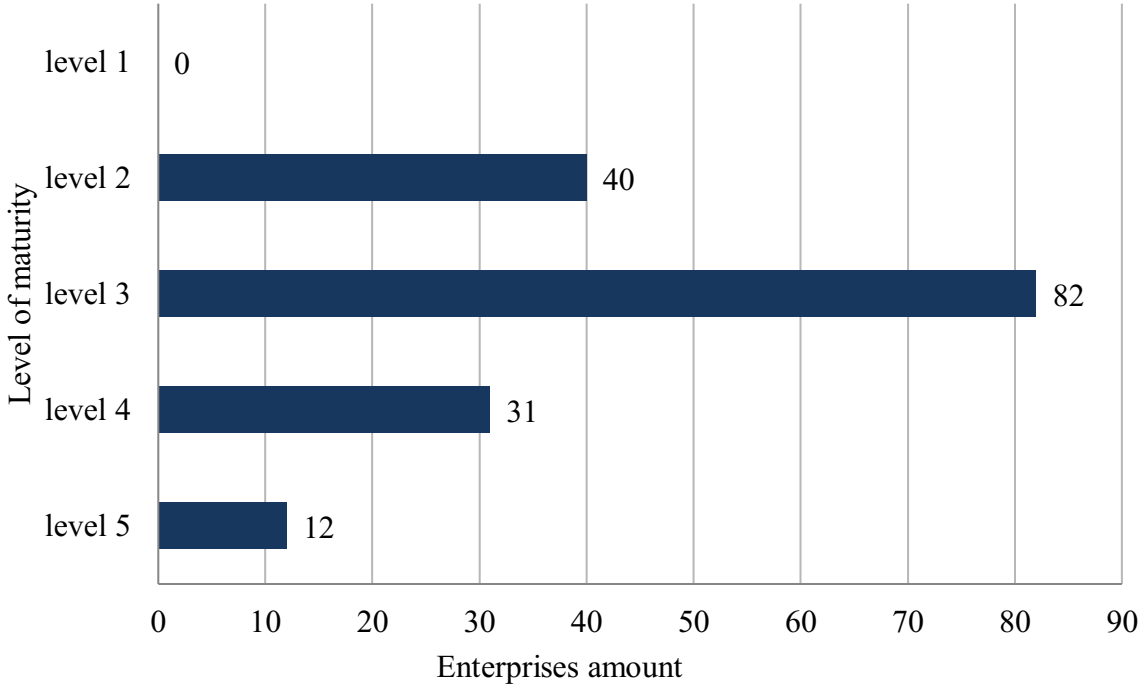
The average of the evaluation revealed that the organization reached a maturity level of 2,66 (full score of 6).

The result indicates that the organization is near achieving transparency and significant score disparities among capabilities in level 2 (total of 6 levels). The second observation is that

digitization is overdue for development, given that culture and organizational structures are more mature.

6.1.5 The maturity level in Taiwanese enterprises

Figure 16. Number of enterprises in maturity model levels



To assess enterprises' maturity level, an online survey was conducted among senior executives, operation managers, and project managers from the IT, engineering, or manufacturing fields. Data were collected from 165 Taiwan-based enterprises, and the respondents were asked to rate questionnaire items on a five-point Likert scale.

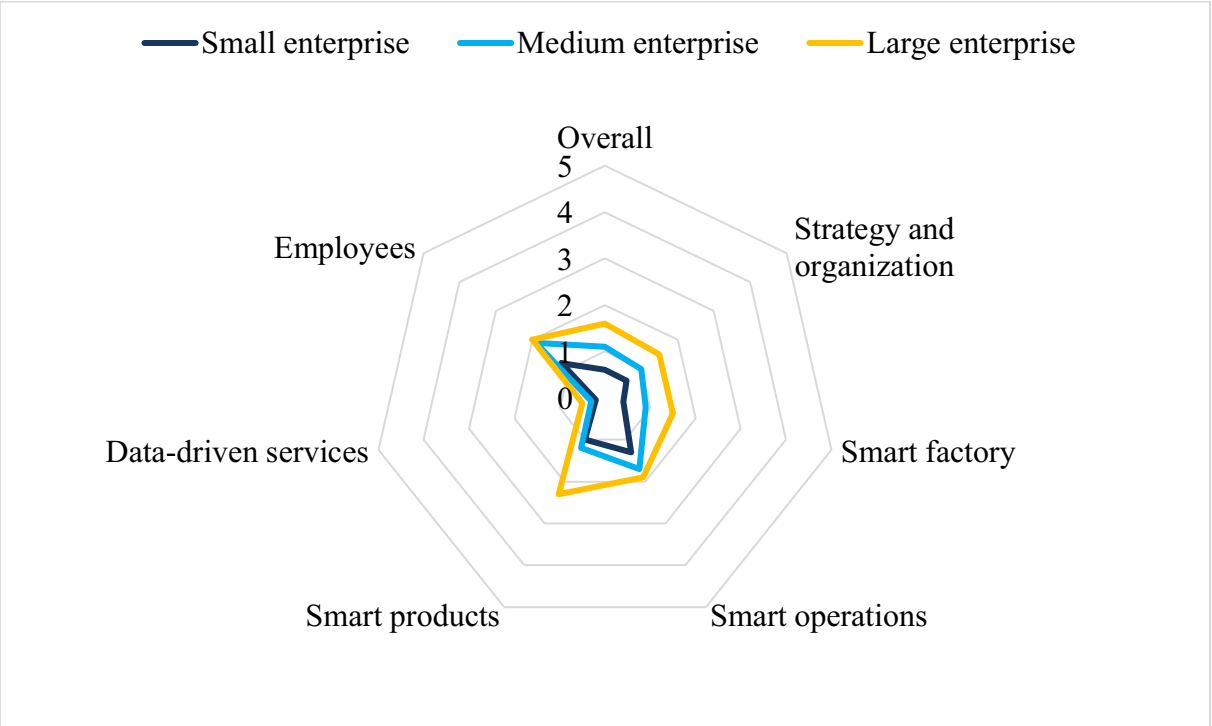
Of the total number of firms surveyed, 40 enterprises were immature (0 at level 1 and 40 at level 2), 113 enterprises were mid-mature (82 at level 3 and 31 at level 4), and 12 enterprises were mature (level 5). This finding indicates that Taiwanese enterprises intensively invested in smart manufacturing transformation, and the number of mid-level mature and mature enterprises increased. Moreover, enterprises invested in transformation plans or executed the plan from 2018 to 2021. The results revealed that most Taiwan-based enterprises were in the transformation plan planning and execution stages in 2021. The structure of the manufacturing industry has changed, which has promoted the upgrade of the entire industrial supply chain system to a new ecosystem of smart manufacturing.

6.1.6 Enterprises maturity level in Germany and Brazil

This article used the maturity model in industry 4.0 developed by VDMA, applied it to German companies and Brazilian companies, analyzed of maturity level in industry 4.0, and sought to identify learning opportunities to increase competitiveness. Field research was carried out with 46 manufacturing industries, 6 dimensions of the model, and the general result on a scale of 0 to 5.

The survey applied the industry 4.0 Maturity Assessment Model to 289 large, medium, and small industries in Germany. And Brazilian companies, from Espirito Santo State, one of the states in the Southeast, are the most developed region in Brazil.

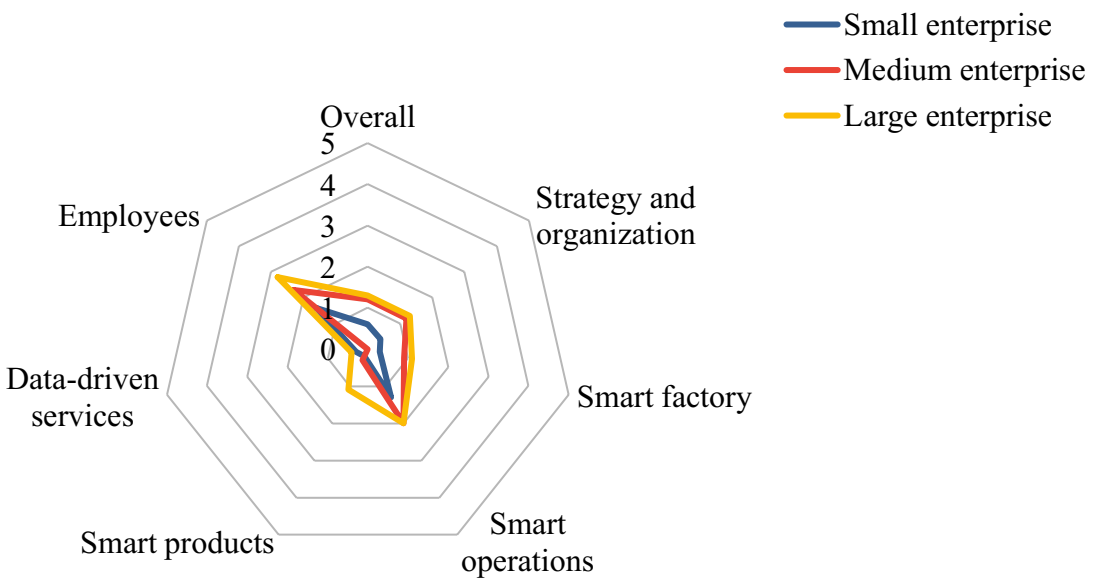
Figure 17. Average maturity level in small, medium, large enterprise in Germany



The general result of the German companies on a scale of 0 to 5, was 0.9, indicating at outsider level. The results of the survey showed that large companies stand out from small and medium-sized companies in all dimensions. Only in the Data-Driven Services dimension, there are three groups have very close results. Also, in the Employees dimension, the results were similar for large and medium-sized companies (1.9 and 2.0). Considering all companies, 76.5% are classified as newcomers that are at levels 0 or 1. At level 2 called learners, 17.9% of the companies. Finally, 5.6% of enterprises are in levels 3 to 5 and are classified at leaders. Regarding the expectations of German companies concerning Industry 4.0, the study indicated that more than 60% of companies expect to increase revenues, increase their product or service portfolio and increase customer retention rates. 57.2% said that were already involved in the Industry 4.0 issue, but, for the most part, 53% of the industry in general, has defined themselves

as an "observer". Overall, these results show that Industry 4.0, for German companies, is associated with clear business opportunities and objectives.

Figure 18. Small, medium and large enterprises maturity level in Brazil

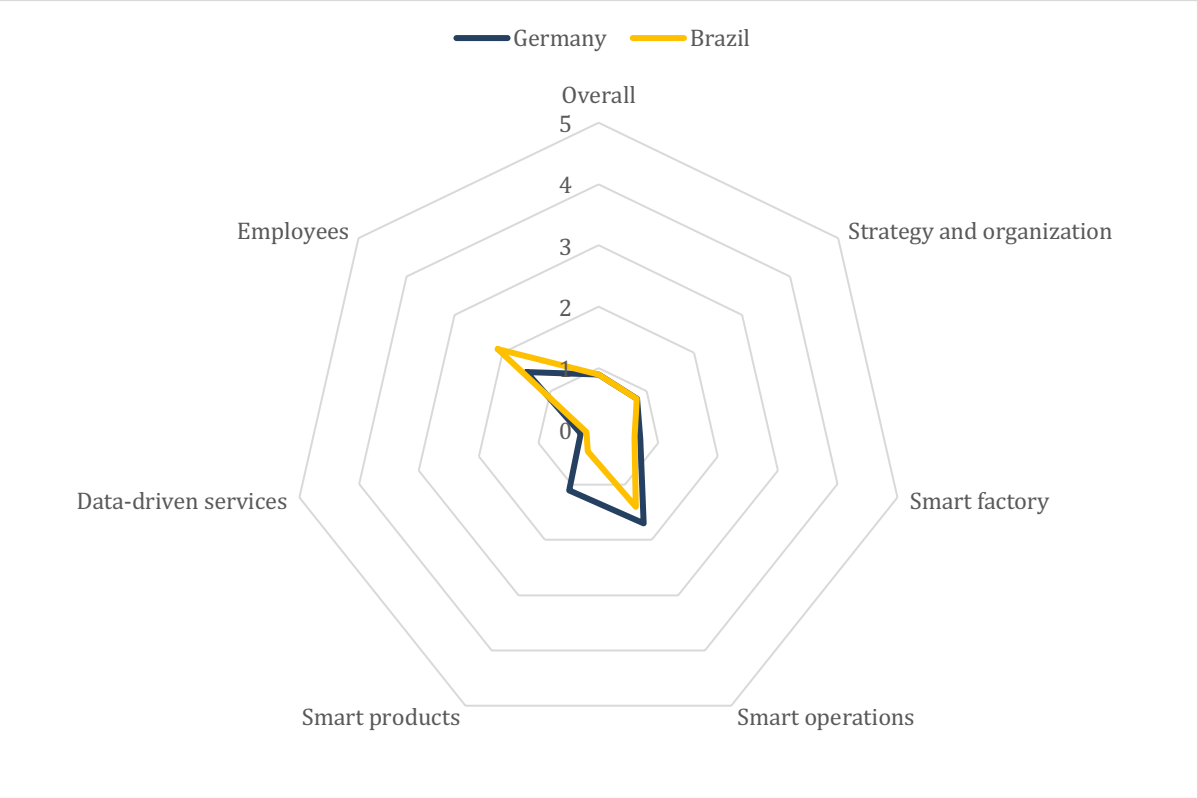


The result of the general average of Brazilian companies (in Espirito Santo State) was 0.94, on a scale of 0 to 5, classified as Newcomers. This result is similar, slightly higher than that obtained in the German companies' valuation, which was 0.9. The large companies presented superior results for five of the six dimensions and only in the dimension of employees the medium companies obtained greater value. In the Data Driven Services dimension, the three groups, large, medium, and small companies present very close results, being the dimension with the lowest evaluation of all, similar to German companies. The results of medium-sized companies for some dimensions are very close to the results of large companies, but for two dimensions are smaller than those of small companies, such as Smart Products and Data-Driven Services.

Regarding the group's result, 77.8% of enterprises are classified as Newcomers, are in levels 0 to 2, and 22.2% of enterprises are Learners, being in level 3. In levels 4 or 5, classified as Leaders, there are no Brazilian companies. Considering all surveyed companies, 61.9% said that they still do not know or are studying the subject and only one-third intend to develop an Industry 4.0 project. Asked about the greatest difficulties, 71.4% of respondents indicated that they are planning the best solution, and 33.3% of interviewees defined the best business model. Regarding the term to develop the project, enterprises do not see it as a very urgent project, because 42.9% of interviewees did not set a deadline and 33.3% of respondents think in the

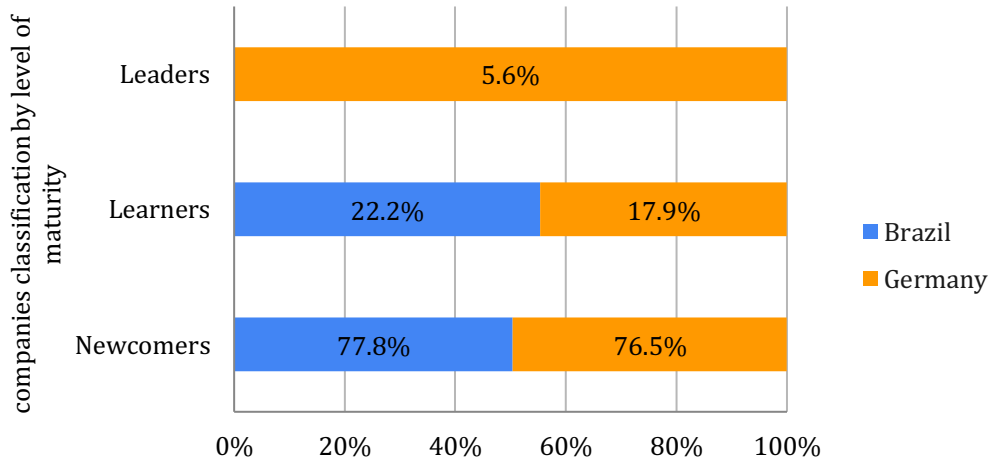
medium term, in two years. Overall, these results show that Brazilian companies still do not see Industry 4.0 as an opportunity for growth or results improvement, clearly being in a "wait and see" position.

Figure 19. Comparison of overall maturity results in Brazilian and German companies



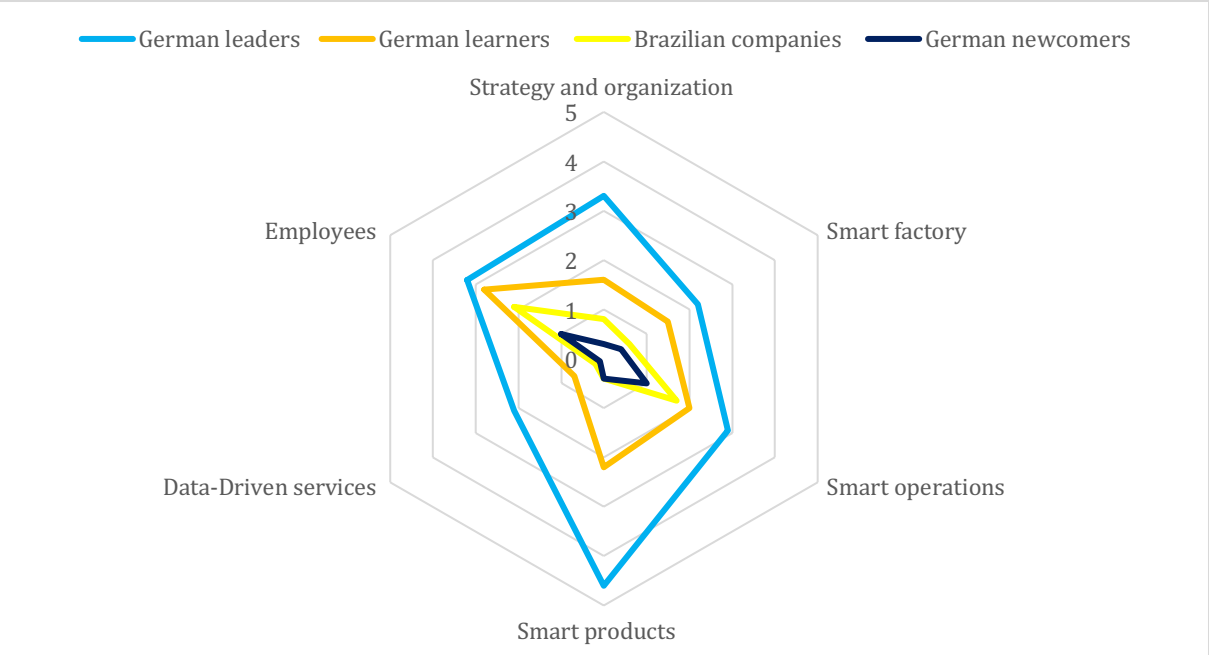
Comparing and analyzing Brazilian and German Results is to identify important factors to guide the path to be followed by Brazilian companies. In the result of the general average, in six dimensions of the VDMA model, the companies present practically the same level, 0.9 for the Germans and 0.94 for the Brazilian, Germans companies are defined as outsiders, Brazilian enterprises being are defined as Newcomers.

Figure 20. Companies' classification by level of maturity



The comparison of these two countries shows an interesting difference. The percentage of Brazilian companies studied is slightly higher at the Newcomers and Learners levels, but 5.6% of German companies are at the Leaders level, and there are no Brazilian companies (ES State) at this level. It means that German companies already invest in Industry 4.0 more intensely, especially the companies that develop industrial technology, in which the German Industry stands out and becomes the leader of industry 4.0.

Figure 21. Comparison of overall results of Brazilian companies (ES state) with German companies classified as Newcomers (0 to 1), Learners (2), and Leaders (3 to 5).



Although the general average results are close, when compared to the German Leader's companies the differences are quite significant in all dimensions. Even though this comparison is not precise, but the intention is to show that there is already a great distance for the German companies that are leading and investing in Industry 4.0.

6.1.7 Enterprises maturity level in China

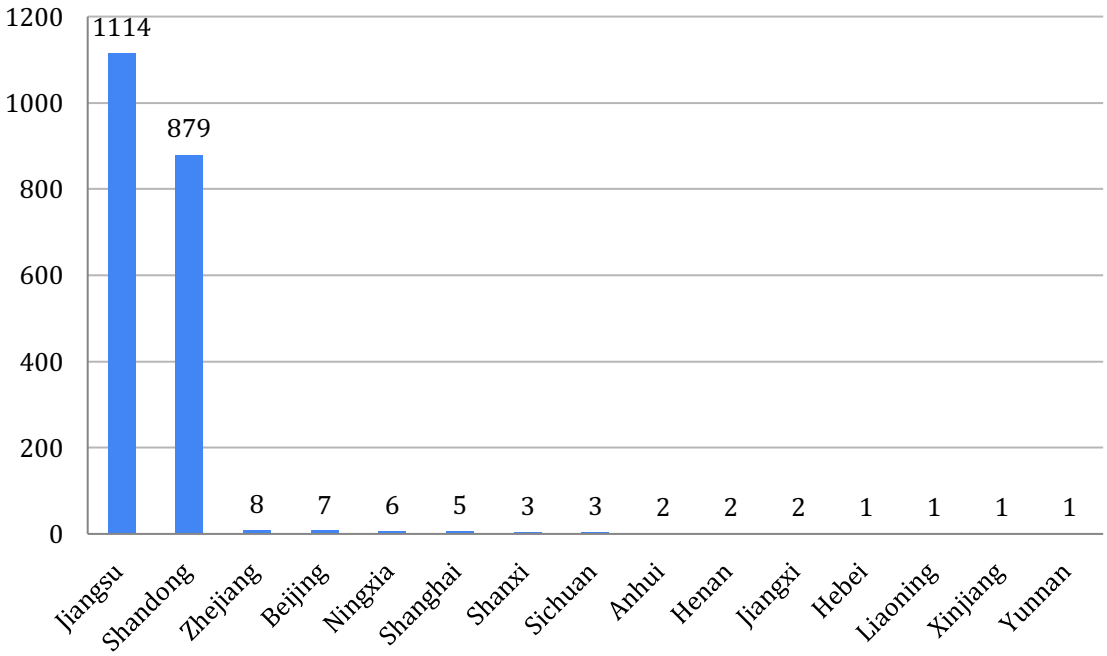
This model has been applied in self-evaluation in key areas such as Jiangsu and Shandong, with 4,235 participating enterprises, including 2,037 valid data in Fig. 22.

The self-evaluation results are divided into 1-5 grades from low to high according to the requirements of the standard in Fig. 23.

Among the participating enterprises, enterprises below grade 1 accounted for 60%, those who reached level 1 accounted for 29%, those who reached level 2 accounted for 6%, and those who reached level 3 accounted for 3%, and the proportion of enterprises with level 4 reached 1%, reaching 5 companies accounted for 1% which show in Fig.23.

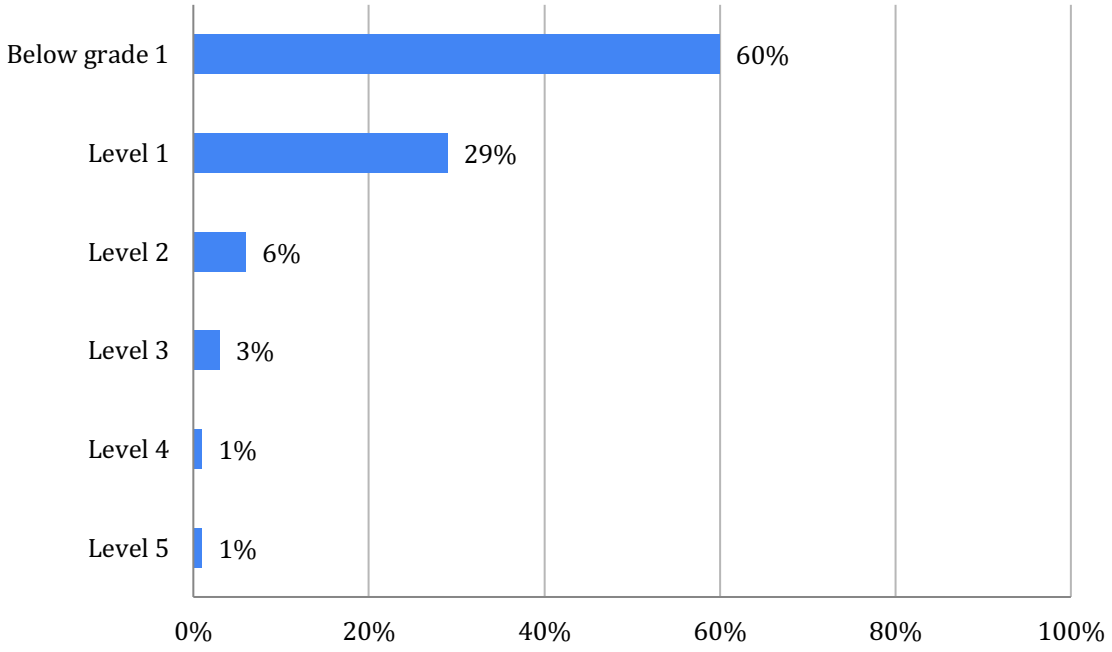
After the above analysis, we can find that most of China's manufacturing companies have a low level of maturity in their intelligent manufacturing capabilities, especially in the traditional manufacturing industry.

Figure 22. The regional distribution



The regional distribution is as follows:

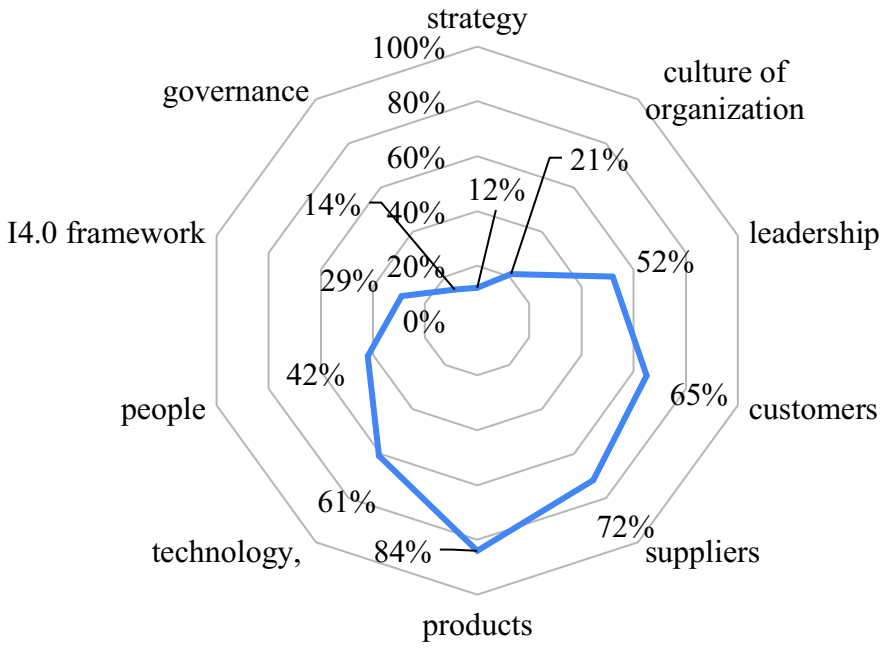
Figure 23. Companies' percentages in different maturity levels



6.1.8 SEMs Enterprises maturity level in Serbia

Serbia is intensively working on this program of implementation for Industry 4.0. They are using a model for assessing the maturity and readiness of manufacturing organizations to operate and implement Project I4.0 in their environment. Questionnaires were distributed to 106 SMEs from the manufacturing sector, and 49 responses were obtained.

Figure 24. SEMs Enterprises maturity level in Serbia



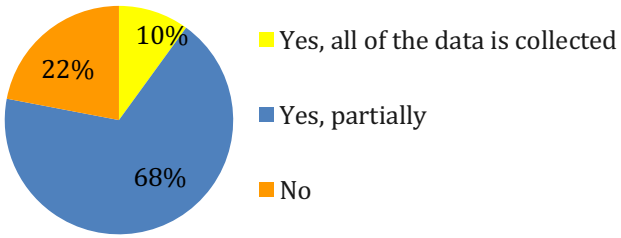
As can be seen in figure 24, there are 10 dimensions with different percentages of implementation. Strategy dimension has 12% of maturity, the culture of an organization dimension has 21% of maturity, leadership dimension has 52% of maturity, customers dimension has 65% of maturity, suppliers dimension have 72% of maturity, products dimension have 84% of maturity, technology dimension has 61% of maturity, people dimension has 42% of maturity, governance dimension has 14% of maturity, I4.0 framework dimension has 29% of maturity. In general, the average implementation of all dimensions is 45% which belongs to level 2- partially implemented (total of 4 levels). And the highest level of readiness was accomplished for these dimensions: customers (65%), suppliers (72%), and products (84%), where the average percentage of all the dimensions without considering different weights is 45%. As a result, the SMEs enterprises should improve their levels in strategy, the culture of an organization, and governance dimensions, with the support from Serbia government.

6.1.9 Enterprises maturity level in Hungary

According to the survey, the first results of the evaluation of questions concerning data collection, processing, and utilization were presented, without using the maturity model to show the final results. Therefore, we only can get some basic information about digitalization process in Hungary case and assume the maturity of Hungary on Industry 4.0.

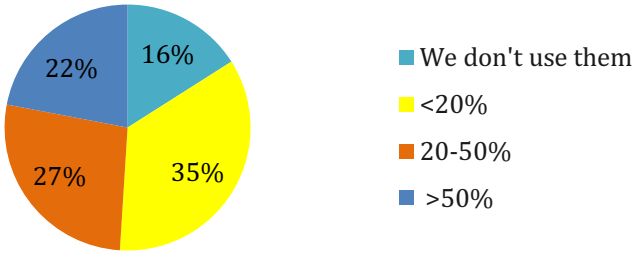
78% of the companies had at least partial data collection in Fig. 25, primarily for quality control and production statistics purposes. However, in most cases, its actual use has not yet become an integral part of the manufacturing and production processes.

Figure 25. Does your company collect data about production processes and machines?



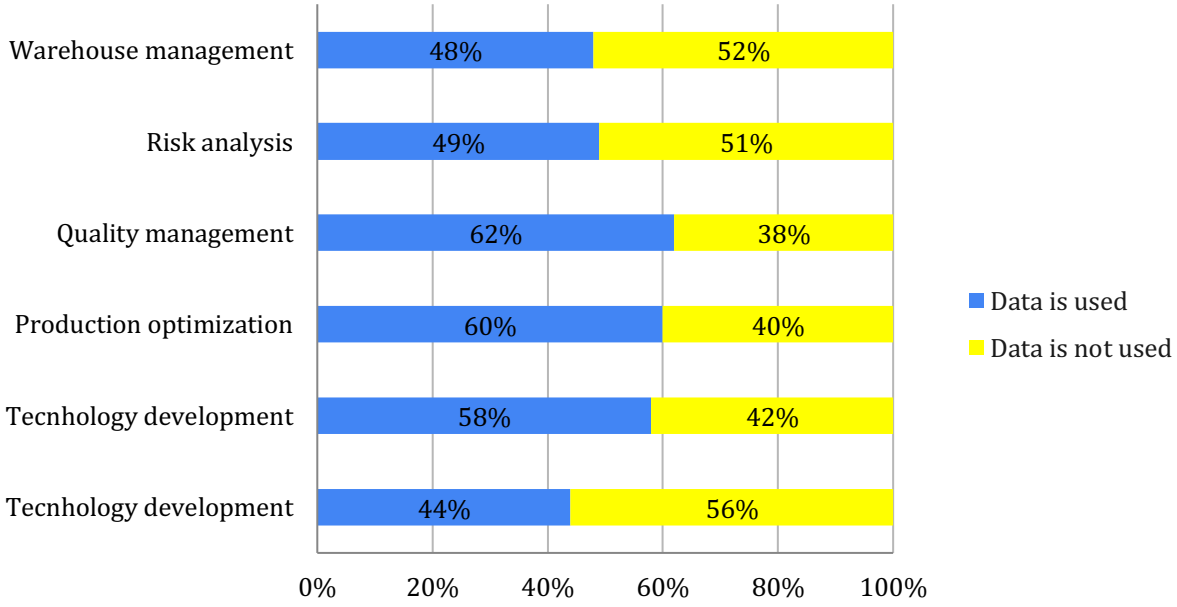
As one can see in Fig.25, most of the Hungarian companies have recognized that data collection is indispensable if they want to remain competitive in the future: in total, about 78% of them collect production data at least partially.

Figure 26. To what extent does the company use the collected data?



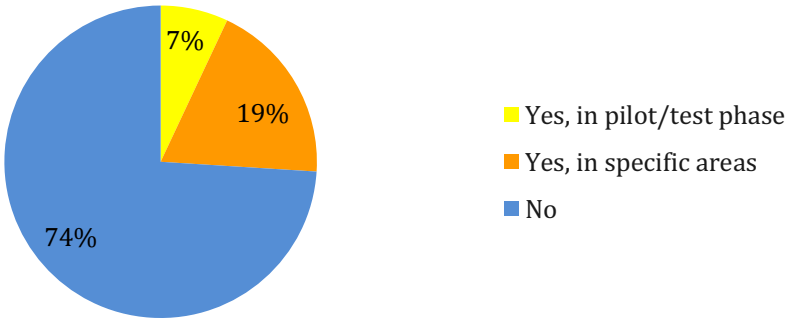
The next step after data collection is data processing, intending to use it for a specific purpose. An interesting result is that not the entire volume of the collected data is evaluated: in general, 16% of the data is not used but collected.

Figure 27. In which areas does your company use the collected data?



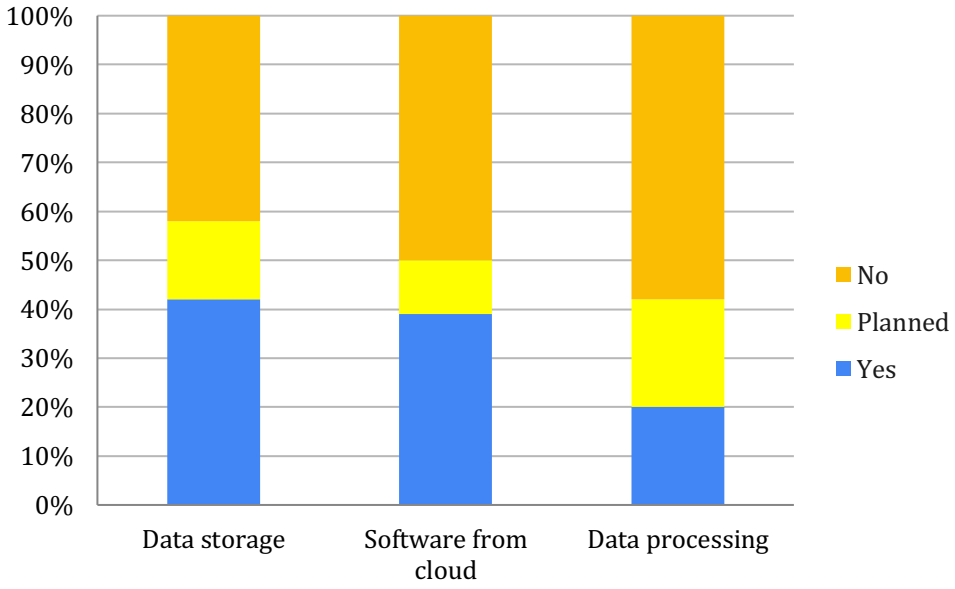
In the case of production data, the top three areas are quality management, production optimization, and technology development in Fig.27. Interestingly, almost 13% more companies use data for technology development, than for product development.

Figure 28. Are there any cases where a process reacts to changes in the manufacturing conditions in real time?



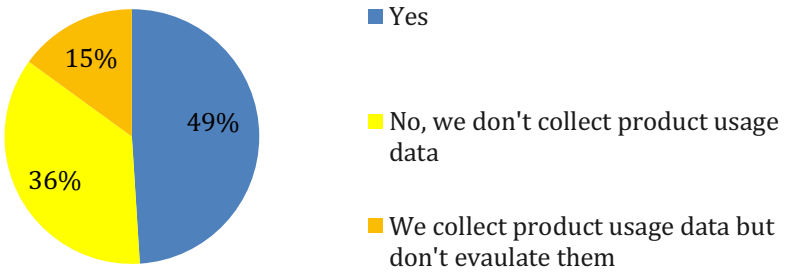
The survey contained questions about the industry 4.0 technologies related to production data, too. The participants were asked if they have any examples where the production process reacts to the manufacturing conditions in real-time: 74% of them answered with "No", as one can see in Fig. 28.

Figure 29. Does the company use cloud-based services in the specified areas?



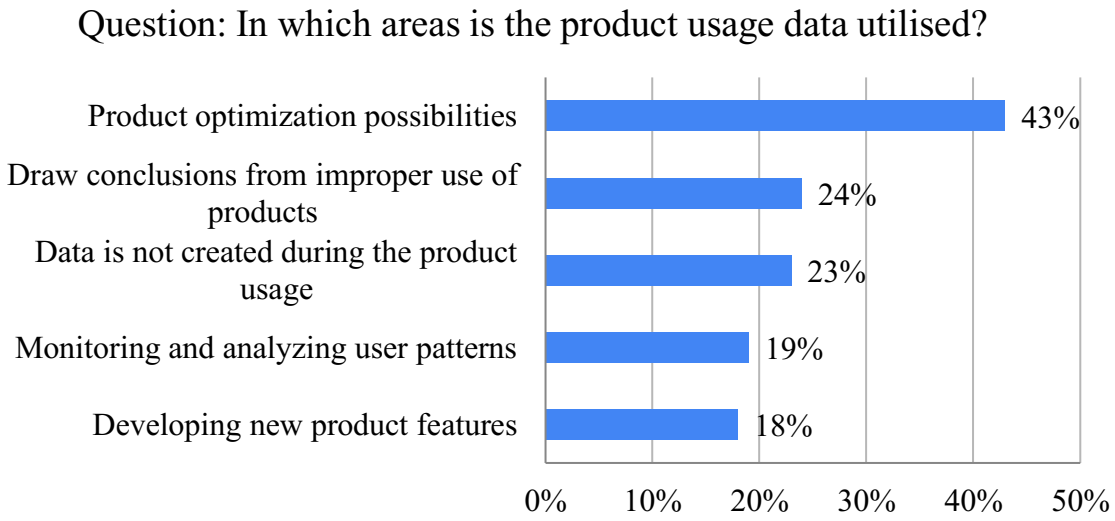
Cloud-based technologies are used by approximately a third of the participants, as Fig.29 showed. The evolution of cloud usage is evident: based on IT security and cost considerations, it is primarily used for backups, data storage, or software running. However, the actual breakthrough, the use of cloud services in manufacturing, is still far away, although this could be the area where SMEs could be benefitted most from the cost savings.

Figure 30. Is product usage data evaluated?



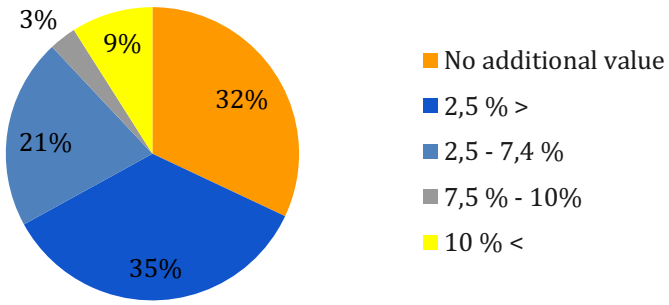
In the case of product usage data, almost half of the companies use the data, 15% of them only collect information about products but never use them, and more than a third of them (36%) do not collect product usage data at all (Fig. 30).

Figure 31. Question: In which areas is the product usage data utilized?



Comprehensive data collection and processing about product usage affect the enterprise business model since additional services could be created by utilizing it. In our sample of respondents, most of this data is used for product optimization purposes and is utilized to the smallest extent for developing new product features in Fig. 31.

Figure 32. Question: Income share of special services offered by manufacturers based on collected data



One can see in Fig. 32 that Hungarian companies are not strong at offering special services based on collected data. In a third of them, there is no additional value produced in connection to the products, and only 9% of them indicated that more than 10% of their income comes from this type of service.

According to the survey, the majority of industrial companies in Hungary understood the importance of this fact: 78% of them had at least partial data collection, primarily for quality control and production statistics purposes. Although data is being collected, in most cases its actual use has not yet become an integral part of the manufacturing and production processes. Based on the survey, Hungarian companies are striving to use the collected product data, but they are yet far from fully utilizing the revenue-generating potential of the additional services developed on this basis. They are thus ahead of a long familiarization, technical development, and innovation process affecting their entire operation in terms of business model and integration of the new technologies.

Based on the data evaluation view, we only can have a preliminary and predicted results through those questions answers. And it is reasonable to comment that the maturity level in Hungry is around level 1 and level 2, but still far from level 3.

6.1.10 SMEs Enterprises maturity level in Turkey

SMEs have a high enterprise share of 99.8% in Turkey, means large enterprises owning 0.2%. And during this e-survey, except for companies from the beverages and tobacco manufacturing sector, 1040 companies are participating. Here are the industrialization level results in each manufacturing sectors.

Table 9. Survey participation numbers of sectors and industrialization levels

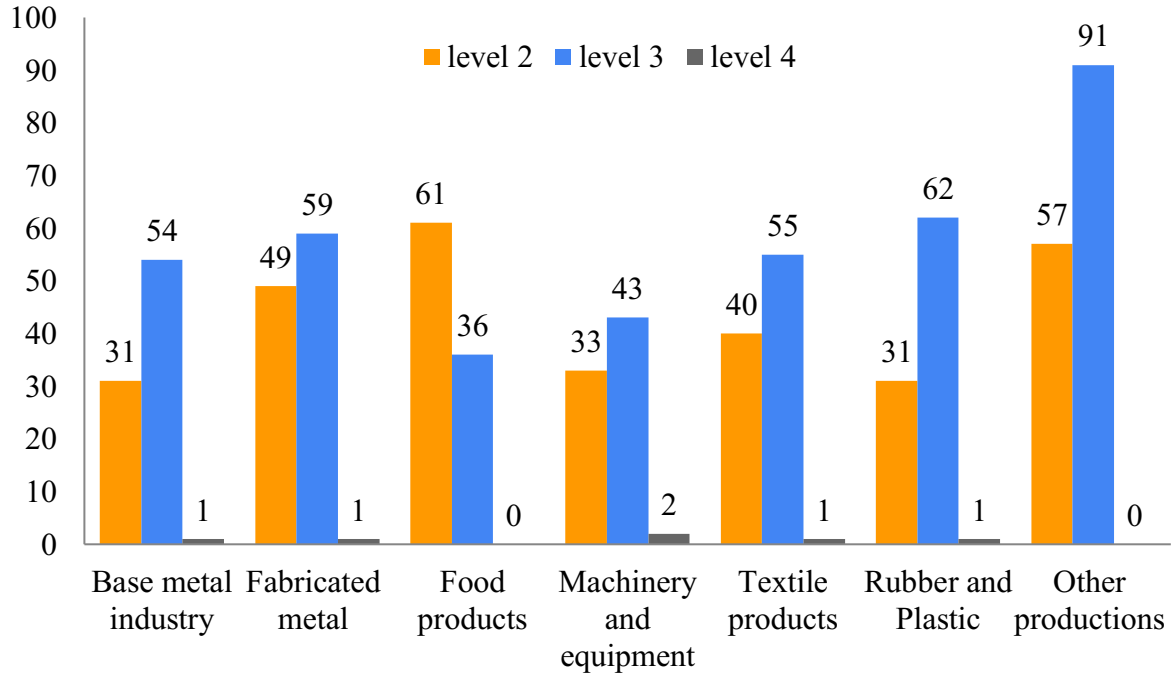
Manufacturing Sectors	**Number of participant SME**	**Average industrialization level**
Manufacturing basic pharmaceutics and pharmaceutical materials	13	2.72
Manufacture of other transport vehicles	5	2.66
Manufacturing computers, electronics, and optic materials	25	2.64
Printing and copying recorded media materials	5	2.62
Manufacture of motor vehicles, trailers, and semi-trailers	22	2.54
Manufacturing rubber and plastic materials	94	2.52
Manufacturing chemicals and chemical products	47	2.48
Base metal industry	86	2.47
Manufacture of machinery and equipment not elsewhere classified	78	2.47
Manufacturing non-metallic minerals	16	2.47
Other productions	148	2.46
Manufacture of fabricated metal products, except machinery and equipment	109	2.46
Manufacturing electronic equipments	46	2.45
Outfit manufacturing	17	2.45
Manufacture of textile products	96	2.44

Manufacture of paper and paper products	22	2.44
Furniture manufacturing	53	2.42
Installation and repair of machinery and equipment	36	2.42
Manufacture of wood, wood and cork products (except furniture);	14	2.28
Manufacture of food products	97	2.27
Manufacturing leather and its bi-products	11	2.22
Manufacturing beverages	0	-
Manufacturing tobacco products	0	-
Grand total	1040	Average - 2.43

It can be seen in the table 9 that the average industrialization level for the 1040 companies is 2.43. And the "Manufacturing Basic Pharmaceutics and Pharmaceutical Materials" sector has the highest score with 2.72, whereas the lowest score is observed for the "Manufacturing leather and its bi-products" sector with 2.22.

It is seen that the SMEs are still not achieving the Industry 4.0 level, and yet they are behind the 3.0 level which means they are still in level 2.

Figure 33. Based on different industries, the amount of the company in each level

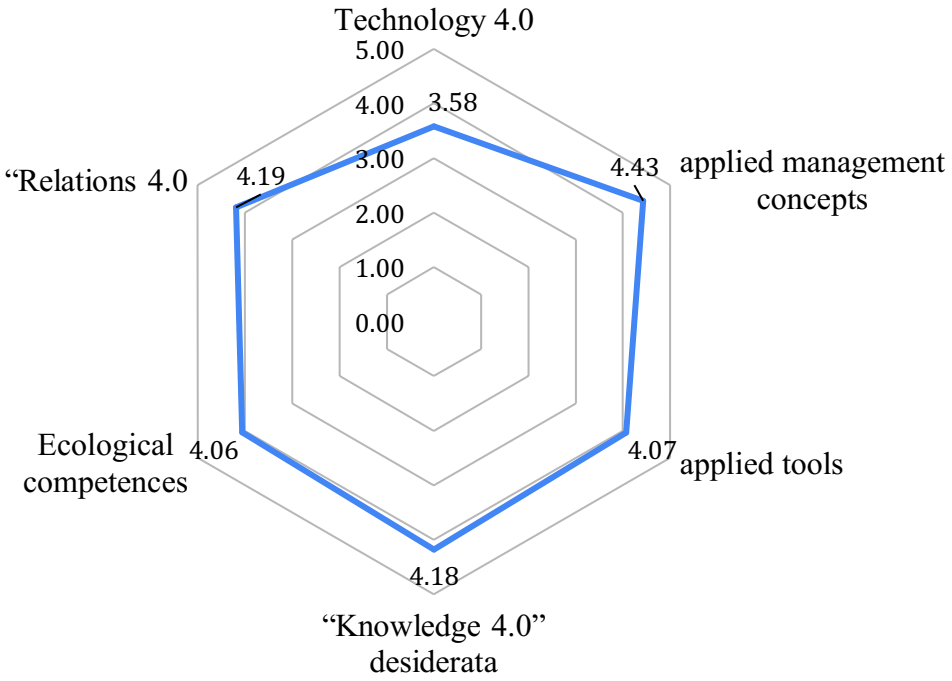


Regarding to the selected 7 cluster sectors in Fig. 33, 302 companies show Industry level 2.0 while 400 companies show Industry level 3.0, and 6 enterprises show industry level 4.0. In another words, level 2 and level 3 have more proportion in Turkey 4.0 industry development, and it stills need to improve themselves in leader level in level 4.

6.1.11 Agricultural machinery enterprises maturity level in Poland

The basic research was carried out on a sample of 71 enterprises representing Poland's agricultural machinery sector in manufacturing industry. To conduct this assessment, a five-point scale was adopted to describe the maturity level of individual descriptors corresponding to the selected areas of Industry 4.0. (5 – high level of maturity, 1 – low).

Figure 34. The average score in 6 dimensions



From the Fig.34. The score of average Technology 4.0 is 3.58 means that surveyed enterprises significantly used technology within Industry 4.0, And the majority of Polish enterprises in the agricultural machinery sector do not mass produce but offer their products only on request. The average Management concept' score is 4.43. Applied tools' score is 4.07, 'Knowledge 4.0' desiderate' score is 4.18, Ecological competences' score is 4.06, and relations 4.0' score is 4.19. The average score of 6 dimensions without considering different weights is 4.09. According to its rank, it belongs to level 4.

6.1.12 Steel Manufacturing Enterprises maturity level in Poland

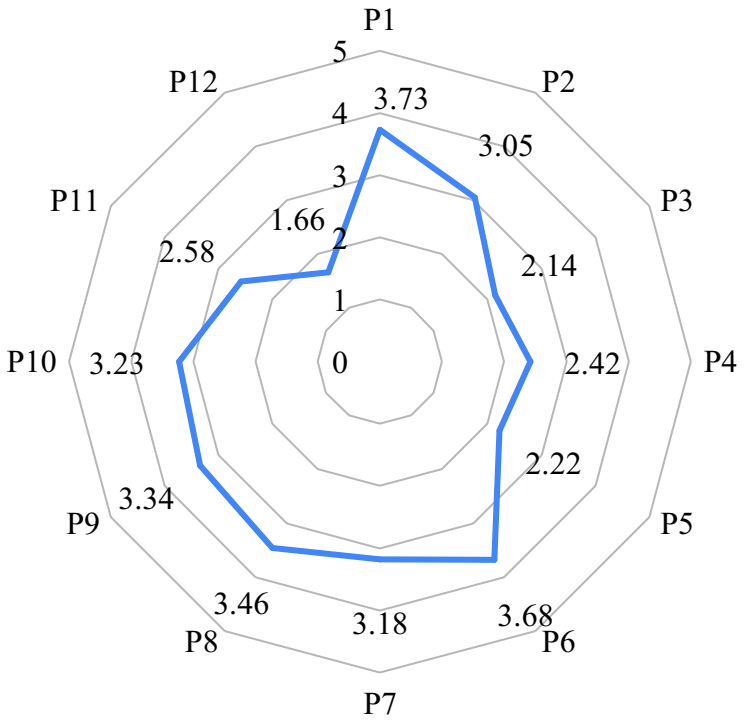
The research was carried out with 79 selected steel enterprises in Poland for the pilot study. A five-point assessment scale was used to measure the degree of maturity of developed enterprises by implementing projects of smart manufacturing (SM).

Based on the research, it was established that the segment of enterprises in the Polish steel market are at the third level of maturity in the five-level scale of the model. Here is the data in each dimension in Fig. 35 below.

Automation of production using single machines (P_1) is 3.73, automation of production using interacting machines in production nests (P_2) is 3.05, automation and robotization of full production lines (P_3) is 2.14, automation of warehouse processes—the stage of partially or fully automated warehouses (P_4) is 2.42, multi-tasking production lines controlled automatically with machine learning (ML) (P_5) is 2.22, Internet and mobile technologies

(ICTs) in customer services, including EDI, e-invoicing system (P_6) is 3.68, TPM—equipment with sensors generating data about efficiency of machines in real time (P_7) is 3.18, development and compatibility of production support information systems: CAx, MRP, MES (P_8) is 3.46, business network and chain integration with the system end-to-end engineering (P_9) is 3.34, extension of databases (Big Data) and process visualization (P_10) is 3.23, access to cloud services and the Industrial Internet of Things IIoT (P_11) is 2.58, development of block chain in the steel sector and distribution of steel products (product protection, cybersecurity in chain, etc. (P_12) is 1.66. The average score of 12 dimensions without considering different weights is 2.89.

Figure 35. The average score in 12 dimensions



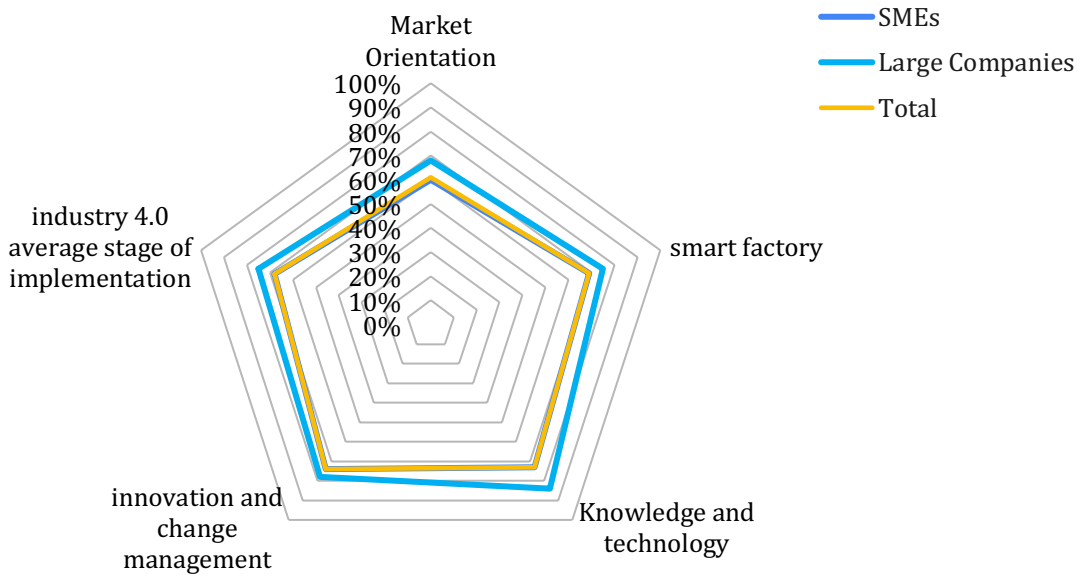
Based on the research, it was established that the segment of enterprises in the Polish steel market is at the third level of maturity in the five-level scale of the model, where level 1 is the "preliminary" level, and 5 represents the optimal maturity level. Poland is currently entering the third level of maturity of technological solutions toward smartness.

6.1.13 Enterprises maturity level in Portugal

The research was carried out with all industries in Portugal. Manufacturing belongs to one of the industries in this paper, and have 126 responses.

And the maturity level in the manufacturing industry shows in Fig. 36 which use percentage to evaluate the degree.

Figure 36. The average score of 5 dimensions in Portugal



The percentage of Market orientation maturity level is 61%, the percentage of the smart factory's maturity level is 69%, the percentage of Knowledge and technology's maturity level is 73%, the percentage of innovation and change management's maturity level is 74%, the percentage of industry 4.0 average stage of implementation's maturity level is 68%, the average percentage of all dimensions maturity level is 69% without considering different weights, which equal to 3.45 in 5 scores.

6.1.14 SEMs Enterprises maturity level in Italy

The study's model has been built and validated through two pilot case studies, with the final model used in extensive case studies research with 20 enterprises. The SMEs used in this research present an intermediate readiness level concerning Industry 4.0.

In Fig. 37, the data shows that the score of strategy is 2.9, the score of people is 2.8, the score of processes is 3.4, the score of technology is 2.3 and the score of integration is 2.5. Thus, the Integration average of 5 dimensions is 2.8 which belongs to DRL 3 (2.6 - 3.4).

The resulting DRL in Fig. 38 means that companies currently are approaching the path towards Industry 4.0 and the digitalization of their processes. Because 50% of the companies are in DRL 3, 35% of the enterprises are in DRL 2, 10% of the enterprises are in DRL 4, and 5% of the enterprises are in DRL 1. However, the room for improvement to companies still remains.

Figure 37. Average scores in 5 dimensions

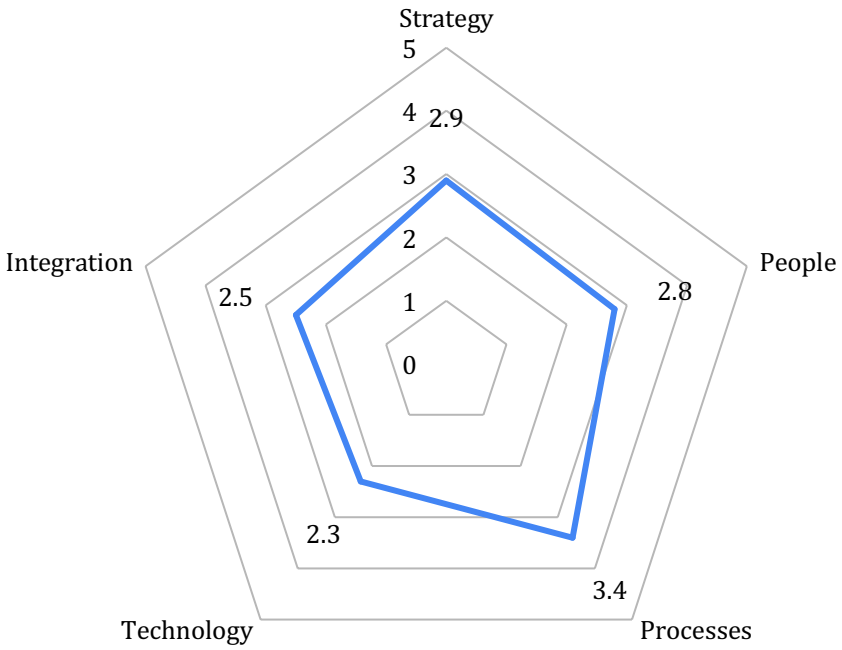
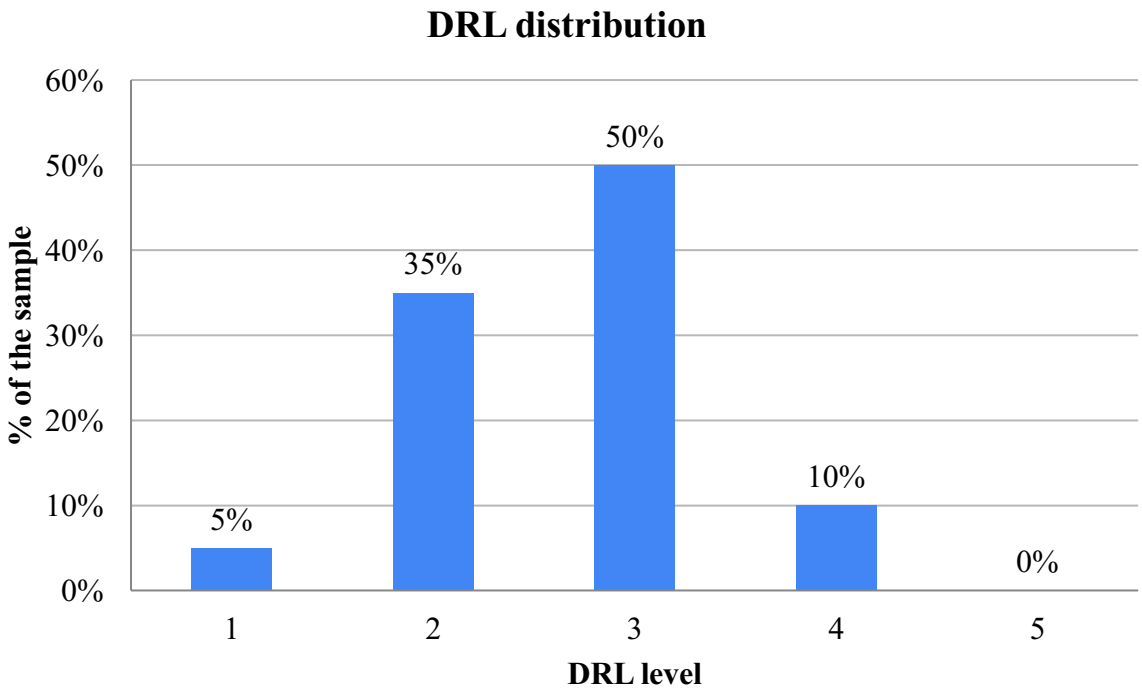


Figure 38. Enterprises DRL levels distribution

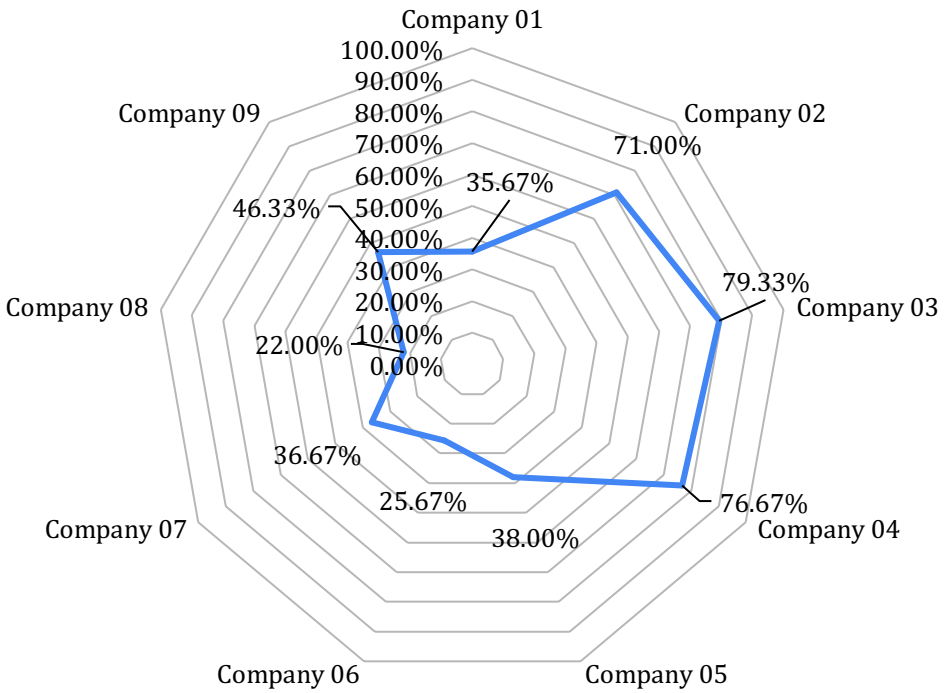


6.1.15 Enterprises maturity level in Southern Brazil

Fig. 39 presents the result of the evaluation of the Readiness I4.0 model for the 9 companies together with the classification in which they fit. Regarding the classification, the first (Traditional) was used to facilitate the understanding of professionals who are not familiar with this type of description, whereas the second categorization deals with how the authors of the Readiness I4.0 model mention the company's position concerning the obtained maturity index. According to the data shown in Fig. 39, companies 02, 03, and 04 are the best ranked. They have invested a lot in technology in recent years in addition to training their professionals in aspects related to management and culture. There are ongoing initiatives that have shown satisfactory results. Interestingly, they are at an average maturity index and are classified by the authors of the Readiness I4.0 model as “Survival”. If considering the reality where Brazilian industries are inserted, it should be emphasized the good leverage that organizations obtained in a short time. As a result, we have company 09, which has also been investing in innovation and technology for some time, however, in the view of the experts who answered the questionnaire, there is still no improvement in internal processes.

In the end, the average maturity level of 9 companies is 47.93 % which is in Existence level. If we use the 5 scales to calculate, it will be at 2.3965 at level 2.

Figure 39. Results of the Readiness I4.0 model in 9 companies



6.1.16 SEMs Enterprises maturity level in Italy

A web-based survey was conducted, and 77 companies were interviewed in this article. In particular, the sample is composed of 21% of medium-sized companies, 29% of micro-size, and 50% of small-size.

What I need to point out is that this article does not use the maturity model to describe the maturity of the enterprise, but uses two dimensions to classify the enterprise, so in this article, we cannot directly get the maturity level, but it can only be estimated by indirect methods, so only preliminary conclusions can be obtained in the end.

From Fig. 40, 41, and 42, the industry 4.0 knowledge degree in micro, small and medium enterprises mostly are basic level. From Fig. 43, 44, and 45, the industry 4.0 application degree is in micro with no action, small enterprises are in preliminary and no action and medium enterprises are mostly preliminary and high level. Thus, the survey results underline that MSMEs still have limited knowledge about I4.0 and are not well prepared for its implementation. As a result, we can estimate that Italian SMEs maturity level are at the level 2.

Figure 40. Micro enterprise I4.0 knowledge degree

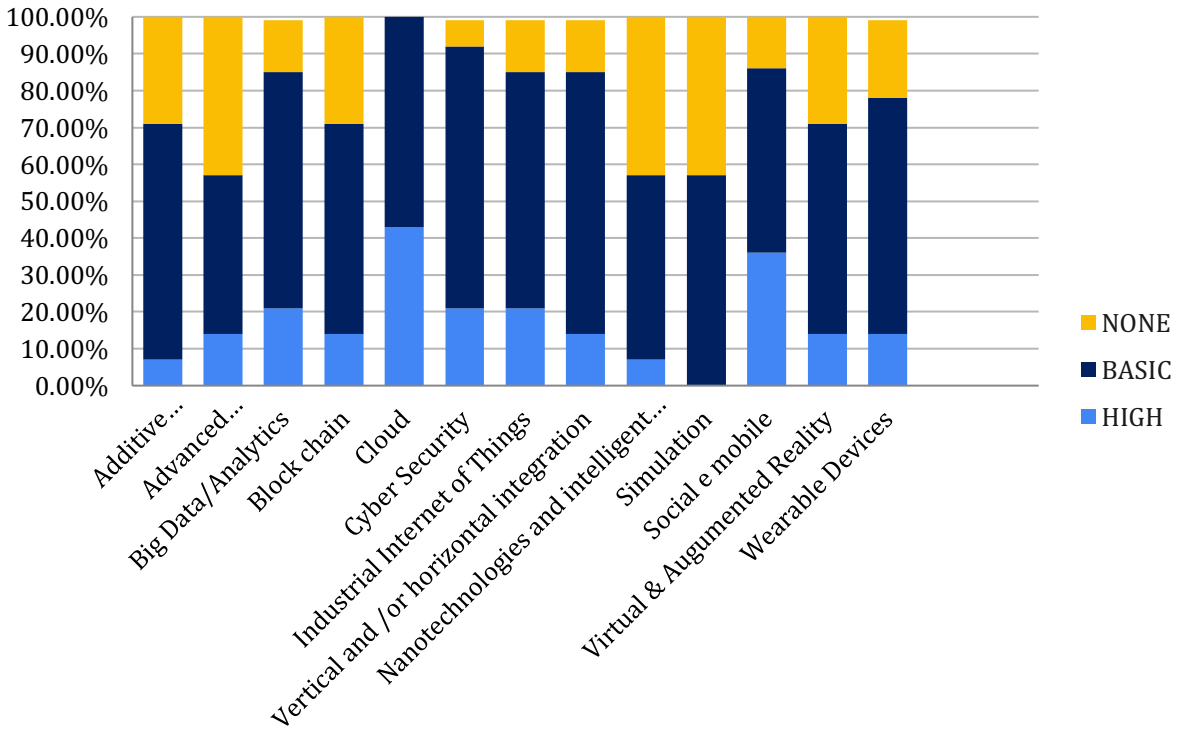


Figure 41. Small enterprise I4.0 knowledge degree

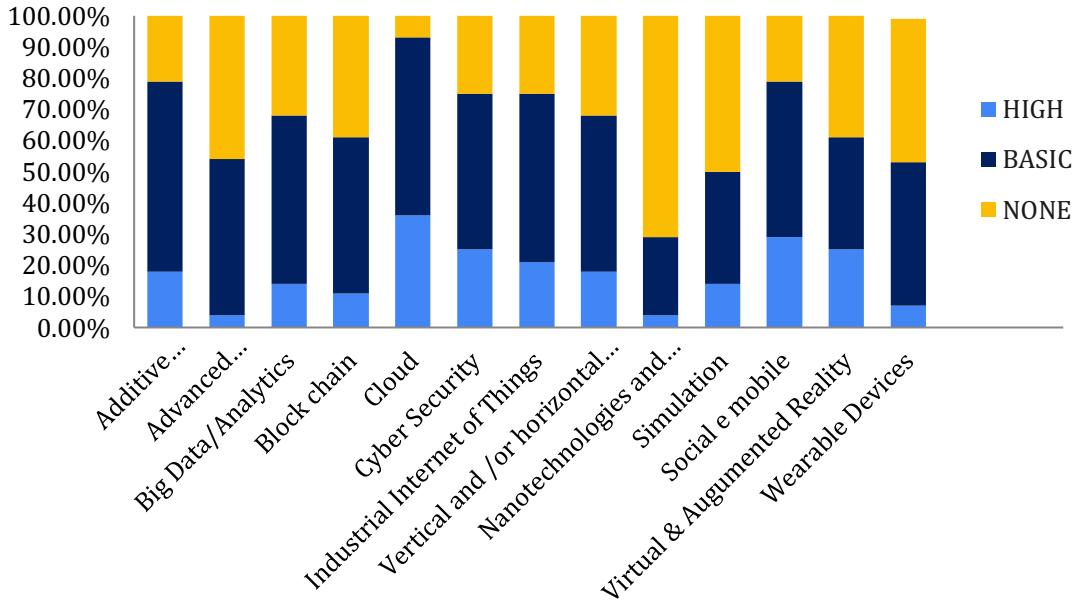


Figure 42. Medium enterprise I4.0 knowledge degree

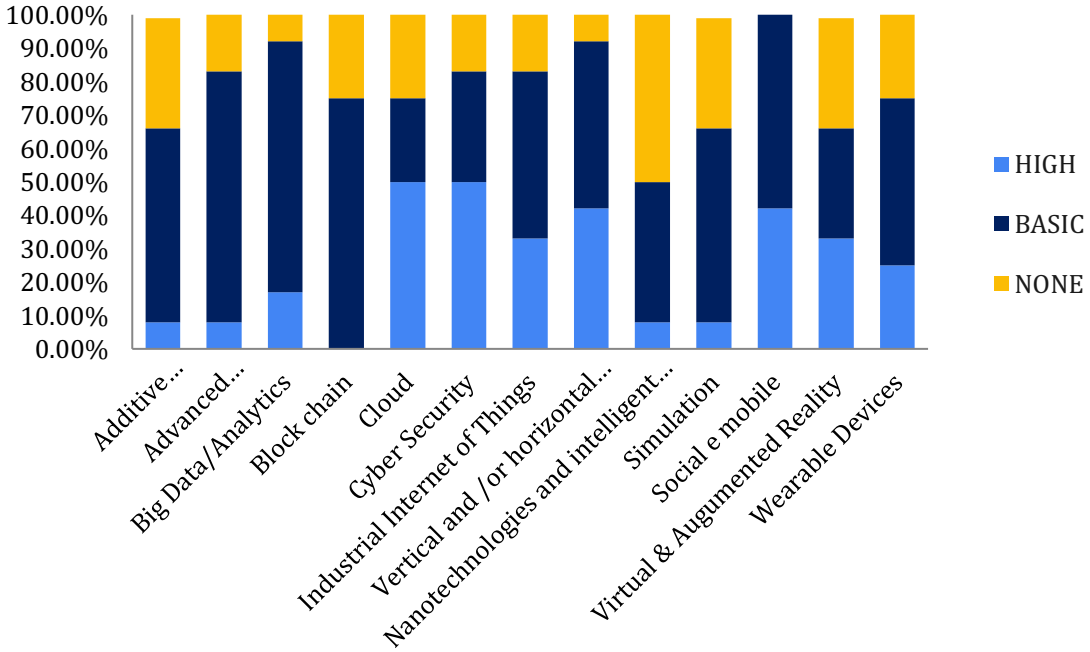


Figure 43. Micro enterprise I4.0 application degree

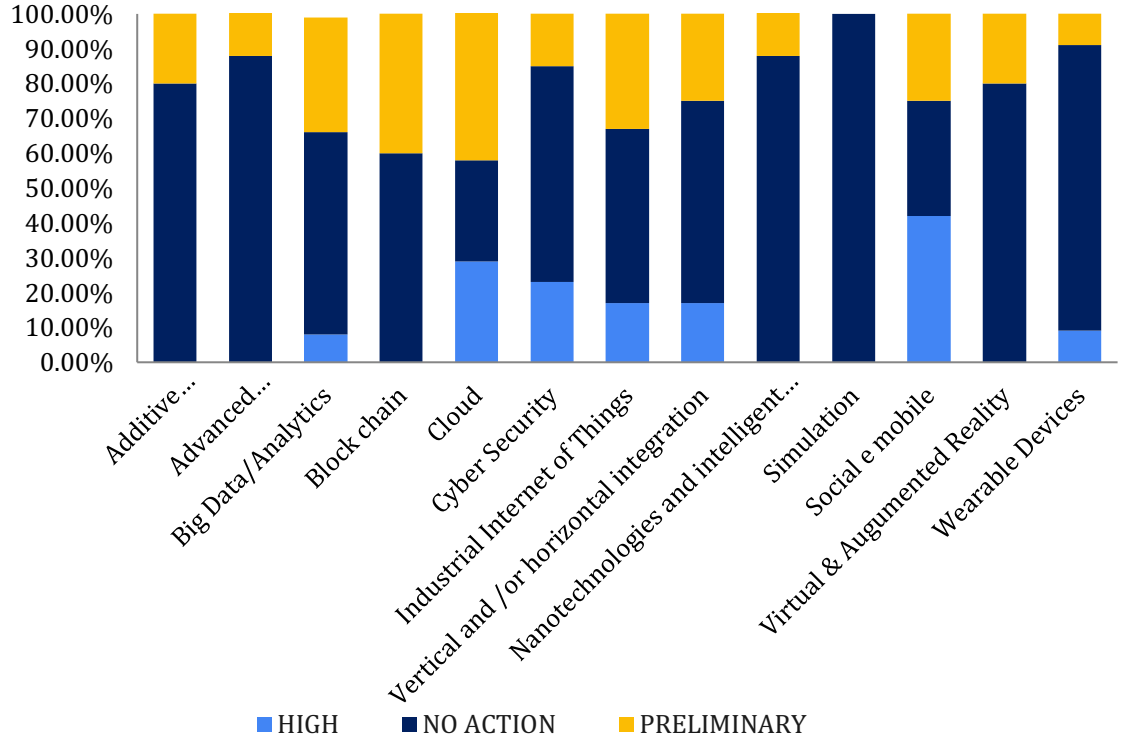


Figure 44. Small enterprise I4.0 application degree

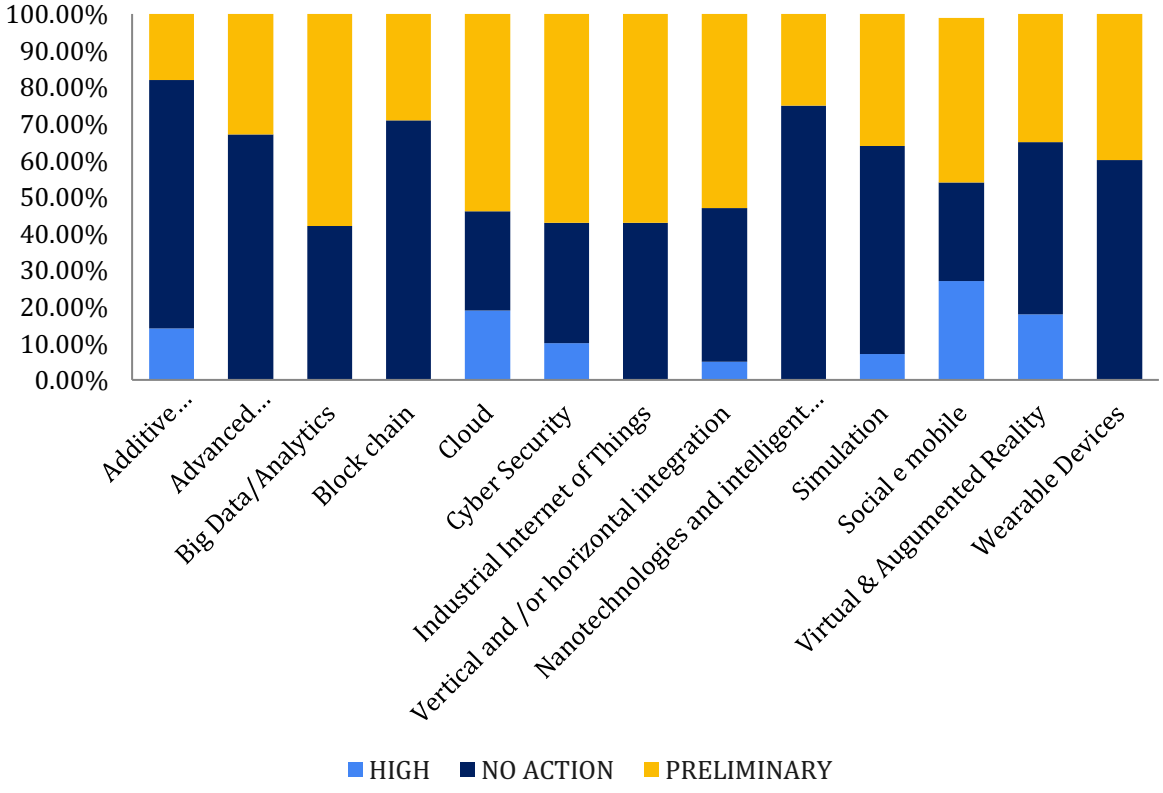
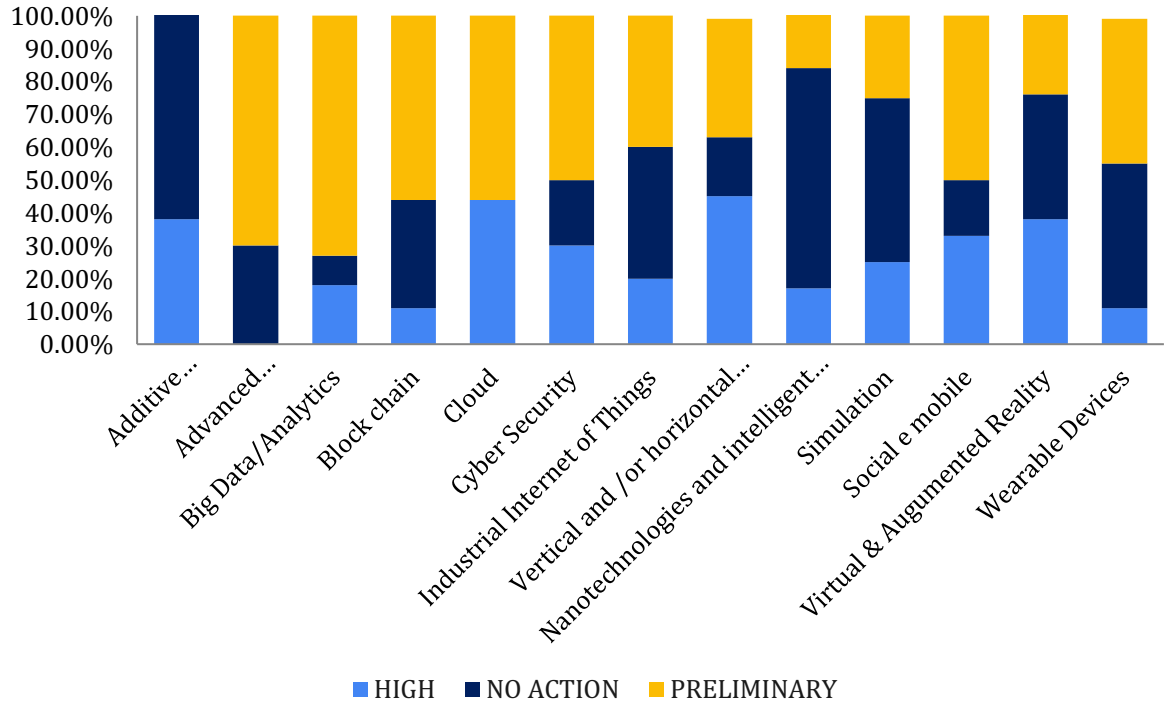


Figure 45. Medium enterprise I4.0 application degree

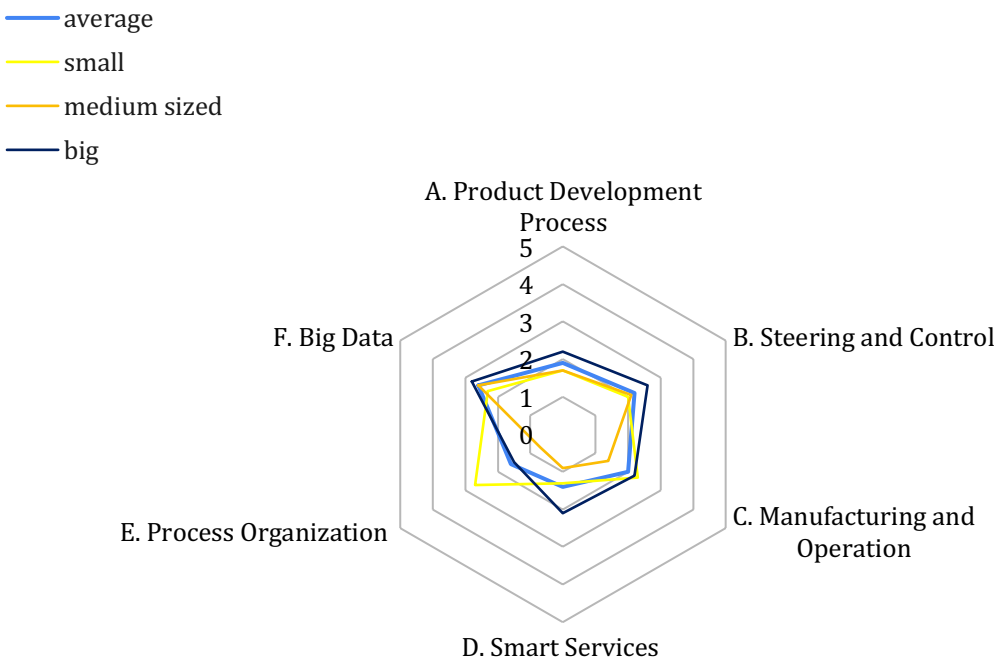


6.1.17 Manufacturing Enterprises maturity level in Germany

24 German enterprises were interviewed focusing on six different dimensions.

As an overall result in the product development process (1.9), steering and control (2.2), manufacturing and operations (2.0), smart services (1.4), process organization (1.6), and big data (2.6). Thus, the average score of the 6 dimensions is 1.95, which belongs to level 1 but close to level 2. And it can be determined that level two (intermediate) was the highest average level that has been achieved relating to the enterprise size. The highest rating was reached in the field of big data. However, it has to be noted that there is a large potential for German companies to reach a higher readiness level in terms of Industry 4.0.

Figure 46. 24 German companies Radar chart of maturity scoring



6.2 Group comparison results

Table 10. Summary of the final result in 17 articles

Country	Scale	Industry	Capacity	Score	Total levels	Level
Colombia	SMEs	Manufacturing	23 enterprises in Bogotá city	4.13	5 levels	level 3
Kazakhstan	SMEs	Textile	14 different cities 27 responses.	2.24	5 levels	level 2
Indonesia	All	Textile	Two textile experts	1.32	5 levels	level 2
Malaysia	All	medical devices	54 responders	3.06	6 levels	level 2
Taiwan	All	Manufacturing	165 enterprises	no score	5 levels	level 2: 40 level 3:82 level 4: 31 level 5: 12
Germany & Brazil	All	Manufacturing	Germany: 289 Brazil Espirito	G:0.9 B:0.96	5 levels	G: level 0

			Santo State			B: level 1
China	All	Manufacturing	2,037 valid data.	no score	5 levels	60% below grade 1, 29% level 1, 6% level 2, 3% level 3, 1% level 4&5
Serbia	SMEs	Manufacturing	49 responses	45.2%	4 levels	level 2
Hungary	All	All	no mentioned	no score	%	no mentioned
Turkey	SMEs	Manufacturing	1040 companies	2.43	4 levels	level 2
Turkey	SMEs	Textile	96 companies	2.44	4 levels	level 2
Poland	All	agricultural machinery sector	71 company	average 4,09	5 points	4 points
Poland	All	Steel Manufacturing	79 company	average 2.90	5 levels	level 3
Portugal	All	Manufacturing	23 results	68% = 3.45	%	level 3
Italy	SMEs	Manufacturing	22 SMEs	3.18	5 levels	DRL 3
Southern Brazil	All	Manufacturing	9 companies	47.93 % Existence =level 2.3965	%	level 2 in 5 levels
Italy	SMEs	Manufacturing	no mentioned	no score	no mentioned	no mentioned
Germany	All	Manufacturing	24 companies	1.95	5 levels	level 1

Since there are differences in company size and industry type in these 17 sets of data, their results need to be compared in different groups. The classification method is divided according

to the company scale, industry type, and same country, and is mainly divided into the following 6 groups for comparison.

It should be noted that the models used in the 17 articles are not the same, so the impact of different models on the data should be ignored when comparing. More importantly, a more similar level is used for comparison. More importantly, the model level is used for comparison, because the description of each model level is similar, and even some levels classifications are the same.

6.2.1 Colombia Colombia-Bogotá city vs Brazil Espírito Santo State

The first comparison group is between Colombia and Brazil, because in these two groups of data, the companies are in developed regions, so under such sample data, the results could be relatively high. The first group data comparison can be made to draw the difference in the maturity of these two developed regions.

Table 11. Colombia Colombia-Bogotá city vs Brazil Espírito Santo State

Country	Scale	Industry	Capacity	Score	Total levels	Level
Colombia 2022	SMEs	Manufacturing	23 enterprises in Bogotá city	4.13	5 levels	level 3
Germany & Brazil 2020	All	Manufacturing	Germany: 289 Brazil Espirito Santo State: no data	G:0.9 B:0.96	5 levels	G: level 0 B: Level 1

Here we can see that the maturity number for Colombia is 3.73 in level 3, according to the level description, level 3 means it represents the level to which the surveyed companies have partially applied technologies to their processes. The maturity degree for Brazil is 0.96 in level 1 as a beginner. Comparing these two different 5 levels description, Ávila-Bohórquez J.H (2022) level 1 matches Luciano Raizer Moura A (2020) level 2, which represents the level to which the surveyed companies have started strategic activities of research and analytical studies, as well as pilots to include and appropriate technology.

Therefore, the Colombia-Bogotá city maturity level is significantly higher in 2022 than Espírito Santo State in Brazil in 2020. Since both Colombia and Brazil are in Latin America, we can draw a preliminary conclusion that the Colombia-Bogotá city maturity level in 2022 is more mature than Espírito Santo State in Brazil in 2020. It should be noted that since Colombia's data is relatively small, and Brazil did not mention the sample size, this can only be used as a preliminary result.

6.2.2 Textile industry comparison in Kazakhstan, Indonesia, and Turkey

The second set of data is about the comparison of textile industry data.

Table 12. Textile comparison in Kazakhstan, Indonesia, and Turkey

Country	Scale	Industry	Capacity	Score	Total levels	Level
Kazakhstan 2022	SMEs	Textile	14 different cities 27 responses.	2.24	5 levels	level 2
Indonesia 2020	All	Textile	Two textile experts	0.36(1)	5 levels	level 2
Turkey 2021	SMEs	Textile	96 companies	2.44	4 levels	level 2

Kazakhstan, Indonesia, and Turkey, all three countries are developing countries. Among them, the data of company scale is all sizes, and the other two countries are mainly SMEs enterprises. Even though the enterprise scales are different and the amount of sample data is not the same, the final maturity levels are at level 2. And according to the level description in different models, level 2 in Kazakhstan means a beginner, level 2 in Indonesia means Potentialists, which is equal to level 2 in Kazakhstan, level 2 (total 4 levels) in Turkey means some systematic implementations are introduced to the system. Electricity is used instead of manpower. Personal computers, simple software and the Internet are present in the company, but not integrated with each other and not for managing the processes. Thus, we can conclude that the Turkish textile industry is the highest maturity level in these three countries.

6.2.3 Specific industries comparison in Malaysia and Poland.

The third group is about the comparison in subdivided industries, agricultural machinery in Poland, Steel Manufacturing in Poland, and medical devices manufacturing in Malaysia.

Table 13. Malaysia and Poland maturity degree

Country	Scale	Industry	Capacity	Score	Total levels	Level
Poland 2020	All	Agricultural machinery sector	71 company	average 4,09	5 points	4 points
Poland 2022	All	Steel Manufacturing	79 company	average 2.90	5 levels	level 3

Malaysia 2022	All	medical devices	54 responders	3.06	6 levels	level 2

In these three sets of data, the size of the firm is the same, that is, firms of all sizes and the sample capacity are very closed. Comparing the results, the Polish enterprise maturity level of the agricultural machinery sector is the highest at level 4 (total of 5 points), and Steel Manufacturing is entering level 3 as Bozena Gajdzik (2022) said. Malayan medical devices is at level 2, meaning the connectivity phase has been substantially completed.

It is worth mentioning that level 4 appears for the first time, so we can draw the result that the average digital maturity of the agricultural machinery sector in 2020 in Poland is the highest in these 17 sets of data.

6.2.4 All scales enterprise and all industries comparison in Taiwan, Germany, China, Hungary, Portugal, and southern Brazil

Table 14. maturity results in Taiwan, Germany, China, Hungary, Portugal, and Southern Brazil

Country	Capacity	Score	Total levels	Level
Taiwan 2021	165 enterprises	no score	5 levels	level 2: 40 level 3:82 level 4: 31 level 5: 12
Germany & Brazil 2020	Germany: 289 Brazil Espirito Santo State: no data	G:0.9 B:0.96	5 levels	G: level 0 B: Level 1
China 2019	2,037 valid data.	no score	5 levels	60% below grade 1, 29% level 1, 6% level 2, 3% level 3, 1% level 4&5
Portugal 2019	23 results	68% = 3.45	%	level 3

Southern Brazil 2021	9 companies	47.93 % Existence =level 2.3965	%	level 2 in 5 levels
Germany 2018	24 companies	1.95	5 levels	level 1

In this group, all data have the same dimension in enterprise scale and industry. However, the difference in sample capacity is relatively large, the maximum value is 2037 in China and the minimum value is 9 in Southern Brazil.

Surprisingly, Comparing the results in this group, the maturity in Germany as an outsider and 60% below grade 1 in China and below, while others such as Portugal and Taiwan are at a higher level. The reason for this difference may be the capacity of the sample.

The reason why China's low maturity level can be the data of different cities varies greatly. Because the data is mainly in Jiangsu and Shandong city, and other first-tier cities are very few and not involved, so the maturity value can be relatively low. Therefore, the researchers can concentrate on researching manufacturing companies in China's first-tier cities to fill the gap.

In German data, as mentioned in Luciano Raizer Moura A (2020), 5.6% of the German companies are in the leader position, which means that there is a large gap in enterprises maturity level in Germany.

As a result, Germany, China and Taiwan have the leaders level enterprises, need to improve the average level. And enterprises in Brazil and Portugal need to increase an expert level company.

6.2.5 SMEs company in Serbia, Turkey, and Italy

The biggest feature of this group of data is that the scale of enterprises in SEMs.

Table 15. SMEs companies comparison in Serbia, Turkey, and Italy

Country	Scale	Capacity	Score	Total levels	Level
Serbia 2020	SMEs	49 responses	45.2%	4 levels	level 2
Turkey 2021	SMEs	1040 companies	2.43	4 levels	level 2
Italy 2019	SMEs	22 SMEs	3.18	5 levels	DRL 3

Italy 2021	SMEs	no mentioned	no score	not mentioned	not mentioned

Among this set of data, the Turkish data is relatively the most objective, because the sample size here is relatively large.

Comparing all the data, the level of Serbia is at level 2 which means partially implemented, and level 2 (total 4 levels) in Turkey means some systematic implementations are introduced to the system. The result in 22 Italian SMEs is at DRL 3 means partially applied technologies to their processes. The final one in Italy does not use the maturity model and maturity level to measure, but with the result of the industry 4.0 knowledge degree and the enterprise I4.0 application degree in micro, small and medium enterprises. but the preliminary estimate is at the level 2. Thus, the maturity level in Serbia, Turkey and Italy SEMs enterprises are approximative.

6.2.6 Different references in the same country

This group is characterized by the fact that measures of country maturity levels appear in different works of literature. They are Poland, Germany, Brazil, and China. Thus, we mainly compare whether the data is consistent and the reasons for the inconsistency.

Table 16. Polish maturity level in different references

Country	Author	Industry	Capacity	Score	Total levels	Level
Poland	Bogdan Nogalski1 (2020)	agricultural machinery sector	71 company	Average 4,09	5 points	4 points
Poland	Bozena Gajdzik (2022)	Steel Manufacturing	79 company	Average 2.90	5 levels	level 3

These two articles in Poland, it is clear that in the two sets of data in Poland, the maturity level is inconsistent, one is entering level 3 and another one is at level 4, and the reason for the inconsistency is the inconsistency of the research industry. In conclusion, we can comment that Poland's agricultural machinery sector is more mature than its steel manufacturing in industry 4.0. In general, the agricultural machinery sector and Steel Manufacturing enterprises are in a good situation in industry 4.0 development.

Table 17. German maturity level in different references

Country	Author	Industry	Capacity	Score	Total levels	Level
Germany 2020	Luciano Raizer Moura A (2020)	Manufacturing	Germany: 289	0.9	5 levels	G: level 0
Germany 2018	Daniel Bittighofer (2018)	Manufacturing	24 companies	1.95	5 levels	level 1

Those two articles in Germany, the results are very near to level 1. The reason for the inconsistency in this group of data is the difference in sample capacity. Surprisingly, Germany is not as digitally advanced as expected, but with a lower level. As a result, the maturity of German companies is unevenly developed, but there is a certain proportion in leader level, but Germany should improve the overall maturity level of companies.

Table 18. Brazilian maturity level in different references

Country	Author	Scale	Capacity	Score	Total levels	Level
Southern Brazil	Luiz Felipe Pierin Ramosa (2021)	All	9 companies	47.93 % Existence =level 2.3965	%	level 2 in 5 levels
Brazil	Luciano Raizer Moura A (2020)	All	Espirito Santo State	Brazil 0.96	B: newcomers	level 1

These two articles in Brazil, the biggest difference of this group data is sample different in the survey area. The area in the first literature is in 9 companies in southern Brazil, and the second literature is in Espirito Santo State.

We can see that the result of the first case is at level 2 and the second is at level 1, so the sample may affect the result. However, we can get a preliminary conclusion that there is diversity in Brazil's digital maturity in different regions.

Table 19. Chinese maturity level in different references

Country	Author	Scale	Capacity	Score	Total levels	Level
Taiwan 2021	Lin T.-C (2021)	All	165 enterprises	no score	5 levels	level 2: 40 level 3: 82 level 4: 31 level 5: 12
China 2019	Jingyi Hu a (2019)	All	2,037 valid data	no score	5 levels	60% below grade 1, 29% level 1, 6% level 2, 3% level 3, 1% level 4&5

These two articles in China. We can see that Taiwanese companies have a large proportion of levels 2, 3, 4, and 5 in 2021, but in contrast to China in 2019, they have 60% of the companies are below grade 1 and 29% in level 1, which is close to 80%.

There are three reasons for the difference in this set of data. First, as an enterprise in mainland China, there are differences in data at different maturity levels. The second point is that there are differences in data samples. Thirdly because the survey time are different. But what we can see is that Taiwan has shown a high level in the process of digitization. As a result, we can draw a preliminary conclusion that there are differences in China's maturity levels in different regions.

7. Conclusion

At present, the literature on adopting maturity models to measure the maturity degree of countries is still insufficient. From now on, only 15 articles have been found that use maturity models to measure the digitization process, and the other 2 articles do not use maturity models to evaluate. However, there has been a substantial increase over the past three years compared to 2018. Generally speaking, the distribution of these documents is still uneven in different countries. Compared with developed and developing countries, developing countries have more contribution in this area. Some developed countries, such as the United States and the United Kingdom, have not found such articles in databases. At the same time, the first proposed and implemented the concept of digital manufacturing, in Germany, the contribution of literature is not ideal. Also, China's contribution is insufficient in this type of research.

So far, most of the literature uses five-level and five-dimensional models. About choosing the models, the most popular and common one named IMPULS is proposed by the VDMA organization in Germany. Some authors modify and add some dimensions based on this model so that the model is more appropriate to apply in this company. For example, some models need to be more suitable for small and medium-sized enterprises, etc.

Comparing the results when the concept of intelligent manufacturing was proposed and the current results, the degree of development of digital manufacturing is not as high as expected. However, the epidemic has greatly helped that digitization in the past few years.

One point of many documents their departure is not only a maturity review of this country but also to provide better suggestions and some improvements in the future. One of the main reasons is not limited to the use of models and measurement of the results itself, but to propose a model that is more suitable for the country, which is greatly helpful for the country's future development.

References

[1] Ávila Bohórquez, John Henry, and Richard de Jesús Gil Herrera. "Proposal and validation of an industry 4.0 maturity model for SMEs." *Journal of Industrial Engineering and Management* 15.3 (2022): 433-454.

[2] Bittighofer, Daniel, et al. "State of Industry 4.0 across German companies." *2018 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC)*. IEEE, 2018.

[3] Castelo-Branco, Isabel, et al. "Measuring the fourth industrial revolution through the Industry 4.0 lens: The relevance of resources, capabilities and the value chain." *Computers in Industry* 138 (2022): 103639.

[4] Dikhanbayeva, Dinara, et al. "Analysis of Textile Manufacturing SMEs in Kazakhstan for Industry 4.0." *Procedia CIRP* 107 (2022): 888-893.

[5] Emir, Oğuz, et al. "A Comparative Sectoral Analysis of Industry 4.0 Readiness Levels of Turkish SMEs." *Digital Conversion on the Way to Industry 4.0: Selected Papers from ISPR2020, September 24-26, 2020 Online-Turkey*. Springer International Publishing, 2021.

[6] Elibal, Kerem, and Eren Özceylan. "A systematic literature review for industry 4.0 maturity modeling: state-of-the-art and future challenges." *Kybernetes* (2020).

[7] Flamini, Marta, and Maurizio Naldi. "Maturity of Industry 4.0: A Systematic Literature Review of Assessment Campaigns." *Journal of Open Innovation: Technology, Market, and Complexity* 8.1 (2022): 51.

[8] Gajdzik, Bożena. "Frameworks of the Maturity Model for Industry 4.0 with Assessment of Maturity Levels on the Example of the Segment of Steel Enterprises in Poland." *Journal of Open Innovation: Technology, Market, and Complexity* 8.2 (2022): 77.

[9] Hu, Jingyi, and Sini Gao. "Research and application of capability maturity model for Chinese intelligent manufacturing." *Procedia CIRP* 83 (2019): 794-799.

[10] Lin, Tzu-Chieh, and Kung Jeng Wang. "Project-based maturity assessment model for smart transformation in Taiwanese enterprises." *Plos one* 16.7 (2021): e0254522.

[11] Moura, Luciano Raizer, and Holger Kohl. "Maturity assessment in Industry 4.0–a comparative analysis of Brazilian and German companies." *Emerging Science Journal* 4.5 (2020): 365-375.

[12] Majstorović, Vidosav D., Radivoje M. Mitrović, and Žarko Z. Mišković. "Assessing industry 4.0 readiness in manufacturing companies from Serbia." *Proceedings of 5th International Conference on the Industry 4.0 Model for Advanced Manufacturing*. Springer, Cham, 2020.

[13] Nick, Gábor, et al. "Industry 4.0 readiness in Hungary: model, and the first results in connection to data application." *IFAC-PapersOnLine* 52.13 (2019): 289-294.

[14] Nogalski, Bogdan, and Przemysław Niewiadomski. "Industry 4.0 desiderata as micro foundations in the assessment of companies' maturity–case study." *Management and Production Engineering Review* 11 (2020).

[15] Pirola, Fabiana, Chiara Cimini, and Roberto Pinto. "Digital readiness assessment of Italian SMEs: a case-study research." *Journal of Manufacturing Technology Management* (2019).

[16] Ramos, Luiz Felipe Pierin, Eduardo de Freitas Rocha Loures, and Fernando Deschamps. "An analysis of maturity models and current state assessment of organizations for industry 4.0 implementation." *Procedia manufacturing* 51 (2020): 1098-1105.

[17] Rahmadi, Arie. "Industry 4.0 Readiness for the Circular Economy: Transition Trends and Readiness of Indonesia's Textile and Electronics Sectors." *Assessing the Readiness for Industry 4.0 and the Circular Economy* (2020): 251.

[18] Stark, Christian, and Jeng Feng Chin. "Industry 4.0 Maturity Assessment in a Medical Devices Manufacturing Industry." *International Journal of Operations and Quantitative Management* 28.1 (2022): 259-279.

[19] Tortora, Alessia MR, et al. "A survey study on Industry 4.0 readiness level of Italian small and medium enterprises." *Procedia Computer Science* 180 (2021): 744-753.