

Industry 4.0 maturity assessment in manufacturing enterprises: a mixed-methods approach for SMEs

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Abstract

Purpose – This study aims to evaluate the adequacy of existing I4.0 maturity models in small and medium-sized enterprises (SMEs) located in an under-industrialized region and comprehensively assess the extent to which these scales reflect the specific conditions of SMEs using a mixed-methods approach.

Design/methodology/approach – This study involved a two-step process using both quantitative and qualitative methods. Initially, we applied the nine-dimensional I4.0 maturity evaluation model developed by Schumacher, Erol, and Sihn (2016) to 21 manufacturing enterprises in the developing Bartın Organized Industrial Zone in Türkiye to determine their I4.0 maturity levels. Subsequently, thematic analysis of semi-structured interview data from these enterprises was conducted using MaxQDA, aligning themes with scale dimensions. This revealed variances and alignments in maturity scores across dimensions.

Findings – It was observed that the participants gave more appropriate answers to the content and scope of the relevant dimension in the dimensions where they got high scores. In addition to the participants' focus on technology for I4.0, it was observed that they perceived this process only in terms of production and operational efficiency increase, and their expectations for organizational structures or enterprise processes were limited.

Originality/value – This study addresses the gap in the literature regarding the applicability of existing quantitative I4.0 maturity models to SMEs in under-industrialized regions. By combining quantitative and qualitative methods, this research highlights the need for qualitative research alongside quantitative methods in measuring the I4.0 maturity of SMEs. This novel approach demonstrates how qualitative methods can enrich the understanding of I4.0 perceptions, overcoming the limitations of standardized scales.

Keywords Maturity model, Industry 4.0, Manufacturing enterprises, MaxQDA

Paper type Research paper

Introduction

The development and rapid advancement of digital technologies require industrial sectors to re-evaluate their traditional enterprise models. The fourth industrial revolution, Industry 4.0 (I4.0), represents the integration of the physical and digital worlds. It aims for radical changes in production processes (Kieroth, Brunner, Bachmann, Jodlbauer, & Kurz, 2022). Industry 4.0 contains many innovative elements, such as smart factories, human-machine-operation, data-based decision-making and improvements in customer experience (Galati & Bigliardi, 2019; Sehgal, Khanna, Dubey, & Khanna, 2022). I4.0 is the paradigm that will change the production value chains of developed industrial countries and developed industrial countries on a local and global scale (Bernhard, 2019; Atieh, Cooke, & Osiyevskyy, 2023).



The transformation within the scope of I4.0 affects enterprises' strategies, organizational structure, operational processes and technological development. The enterprises aware of this process have entered the preparation process for the transition to I4.0. The first step in the I4.0 transition roadmap is for enterprises to assess their current situation and determine if and how they are ready for this new industrial revolution (Issa, Hatiboglu, Bildstein, & Bauernhansl, 2018; Senna, Barros, Bonnin Roca, & Azevedo, 2023; Schumacher, Nemeth, & Sihm, 2019).

As we enter the I4.0 phase, interest in assessing enterprises' readiness has surged. The growing importance of I4.0 necessitates models to help enterprises gauge their current status, recognize necessary changes and strategize their transition to I4.0. Maturity models are crucial in determining enterprises' preparedness for I4.0, identifying areas for improvement and assessing their alignment with the new industrial revolution's requirements.

While most studies on I4.0 maturity models have predominantly focused on large enterprises, there is a growing recognition of the need for distinct I4.0 models that address the unique challenges and characteristics of small and medium-sized enterprises (SMEs) (de Mattos, Pellegrini, Hagelaar, & Dolfsma, 2024; Thrassou, Uzunboylyu, Vrontis, & Christofi, 2020), which often lack the resources and infrastructure available to larger firms. We addressed this gap by focusing on SMEs and evaluating how well existing I4.0 maturity models cater to their needs.

Moreover, most studies examine highly developed industrial regions where entities adopt technological advancements more readily. However, there is a significant need to explore how I4.0 maturity models apply in developing industrial regions, where the pace of digital transformation may differ due to varying levels of infrastructure and human resources. This study contributes to this underexplored area by focusing on the Bartın industrial zone, a developing region in Türkiye.

The impact of I4.0 on enterprises of different sectors and sizes raises questions about the adequacy of existing maturity models. Studies on I4.0 maturity levels often rely on quantitative methods using standardized questionnaires, which, despite their usefulness, have limitations. Particularly in less industrialized cities, the scarcity of qualified human resources can create challenges regarding the reliability and validity of questionnaires' responses. In this study, we collected both quantitative and qualitative data in 2023 from a developing industrial zone in Bartın-Türkiye, where 53% of the population lives in rural areas. This region includes enterprises of various sizes, providing a comprehensive overview of the local industrial landscape. For example, some enterprises in our sample have high technological facilities and more qualified human resources and manage their management and strategic decisions from another center. On the other hand, some enterprises are smaller-scale enterprises operating with more limited technological facilities, relying on local resources and making management decisions at the local level.

In such cases, qualitative research methods can help effectively obtain more in-depth and comprehensive information. Mixed methods that utilize both qualitative and quantitative research are few, and researchers have applied many of them in developed industrial regions. It is widely accepted that the mixed method approach, encompassing the strengths of both methods, enhances research quality and reliability and thereby grounds the resulting information on a more robust scientific basis (Doyle, Brady, & Byrne, 2009; Timans, Wouters, & Heilbron, 2019).

We aimed to assess the applications of the existing I4.0 maturity model in SMEs more comprehensively and in-depth by utilizing the advantages of a mixed-method approach that uses both quantitative and qualitative data. This approach aims to go beyond standardized surveys to understand the implications of I4.0 and more accurately identify the maturity levels of enterprises, especially those that still need to develop.

Another difference between this study and the existing maturity models is that we applied it to a wide range of manufacturing enterprises of different sizes and in various industries, unlike models that scholars usually test on a single industry or enterprise size. Some advantages of this feature may encompass collecting data across various industries and enterprise sizes,

providing a better understanding of the strengths and weaknesses of the model. Moreover, it helps to understand the varying challenges and opportunities that different types of enterprises face during the transition to I4.0.

Therefore, this study provides three significant contributions to the existing literature: (1) it utilizes a mixed-method approach, combining both quantitative and qualitative data to offer a more comprehensive analysis; (2) it shifts the focus from large enterprises to SMEs, addressing their specific needs in the context of I4.0; and (3) it explores the applicability of I4.0 maturity models in a developing industrial region, providing insights that researchers often overlook in studies centered on developed regions. This approach highlights the importance of solely relying on quantitative methods for preparing the I4.0 process or determining the maturity level but also emphasizes the importance of evaluating participants' perspectives on the I4.0 maturity components through qualitative methods. In this context, we have uncovered participants' perceptions of I4.0 and the underlying thoughts behind their responses to the survey questions. In the study, we compared the quantitative research results with the results of the qualitative research to evaluate how enterprises perceive I4.0 dimensions. Furthermore, as a result of the quantitative research, for each dimension, we separately evaluated the perceptions of enterprises with above-average maturity scores (3.00 and above) and below-average enterprises (2.99 and below) on I4.0. This comparison has revealed how enterprises utilize I4.0 technologies in these dimensions, their differences and similarities and the opportunities and challenges they encounter. This process will provide critical information about the applicability of the maturity model for different sizes and sectors and offer significant insights for future research.

The article first reviews existing Industry 4.0 maturity models, discussing their applicability and limitations, particularly in the context of SMEs. Next, the methodology section explains the mixed-methods approach and data collection process. The findings section presents a comparative analysis of quantitative and qualitative results to assess manufacturing enterprises' Industry 4.0 maturity levels. This is followed by a discussion of the study's implications, particularly for SMEs in developing industrial regions. Finally, the conclusion summarizes the key contributions, highlights limitations and suggests directions for future research.

Overview of I4.0 maturity models

Maturity models help organizations assess how advanced they are in a specific process or technology by ranking their maturity levels from basic to advanced. This allows them to audit their assessment results, track their progress and identify their strengths and weaknesses (Akdil, Ustundag, & Cevikcan, 2018; Santos & Martinho, 2020). In studies conducted by both academic and consultancy enterprises, many models have been created to determine the I4.0 maturity levels of enterprises.

The literature classifies I4.0 maturity models into two groups: holistic models that cover all components of I4.0 and address all aspects, and specific models that focus on only one area (Schumacher *et al.*, 2016) (1) Holistic approaches examine I4.0 components in all possible aspects and cover many elements; (2) Specific approaches focus on a specific aspect of I4.0 and analyze it in depth. Examples of holistic maturity models that combine different dimensions, such as I4.0 strategies, human resource factor and management competence with a holistic perspective include the models developed by Schumacher *et al.* (2016), Lichtblau *et al.* (2015), Gökalp, Şener, and Eren (2017), Bibby and Dehe (2018), Akdil *et al.* (2018), Santos and Martinho (2020), Colli *et al.* (2019). Specific maturity models focus on a specific area of I4.0 applications, such as the use of information technologies and big data, and the studies by Comuzzi and Patel (2016), Leyh, Bley, Schaffer, and Forstenhausler (2016), Werner-Lewandowska and Kosacka-Olejnik (2019), Rafael, Jaione, Cristina, and Ibon (2020) are the main maturity studies in this field.

In this research, we focused on studies determining the I4.0 maturity level for the manufacturing sector. [Table 1](#) summarizes the primary studies involving the measurement of the I4.0 maturity of the manufacturing sector. We used academic databases such as Scopus, Web of Science and Google Scholar to review the literature. We chose the keywords “I4.0 maturity model,” “I4.0 readiness” and “manufacturing sector I4.0 maturity.” In analyzing the existing models, we focused on manufacturing enterprises. We aimed to reveal the inadequacies of existing models that propose an appropriate I4.0 maturity model for the manufacturing sector in non-industrialized regions. We paid attention to the fact that models are tools that reveal which elements of enterprises are weak and which need to be improved. Moreover, we excluded studies focusing on a single sector. For example, we excluded maturity model studies focusing on specific sectors such as construction, supply chains, logistics and the defense industry. Furthermore, I4.0 maturity models specific to SMEs often focus on the unique challenges and limitations such enterprises face. However, we aimed to assess whether a more general model is adequate for SMEs in industrializing regions such as Bartın. Therefore, excluding SME-specific models allowed us to test the effectiveness of existing general models. We took care to ensure that the analyzed models were academically valid, presented as primary references in studies and had a high number of citations.

As we may see in [Table 1](#), it is difficult to reach a standard I4.0 maturity measurement in current studies. Therefore, I4.0 maturity models do not include the best methods and strategies generally accepted or recommended in the sector, and these models do not cover or consider the ideal or most effective applications ([Semeraro, Alyousuf, Kedir, & Lail, 2023](#)). This deficiency indicates that the model may be less effective in practice or may need improvement in certain areas. Moreover, researchers usually test the models in [Table 1](#) on a single industry. However, this study applied it to manufacturing enterprises of different sizes and sectors.

One of the main problems in the literature on current maturity models is that most of the maturity models are insufficient for the evaluation of enterprises with low industrialization levels, such as SMEs ([Mittal, Khan, Romero, & Wuest, 2018](#); [Amaral & Peças, 2021](#)). For example, [Jesus and Lima \(2020\)](#) suggested that SMEs do not have the necessary resources or advisory support to adapt to I4.0 and are not sufficiently prepared for this new paradigm. Thus, a research problem has arisen regarding the development of the best-performing scales in the measurement of I4.0 maturity of SMEs, and the interest in studies on this subject is increasing. These studies revealed a lack of knowledge and understanding about I4.0, difficulty in evaluating compliance due to the inadequate implementation of its elements, and the field requires a new measurement method that would consider the staff size and be suitable for SMEs. [Ganzarain and Errasti \(2016\)](#) developed a maturity model to measure the readiness level of SMEs for I4.0 and defined five maturity levels that companies need to pass through. Each level consists of three stages: “envision,” “enable” and “enact.” [Semeraro et al. \(2023\)](#) underlined that unstructured processes, lack of IT skills and technological knowledge, inaccurate assessment of digitalization levels, and lack of resources are the main challenges for SMEs in implementing I4.0 and proposed a maturity model linking I4.0 technologies with principles such as specific service management, interoperability, modularity, decentralization, virtualization and real-time capability. Each of the principles in the model requires a certain level of technical knowledge and resources. The capacity of SMEs to effectively implement these principles depends on available resources and skills, which may limit the model’s applicability for some SMEs. [Spaltini, Acerbi, Pinzone, Gusmeroli, and Taisch \(2022\)](#) presented a new methodology to define the digital maturity levels of manufacturing SMEs and developed a digital transformation roadmap based on these results. However, some practitioners stated that the initial minimum digital maturity level was too far from their current state. Moreover, [Amaral and Peças \(2021\)](#) address the challenges in integrating SMEs into I4.0, examining how this revolution can structure the digitalization processes. In this context, by conducting in-depth research on a Portuguese SME, they propose strategies to overcome barriers and take advantage of the I4.0 benefits. [Bogner, Voelklein, Schroedel, and Franke \(2016\)](#) used questionnaire and interview techniques together to determine the current

Table 1. Major I4.0 maturity and readiness models for the manufacturing sector

Authors	Year	Model name	Description	Dimensions
Rockwell Automation	2014	The Connected Enterprise Maturity Model	The model focuses on technological readiness to create unprecedented collaboration between operation and information technology within businesses	<ul style="list-style-type: none"> • Information Infrastructure • Controls and devices (that feed and receive data) • Networks carrying all this information • Security policies
Lichtblau <i>et al.</i>	2015	IMPULSE	This model allows enterprises to self-assess their maturity levels and customize evaluation criteria based on their industry and size	<ul style="list-style-type: none"> • Strategy and organization • Smart factory • Smart operations • Smart Products • Data-driven services • Employees
Schumacher <i>et al.</i>	2016	A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises	This model is a scientific and practical tool to systematically assess the I4.0 development status of manufacturing enterprises. It gathers precise data on I4.0 strategies for revealing the status and potential success factors, while also enabling rigorous self-assessment of I4.0 maturity by enterprises	<ul style="list-style-type: none"> • Strategy • Leadership • Customers • Products • Operations • Culture • People • Governance • Technology
PWC/ Geissbauer <i>et al.</i>	2016	Industry 4.0: Building the digital enterprise	The model provides a roadmap for companies to determine their I4.0 strategies, create pilot projects, define the necessary competencies, perform data analytics, become a digital organisation and plan an ecosystem approach	<ul style="list-style-type: none"> • Enterprises Models, Product and Service Portfolio • Market and Customer Access • Value Chains and Processes • Information Technology Architecture • Compliance, Legal, Risk, Safety and Tax
De Carolis <i>et al.</i>	2017	DREAMY	The model aims to assess the level of readiness of manufacturing firms for I4.0, identify their strengths, weaknesses, opportunities and digitalisation investments in terms of I4.0 and create a roadmap that can help them transition to smart manufacturing	<ul style="list-style-type: none"> • Digital integration • Digital functionality • Digital co-operation • Digital governance • Digital culture
Schuh <i>et al.</i>	2017	ACATECH	Focusing on the phenomenon of digitalisation, ACATECH is a tool that guides enterprises to transform into an agile company that learns from the ground up with digitalisation	<ul style="list-style-type: none"> • Sources • Information Systems • Organizational Structure • Corporate Culture

(continued)

Table 1. Continued

Authors	Year	Model name	Description	Dimensions
Akdil <i>et al.</i>	2018	Maturity and Readiness Model for Industry 4.0 Strategy	Ideal for enterprises embracing I4.0 transformation, helps assess product, process and organizational maturity levels	<ul style="list-style-type: none"> ● Strategy ● Organisation ● Operation ● Products
Gökalp <i>et al.</i>	2017	SPICE-based Industry 4.0 MM	A new maturity model has been developed to overcome the shortcomings of existing maturity models. This model aims to assess the current maturity level of manufacturers and determine steps to reach a higher maturity stage	<ul style="list-style-type: none"> ● Asset Management ● Data Governance ● Application Management ● Process Transformation ● Organizational Alignment areas
Nick <i>et al.</i>	2021	Company Compass 2.0	CCMS 2.0 offers a refreshed framework and a more user-friendly and holistic assessment, arguing that the high number of intervention points and overlapping questions in previous models confused users	<ul style="list-style-type: none"> ● Physical world ● Virtual world ● Human, strategy and ● Culture ● Products and services ● Value chain ● Broader environment
Bibby and Dehe	2018	Defining and assessing industry 4.0 maturity levels	Factories of the future, people and culture and strategy E4.0 maturity assessment based on dimensions of the study, which aims to make the factories of the future for additive manufacturing, cloud computing, manufacturing execution systems, internet of things, cyber-physical systems, big data, sensors, e-value chain and autonomous explores the use of robots	<ul style="list-style-type: none"> ● Factory of the Future ● People and Culture ● Strategy
Colli <i>et al.</i>	2019	A maturity assessment approach for conceiving context-specific roadmaps in the Industry 4.0 era	They propose a new approach using the Problem-Based Learning (PBL) model to structure the maturity assessment. This approach aims to understand the contextual factors of the assessed company and adapt improvement recommendations accordingly	<ul style="list-style-type: none"> ● Governance ● Technology ● Connectivity ● Value creation ● Competences

Source(s): Own elaboration

status and I4.0 maturity levels of SMEs in the digitalization process since they lack a detailed understanding of I4.0, but the automation level is prioritized in the evaluation, which gives a more focused view on digitalization. These studies present different approaches and methodologies for measuring I4.0 maturity through quantitative standardized questionnaires. They are also generally tailored to SMEs in developed industrial regions.

Qualitative methods have supplemented standard questionnaires in evaluating I4.0 maturity. Schumacher *et al.* (2016) employed expert opinions and focus groups to define the maturity model's dimensions. Senna *et al.* (2023) synthesized existing I4.0 models and validated a new model through interviews with enterprise representatives. Highlighting the underuse of I4.0 maturity models, Kieroth *et al.* (2022) conducted interviews with 12 German enterprises, finding that the models' complexity and numerous dimensions, criteria and levels make measurement and evaluation challenging.

Methods

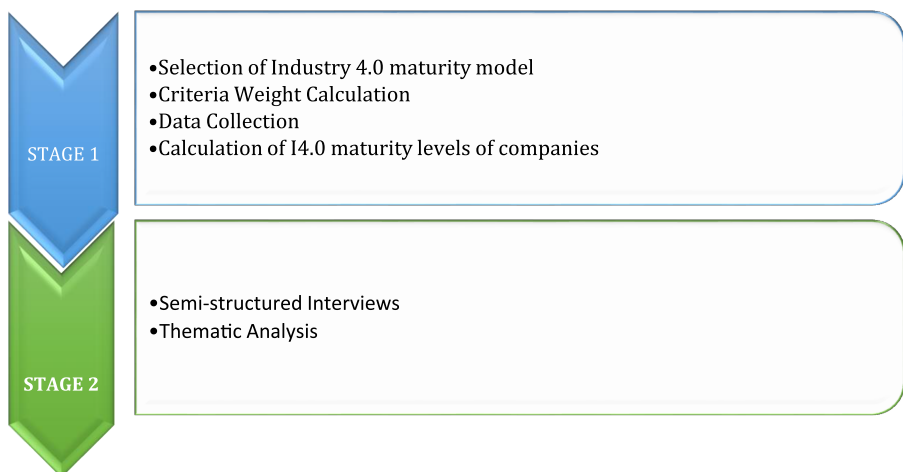
We followed a two-stage mixed methods research process to assess the I4.0 maturity levels of manufacturing enterprises in the Bartın Organized Industrial Zone (BOIZ) (Figure 1). We collected the survey data and semi-structured interview data in 2023.

To determine the I4.0 maturity levels, we first selected the I4.0 maturity model. In this step, we examined various I4.0 maturity models in the literature and selected the most suitable model for the study purpose. Then, we determined the importance degree of the selected model's criteria (criteria weights) by taking expert opinion. In this process, we calculated the criteria weights (dimension) using the analytical hierarchical process (AHP) method. Subsequently, we surveyed 21 manufacturing enterprises located in the BOIZ using a questionnaire based on the selected I4.0 maturity model. Then, we analyzed the collected data and calculated BOIZ's I4.0 maturity levels.

In the second stage, we conducted semi-structured interviews with the surveyed enterprise officials. We designed these interviews to gain an in-depth understanding of the enterprises' perceptions of I4.0 and their experiences in this area. Interviews include topics such as how enterprises perceive I4.0 and I4.0 maturity and dimensions.

We subjected the interview data to thematic analysis using MaxQDA qualitative research software. The analysis revealed the perceptions and understandings of the enterprises regarding the dimensions of I4.0 maturity.

To analyze the I4.0 maturity levels of the enterprises more clearly, we divided their maturity scores into two groups: above and below average. The minimum score that could be obtained



Source(s): Own elaboration

Figure 1. Research procedure

in the I4.0 maturity score calculation was 1.00, and the maximum score was 5.00. We accepted the average threshold score as 3.00 (Schumacher *et al.*, 2016). Setting the average score as a threshold value makes comparing groups systematic and meaningful. This distinction allowed us to compare enterprises' strategic approaches and experiences with different maturity levels in the I4.0 transformation process. For example, above-average firms may show different tendencies in strategic planning and digital transformation than below-average firms.

As a result of these two stages, we synthesized the I4.0 maturity levels of enterprises and evaluated them using both quantitative and qualitative data to establish a connection between the two research methods. For this purpose, we used MaxQDA software to identify the similarities and differences exhibited by enterprises based on their I4.0 maturity levels. The method used for comparing two cases allowed for the comparison of two groups based on different characteristics or criteria (Moeyaert, Ferron, Beretvas, & Van den Noortgate, 2014; Adula, Kant, & Birbirs, 2023; Thiem & Mkrtyan, 2024). This method aims primarily to reveal the extent to which the two groups are similar or different on specific themes. This model is a widely used approach in the literature, particularly in comparative analyses between groups, and scholars frequently prefer it in qualitative analysis software like MaxQDA (Çakmak & Çelik, 2024). The basic rationale behind the method is to see the commonalities and differences between two groups with different characteristics on certain themes or topics and to assess the implications of these differences for the research. For example, in this study, we considered enterprises with above-average I4.0 maturity levels and enterprises with below-average I4.0 maturity levels as two separate groups. By comparing these two groups, we aimed to see what kind of similarities or differences there are in the perceptions and approaches of enterprises on certain themes according to their maturity levels. This distinction is important to understand how the maturity level affects the enterprises' perspective on I4.0 and their integration processes.

The research population is formed by the enterprises operating in various industries in the BOIZ area in Türkiye. Bartın, one of the least populated provinces of Türkiye (207,238), has a 53.22% rural population, 7.35% medium-dense urban population, and 37.55% dense urban population. Regarding industrial facilities, the highest employment is in the textile and garment sector, and this sector alone accounts for approximately 41.5% of the total employment. In November 2023, Bartın achieved an export value of 3.8 million dollars (Western Black Sea Development Agency, 2024). It ranks 46th of 81 provinces in the Social and Economic Development Index (Acar, Bilen Kazancık, Meydan, & Işık, 2019). Small-scale enterprises are more prominent in Bartın. The share of medium-scale enterprises is 16.90%, and the share of large-scale enterprises is 7.60%. According to the sectoral distribution of Bartın's Gross Domestic Product, agriculture has a share of 7%, industry has a share of 29% and the service sector has a share of 53%. (Western Black Sea Development Agency, 2021). This distribution reflects a developing industrial zone with a significant reliance on the service sector, and a smaller, yet vital, industrial base.

Production facilities concentrate in the Bartın OIZ. Recently, 770,000 square meters of land have been expropriated for the expansion of BOIZ, which has attracted significant interest from investors (Bartın Governorship, 2021). Although it has not yet reached full industrial maturity, ongoing investments, and infrastructure improvements indicate that the region is gradually transforming into a thriving industrial zone. We may consider BOIZ to be a developing industrial zone in general. While there are modern enterprises in the region that have adopted advanced technologies to increase production efficiency, there are also enterprises that still use traditional production methods and lag behind in technological integration. Bartın OIZ is ideal for studying the effects of I4.0 on enterprises of different types and sizes. Moreover, Bartın is not yet fully developed in terms of industrialization and presents real-world conditions to evaluate the I4.0 maturity levels of SMEs with limited resources and technological infrastructure deficiencies. This situation can provide significant insights into the model's capacity to adapt to different economic and technological conditions. In total, 21 of the 26 enterprises in BOIZ participated in the research. Noteworthy, 53% of the participating

enterprises belong to the textile industry, and this sector has the highest number of enterprises in the research and is mostly medium-sized. In sectors such as shoe manufacturing, metal cabinet production and the plastic and refractory materials industry, only one enterprise represents each sector, while in the iron and steel, food, forest products and automotive ancillary industries – two enterprises.

Determination of the I4.0 maturity model

There are manufacturing enterprises with different production areas and different sizes within Bartın-OIZ. When applying a single I4.0 maturity model to different enterprises, this model needed to be wide-ranging and flexible, as well as suitable for various types of enterprises and industries. This means that the model is compatible with a wide range of enterprise processes, technological infrastructures and organizational structures. Scholars created dimensions such as strategy, human resources, management, marketing, production and technology for holistic models I4.0 with a holistic perspective. For this reason, this study will obtain more effective findings by using holistic maturity models in maturity measurement. For this reason, we also sought expert opinions. Moreover, we may consider the nine-dimensional model by [Schumacher et al. \(2016\)](#) as a suitable holistic model for application in various manufacturing enterprises. We consulted the experts for model selection and have extensive knowledge of I4.0, digital transformation, data analytics and automation. They have a deep understanding of the data management and analytics aspects of I4.0 and are interested in data analytics and automation technologies for manufacturing enterprises in Türkiye. Furthermore, we also consulted at a company providing solutions in data architecture, business intelligence and analytical applications. We focused on the academic validity of the model we chose, which is widely recognized as a primary reference and has received many citations. In particular, the study by [Schumacher et al. \(2016\)](#) stands out with 708 citations on the Web of Science, making it the most cited study in this area. Experts assessed that the selected model comprehensively measures I4.0 maturity levels, has high applicability and is relatively easy to use.

We chose this model because it is widely used in the sector, commonly applied in studies, accommodates enterprises of various sizes and products, is easy to use for assessing maturity levels and has proven practical in real production environments. [Table 2](#) describes the nine dimensions of the selected I4.0 maturity model.

Data collection

Research data form the basis of this study due to its international validity and comprehensiveness. We collected it using a Turkish survey developed based on [Schumacher et al. \(2016\)](#) dimensions by [Özçelik, Erkollar, and Cebeci \(2018\)](#) for more effective application in the local context. This localization increases the model's applicability for manufacturing enterprises in Türkiye and ensures that the research findings align with local industry dynamics. The questionnaire consisted of two parts with a 5-point Likert scale. The first part asked about the participant and enterprise information, and the second part – about the I4.0 dimensions. Of 21 participating enterprises, 13 were medium-sized, 5 were large-sized and 3 were small-sized, as illustrated in [Figure 2](#). We applied the survey study to the personnel who could answer the survey questions, if any, from the positions of the enterprises such as production planning, R&D, information processing, enterprise development responsible for the digital transformation or technological infrastructure of 21 active enterprises or those closest to these fields. In some enterprises, it was challenging to reach human resources with the training and qualifications to answer the questions. This was due to the enterprises' lack of knowledge and experience in digital transformation or I4.0. It also created suspicion that some respondents did not understand the survey questions correctly and did not provide sincere answers. We obtained ethical approval for the study from the Bartın University Social and Human Sciences Ethics Committee (Approval No: 2022-SBB-0153).

Table 2. I4.0 maturity assessment criteria

Criteria	Description
Strategy	Strategy in I4.0 involves defining vision, goals and plans, indicating the readiness for digital transformation and investment levels. It guides the transition process, objectives and transformation roadmap, enabling enterprises to gain a competitive edge and achieve sustainable growth through I4.0 technologies
Leadership	Digital transformation affects every department and level of the enterprise, making leadership imperative This process requires leadership skills to implement digital transformation, combine different perspectives, successfully manage projects, motivate and empower employees and manage risks
Culture	The transition to I4.0 requires an enterprises culture that is innovative, open to change, collaborative and focused on learning. This culture creates a working environment that supports digital transformation and makes it easier for the enterprise to adapt to changes, develop innovative ideas and work collaboratively
People	I4.0 requires skilled workforce to support new enterprises models. It is critical for employees to have the necessary skills, knowledge and attitude digital transformation. It is important to increase employees' digital skills and enable them to embrace transformation through training, talent development and awareness programs
Technology	I4.0 technologies increase enterprise efficiency, quality and flexibility, smarten products and improve customer service. The efficient use of advanced automation, artificial intelligence, big data and IoT helps enterprises gain an advantage in efficiency and competitiveness
Operations	In the I4.0 process, enterprise success hinges on key factors like process autonomy, simulation, cross-disciplinary cooperation, digital fault prevention and monitoring, robust information infrastructure, investment in digital initiatives, real-time production monitoring and data analysis capabilities
Customers	I4.0 aims to bring the customer experience to a better point with a new personalized product, fast delivery, better price, fast and quality service by focusing on the customer. I4.0 requires instant analysis of customer data. Thus, they will be able to create production processes closer to customer needs and requests
Products	This dimension evaluates the enterprises' product design, development, quality and level of intelligence. Products should be enriched with I4.0 technologies and customized according to customer needs. I4.0 integrated enterprises can offer customers more valuable and innovative products, accelerate the development process and improve quality by personalizing and smartening their products
Governance	Enterprises that integrate I4.0 ensure that they fulfill their legal, ethical and social responsibilities when using legal regulations I4.0 technologies. This dimension covers the decision-making processes and strategic visions of enterprises

Source(s): Özçelik *et al.* (2018), Schumacher *et al.* (2019)

Determination of criteria weights

Fifteen experts determined the significance levels of the nine different dimensions of I4.0 were determined in I4.0 using the AHP. This method involves comparing each dimension with the others and calculating their weight. In this process, one compares each criterion one by one with all other criteria and creates a binary comparison matrix. Experts determined the superiority of the criteria in digital maturity measurement by comparing these nine dimensions with each other. We selected these experts based on their extensive experience and current roles in digital transformation, production planning and automation. They included senior managers, industrial engineers, academic researchers and professionals working in leading companies and institutions within the fields of data analytics, digital transformation and product management. Table 3 lists the importance levels of the nine used dimensions to measure enterprises' digital maturity levels.

Calculation of I4.0 maturity levels of enterprises

We found dimension scores by multiplying the dimension weights determined by the experts and the dimension scores calculated from the data collected from the respondents.



Source(s): Own elaboration

Figure 2. Size and number of employment of participating enterprises by sectors (data specified according to the enterprises' declaration)

Table 3. Weights of dimensions calculated according to the scores given by the experts

Dimension	Weight
Customers	0.1511
Technology	0.1266
Leadership	0.1224
Governance	0.116
Human	0.1002
Products	0.10
Culture	0.0988
Strategy	0.098
Operations	0.0869

Source(s): Own elaboration

Subsequently, we calculated the general I4.0 maturity scores by multiplying the dimension scores computed earlier with the dimension weight values determined through expert opinion. The following formula shows the calculation method.

$$WOD = \sum_{i=1}^n M_i \cdot W_i$$

n: Number of Criteria, M_i : Criteria mean value, W_i : Criteria AHP weight, WOD: Maturity value

Thematic analysis

We conducted semi-structured interviews with the same individuals who participated in the BOIZ survey to gain a deeper understanding of their perceptions regarding various aspects of the I4.0 maturity model. We tailored interview questions to align with specific dimensions of the applied I4.0 maturity model. To ensure participants' familiarity with relevant concepts, we organized an introductory session with enterprise authorities, covering fundamental I4.0 principles, key terms and research topics. This preliminary phase aimed to enhance participants' engagement and awareness during the interviews. Subsequently, we conducted individual interviews with employees from the respective enterprises, recording them with their consent. We transcribed all audio recordings for data analysis, with a focus on anonymizing personal information to safeguard participant confidentiality.

We analyzed each answer by coding with MaxQDA software. Each question represented a main code. Respondents gave the answers to the questions as subcodes. Therefore, we used 13 main codes and 138 subcodes. We analyzed the subcodes according to the responses of the participants, that is, by induction method. Researchers use this method when they do not start with a theoretical framework or hypothesis and create categories and themes by clearly examining the data (Fereday & Muir-Cochrane, 2006; Clarke & Braun, 2017).

For the sake of the analysis' reliability, two independent encoders performed the iterative and cyclic coding process with MaxQDA software and calculated the percentage agreement using the intercoder reliability function to examine the differences between their codes. After two rounds of coding and discussion, we calculated the agreement percentage of the two coders as 93%. According to Belur, Tompson, Thornton, and Simon (2021), this ratio shows a strong reliability between encoders.

To assess the findings on the maturity levels of enterprises, we adopted a comparative analysis approach that allows us to see the similarities and differences between respondents with above and below-average maturity levels. In this context, we divided enterprises into two groups: those with above and below-average maturity levels. We illustrated the common and differently emphasized themes of these two groups for each dimension in all figures (Figures 7–15). In this way, whether the participants had similar or different views, we could still reveal problems or solutions regarding I4.0. The analysis focused on identifying thematic differences and similarities between the two groups using MaxQDA. MaxQDA facilitated this process by providing tools to compare thematic similarities and differences between the two groups systematically.

Results

Since we used mixed methods in the study, we have detailed the qualitative and quantitative research results below.

Quantitative research findings

In the quantitative analysis section, which constituted the first stage, we calculated the weights related to the I4.0 maturity dimensions with the AHP method based on expert opinions to

calculate the digital maturity scores. Table 3 shows the ranking of the weights of the dimensions calculated with AHP. Consequently, we saw that the “customers” dimension had the highest weight with 0.151, and the “operations” dimension had the lowest weight with 0.086. We may interpret this result as an indication that the customer-oriented approach has an important place in I4.0. Furthermore, the “technology” and “leadership” dimensions were also important dimensions for I4.0, with weights of 0.126 and 0.122. We found that other dimensions of I4.0 had similar importance levels, taking values between 0.11 and 0.09. The fact that the consistency rates of the matrices used in the calculation of these weights were below 0.1 also confirmed the method’s reliability.

We determined the maturity levels of each of the I4.0 maturity levels of enterprises in Bartın-OIZ. Table 4 shows the maturity scores of the enterprises according to the dimensions they received and the maturity score of Bartın-OIZ. Analyzing Table 4, we may see that the maturity score of two enterprises in Bartın-OIZ is above 4.00. Three enterprises had maturity scores below 2.00. We may also see that the maturity scores of the other enterprises in Bartın-OIZ were between 2.00 and 4.00. Moreover, the general average of Bartın-OIZ was 2.95. To make pairwise comparisons in the later stages of the study, the researchers divided these enterprises into two groups, i.e. enterprises with an I4.0 maturity score below the average (1.00–2.99) and enterprises above the average (3.00–5.00).

When we examined the averages of the I4.0 dimensions of the enterprises in Bartın-OIZ, we saw that these enterprises had high scores in the “leadership” and “culture” dimensions, while they had lower scores in the “technology” and “governance” dimensions. A score of three or above for each criterion indicated an above-average maturity. Enterprises with a score of 2.99 or below indicated a below-average maturity. In general, although there was a significant difference between all dimension scores, we saw that the I4.0 maturity scores were higher than two in all dimensions. We created the radar chart in Figure 3 to see the maturity scores according to the I4.0 dimensions of BOIZ, to make comparisons according to dimensions quickly and to highlight strong and weak points.

Qualitative research findings

In this section, in line with the data collected in the semi-structured interviews, we will discuss enterprises’ conceptual awareness, opportunities and challenges regarding I4.0. Then, we will evaluate the nine dimensions in the I4.0 maturity model.

Participants’ I4.0 conceptual awareness: opportunities and challenges. Before questioning what each criterion of the maturity model we used meant to the participants, we evaluated the knowledge of the participants about I4.0, their awareness and attitudes towards this issue, and what they think about the benefits and difficulties. Therefore, it will be effective in understanding the thoughts behind the responses according to the I4.0 maturity model. Accordingly, in the semi-structured interview, we first asked the participants to explain what the concept of I4.0 meant to them so as to evaluate their I4.0 awareness. Figure 4 shows the given answers according to their repetition frequency in the documents.

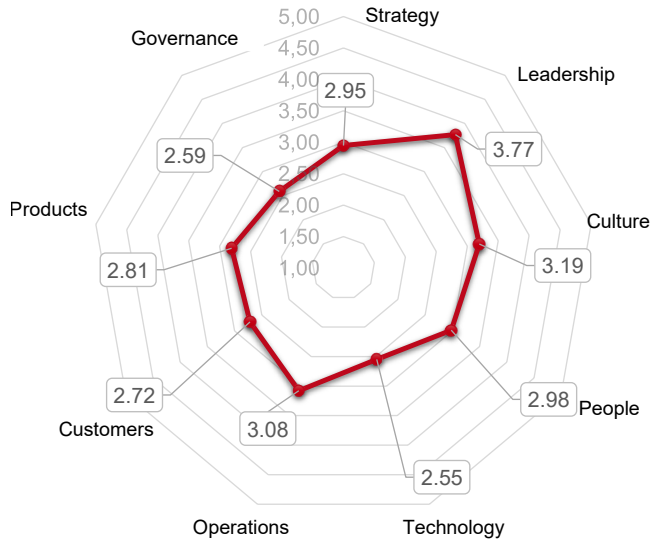
According to Figure 4, participants mostly see I4.0 as a tool that will increase production and technological development, but they ignore these elements due to the absence of any statement regarding elements such as organizational processes, supply chain management and customer relations. Key themes in their views include technology usage, the “Internet of Things” (IoT – devices connected to the internet exchange data with each other and perform automatic transactions), “traceability,” “mechanization, error reduction,” “labor” efficiency” and “automation.” This shows their general awareness of I4.0 technologies and applications. However, they less frequently address critical aspects like data-driven decision-making, which is crucial to I4.0.

When evaluating the participants’ perspective on what opportunities I4.0 offers to enterprises, the participants stated that the most important opportunity offered by I4.0 is “monitoring and control” (Figure 5). Therefore, participants’ perception of the I4.0 opportunity

Table 4. Maturity dimensions and overall I4.0 maturity scores of enterprises

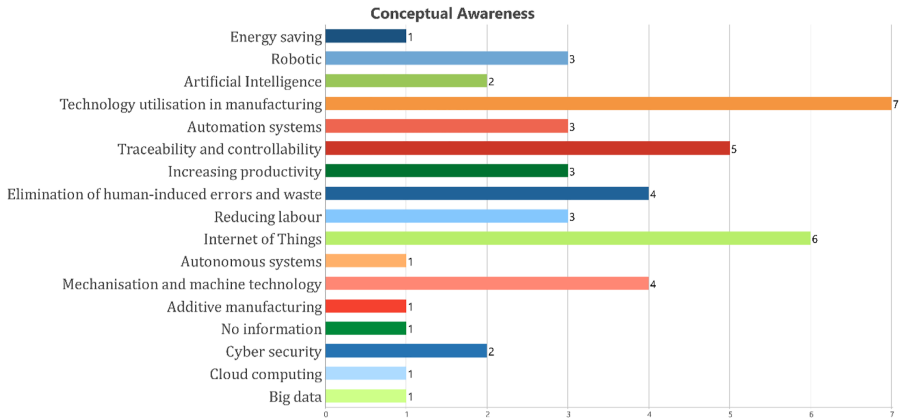
Participant	Strategy	Leadership	Culture	People	Technology	Operation	Customers	Products	Governance	Average scores per participant
P1	2.35	3.30	3.70	3.03	2.52	2.53	2.65	2.51	2.21	2.75
P2	2.29	3.54	1.62	1.54	1.68	2.55	2.71	2.32	2.39	2.33
P3	4.09	5.00	4.00	4.00	3.73	3.69	4.22	4.00	3.60	4.06
P4	3.85	3.92	4.26	3.54	3.39	3.63	3.36	3.90	3.10	3.63
P5	3.11	3.54	2.91	2.23	2.20	3.64	4.26	3.87	2.99	3.22
P6	3.19	5.00	3.62	3.08	2.32	2.99	2.71	2.68	2.30	3.09
P7	3.43	3.16	4.53	4.00	3.32	3.42	1.68	1.96	2.19	2.99
P8	2.39	3.40	2.67	2.91	2.00	3.44	3.72	3.36	2.99	3.00
P9	2.49	3.84	2.62	2.00	1.60	2.92	1.61	2.16	2.30	2.36
P10	2.11	4.00	1.89	1.09	1.00	1.71	2.81	1.00	1.00	1.91
P11	4.00	4.16	4.73	4.31	4.00	3.82	2.68	3.84	2.60	3.73
P12	2.53	4.30	3.18	3.08	2.39	2.80	3.00	3.00	3.00	3.04
P13	1.75	2.16	2.00	1.17	1.48	2.55	1.00	1.00	1.00	1.53
P14	3.75	4.00	4.00	4.00	3.12	3.45	3.16	3.67	3.30	3.57
P15	3.09	4.00	2.94	3.69	2.92	2.76	3.10	3.00	3.30	3.21
P16	1.95	2.00	1.82	2.00	1.80	2.40	1.00	1.84	2.00	1.82
P17	3.60	4.00	3.47	4.00	3.73	3.71	3.33	2.68	3.21	3.52
P18	2.20	3.00	2.91	2.77	1.80	2.20	1.29	2.00	2.00	2.19
P19	2.35	4.00	2.46	2.77	2.60	3.25	3.00	3.00	3.00	2.95
P20	4.25	4.84	4.82	4.77	3.80	4.11	4.33	4.00	3.30	4.24
P21	3.15	4.00	2.92	2.60	2.12	3.08	1.45	3.16	2.60	2.72
Average scores per dimension	2.95	3.77	3.19	2.98	2.55	3.08	2.72	2.81	2.59	2.95

Source(s): Own elaboration



Source(s): Own elaboration

Figure 3. I4.0 radar chart of maturity levels by dimensions

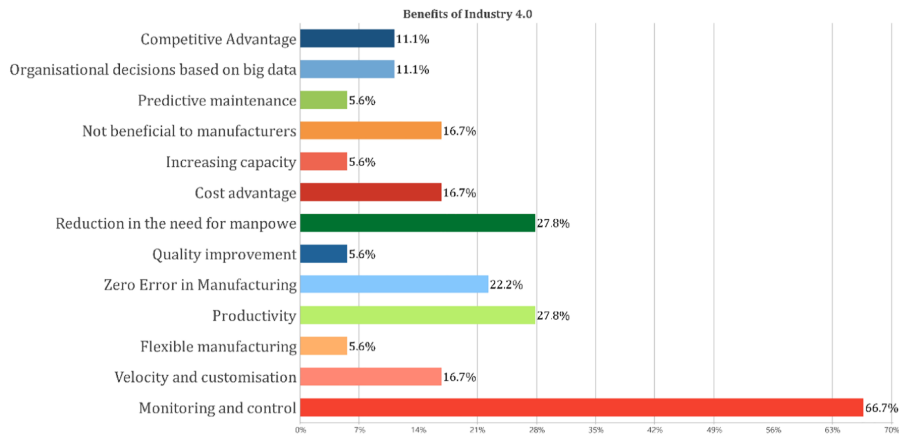


Source(s): Own elaboration

Figure 4. I4.0 conceptual awareness of enterprises

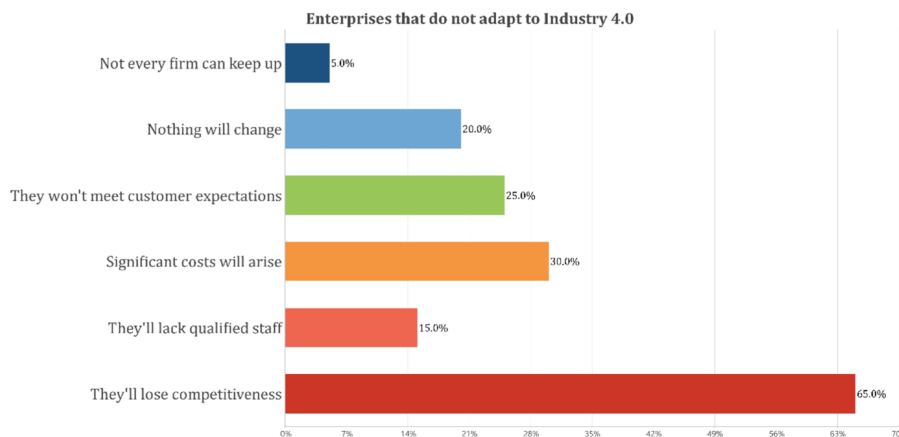
is production-oriented, but it does not include the integration and interaction of these technologies in organizational and enterprise processes. Some participants predict that I4.0 will not be beneficial for contract manufacturers. These enterprises are very cautious about I4.0 and probably skeptical about digital transformation.

Participants are aware that enterprises that cannot adapt to I4.0 will lose their competitiveness (Figure 6). Some participants predict that enterprises that cannot adapt will not be able to meet customer expectations and will face high costs. This means that participants who gave these answers accepted that I4.0 has become necessary.



Source(s): Own elaboration

Figure 5. Participants' views on the opportunities offered by I4.0



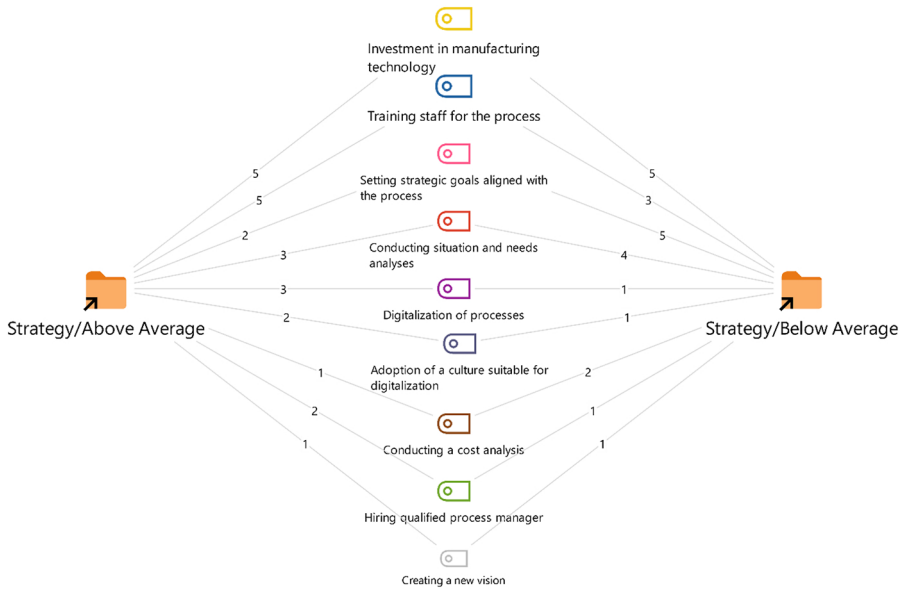
Source(s): Own elaboration

Figure 6. Challenges awaiting enterprises failing to comply with I4.0

Some participants believe that there will be no change or want to maintain the current situation. This may suggest that they are ignoring the opportunities or transformation potential offered by I4.0. Thus, these participants want to continue traditional methods and think that these new technologies are not suitable for their own industry.

Strategy

The roadmap for transitioning to an I4.0 strategy involves integrating existing technologies into enterprise models (Schumacher *et al.*, 2016). Figure 7 illustrates elements for adopting I4.0 technologies, reflecting participants' understanding and desire to implement this paradigm. Figure 7 compares companies with above and below-average levels of 4.0 maturity, focusing on the Strategy dimension. For example, the numbers shown in Figure 7 indicate how often firms with above-average maturity levels and those with below-average maturity levels express a



Note(s): ^aThe figure shows a comparison of themes mentioned by enterprises categorized into two groups based on their Industry 4.0 maturity levels: above-average and below-average. Maturity levels were assessed on a scale of 1 to 5, where 1 to 2.99 was categorized as ‘below-average’ and 3 to 5 as ‘above-average’. The numbers indicate the frequency with which each theme was mentioned by participants during the interviews

Source(s): Own elaboration

Figure 7. Comparison of responses for the strategy dimension between two groups^a

particular theme. These data enable a more systematic examination of perceptual differences between the two groups. This figure shows the common and different views of the two groups.

The prominent findings in **Figure 7** are as follows. Both groups mentioned “investment in manufacturing technology” as the most frequently co-expressed theme in the Strategy dimension. Both groups mentioned this element five times. The below-average group mentioned the theme of “setting strategic objectives aligned with the process” five times, while the above-average group emphasized this theme only two times. “Setting strategic goals in line with the process” was one of the themes with the highest difference between the two groups. The fact that the below-average enterprises emphasize this theme intensively may indicate that they still feel the need for strategic orientation strongly and want to move forward in this regard. On the other hand, this strategic alignment may already be in place for above-average firms as part of the I4.0 maturity process.

Respondents mentioned themes of “hiring qualified process managers” and “creating a new vision” with low frequency in both groups. Thus, both groups focused relatively less on creating a vision and employing managers.

The group below the average mentioned the themes of “setting strategic goals appropriate to the process,” “conducting situation and needs analyses” and “conducting cost analyses” more frequently than the group above the average.

There was no completely differentiated theme among the themes expressed by both groups. Although both groups mentioned certain themes with different frequencies, both groups emphasized all themes at least once.

Respondents emphasized “conducting a situation and needs analysis” closely similar frequencies in both below-average and above-average enterprises. Participants highlighted this theme four times in below-average enterprises and three times in above-average enterprises. These results suggest that both groups attach importance to conducting situations and need analyses to guide their digitalization processes.

Leadership

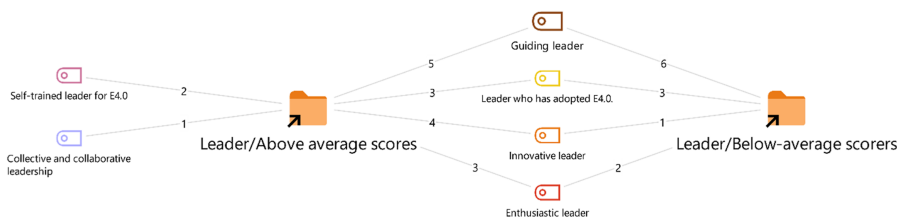
Successful execution of the transition to I4.0 requires leadership to create a shared understanding and vision of why digital transformation is necessary, how to implement it, and the consequences (Schumacher *et al.*, 2016). Leadership plays a role in showing digital transformation as an opportunity rather than an obligation, supporting it in practice and combining different perspectives. According to Figure 8, when we analyze the participants’ responses regarding the leader’s role in the I4.0 adaptation process. Participants emphasized it six times in the below-average group and five times in the above-average group. Therefore, the most frequently mentioned theme by both groups was that leaders guide the I4.0 harmonization process. This result is a fundamental element of the leadership dimension in the current model. This shows that the participants understand that the leader takes on a role that determines, shares and implements the vision, strategy and culture of E.4.0. Participants recognized leaders’ adoption and willingness to adopt I4.0 as a critical factor in the success of the digital transformation process. Therefore, the answers were compatible with these characteristics of the leadership dimension.

Figure 8 shows that enterprises with a low I4.0 maturity score in the leadership dimension mentioned innovative leaders less than enterprises with a high I4.0 maturity score. Participants mentioned the themes of “self-trained leader for I4.0” and “collective and collaborative leader” two times and one time, respectively, only in the above-average group, unlike those with low scores.

Culture

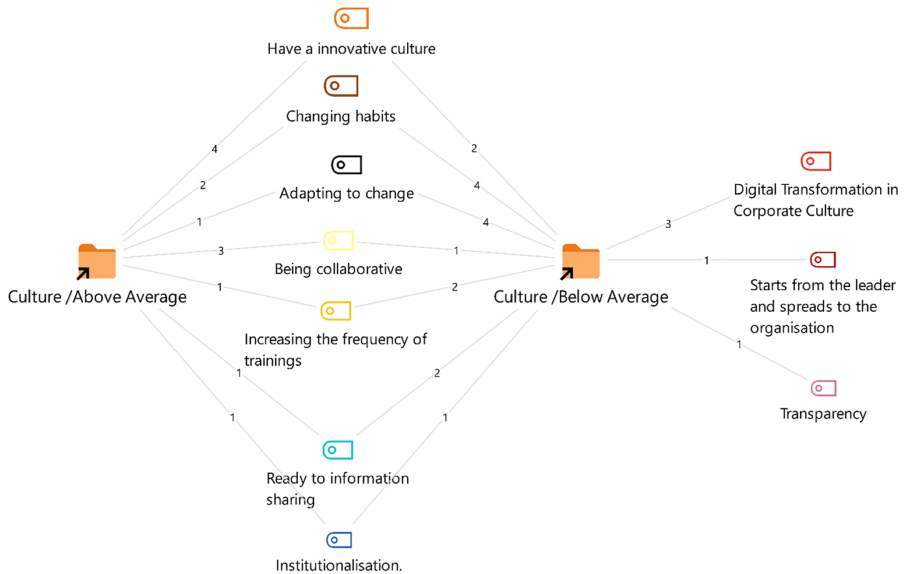
The culture dimension in I.4.0 involves adopting a culture open to innovation and cooperation tolerating risks in transitioning to I.4.0 technologies. This reflects enterprise readiness and competence for digital transformation. According to Figure 9, above-average enterprises have emphasized “having an innovative culture” more frequently. On the other hand, below-average enterprises have placed greater emphasis on the themes of “changing habits” and “adapting to change.” Themes mentioned less frequently by both groups included “increasing the training frequency,” “ready to information sharing” and “institutionalization.” The themes “digital transformation in corporate culture,” “starts from the leader and spreads to the organization” and “transparency” appeared exclusively in the below-average group.

The findings in Figure 9 show that enterprises have different cultural priorities based on their maturity levels in the transition to I4.0. Above-average enterprises have placed greater emphasis on the importance of an innovative culture. From this, we can infer that these



Source(s): Own elaboration

Figure 8. Comparison of responses for the leadership dimension between two groups



Source(s): Own elaboration

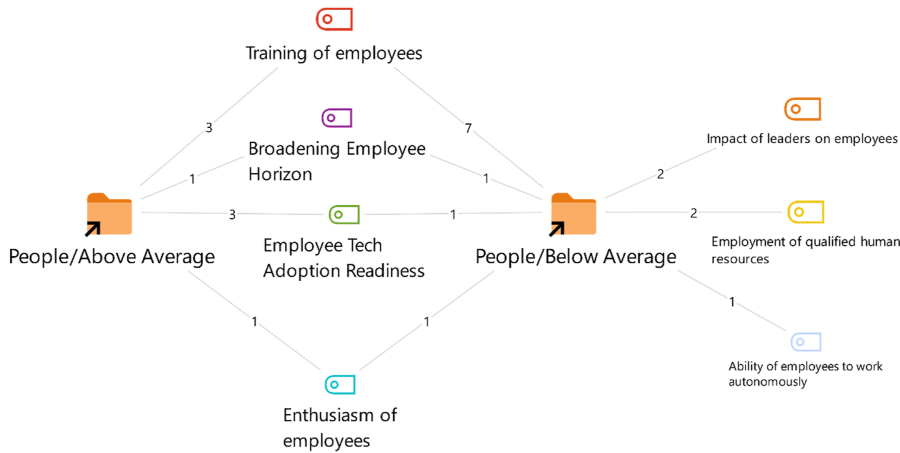
Figure 9. Comparison of responses for the culture dimension between two groups

enterprises view innovation as a core pillar in their I4.0 transformation and shape their organizational culture accordingly. On the other hand, below-average enterprises have focused more on themes such as “adapting to change” ($n = 4$) and “changing habits” ($n = 4$). This suggests that enterprises at the early stages of digital transformation prioritize changing existing business processes and behavior patterns. Themes mentioned less frequently by both groups, such as “increasing the frequency of training,” “ready to information sharing” and “institutionalization” may indicate insufficient focus on the cultural and structural elements necessary to enhance I4.0 maturity. Moreover, only the below-average enterprises mentioned the themes “transparency,” “digital transformation in corporate culture” and “starts from the leader and spreads to the organization.” This suggests that these enterprises have started to recognize the role of leadership and cultural change but have yet to reach a level of innovation and organizational maturity. While above-average enterprises focus on innovative culture, enterprises with lower maturity levels tend to focus more on fundamental adaptation processes and leadership roles. It appears that neither group fully grasped the importance of elements such as training, institutionalization and information sharing.

People

The people dimension encompasses the development of employees’ competencies, adaptation to technology and autonomous working skills in the transition to I4.0 technologies (Schumacher *et al.*, 2016). According to Figure 10, the most important theme for below-average enterprises in the people dimension was “training of employees,” repeated seven times. The most important themes for above-average enterprises were “training of employees” and “employee tech adoption readiness.” The least mentioned themes for both groups were “broadening employee horizon” and “enthusiasm of employees.” Themes mentioned only by the below-average group included “impact of leaders on employees,” “employment of qualified human resources” and the “ability of employees to work autonomously.”

Based on the findings, participants considered employees’ readiness for new technologies a critical factor in the transition to I4.0. Particularly in the high maturity group, participants



Source(s): Own elaboration

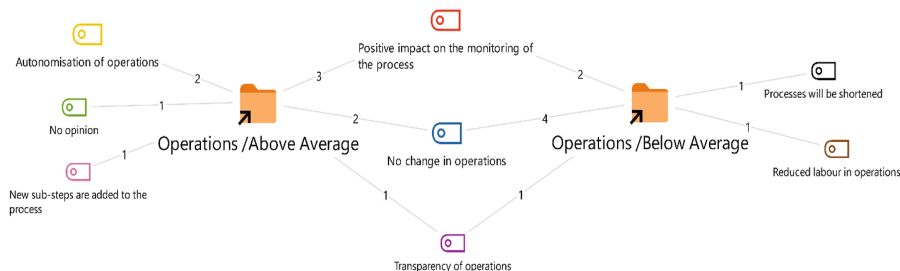
Figure 10. Competencies to be adopted by employees in the adaptation process in I4.0

mentioned the theme “employee tech adoption readiness” more frequently. This indicates that enterprises with higher maturity levels in the human dimension place greater importance on employees’ adoption and technology development. Enterprises with lower maturity levels seem to focus more on employee development and technology adoption, and they require more qualified employees in the transition to I4.0.

Operations

The operations dimension in I4.0 includes process/ autonomy, modeling, simulation and interdepartmental collaboration. According to Figure 11, the theme that above-average enterprises emphasized most was “positive impact on the monitoring of the process,” while for below-average enterprises, it was “no change in operations.” Both groups mentioned the theme of “transparency of operations.” The themes that differentiated the above-average group from the below-average group included “autonomization of operations,” “no opinion” and “new sub-steps are added to the process.” The themes that differentiated the below-average group were “processes will be shortened” and “reduced labor in operations.”

These findings suggest that enterprises with higher maturity levels aim to make their processes more autonomous and create a positive impact on process monitoring, while enterprises with lower maturity levels expect to change or shorten their existing operations.



Source(s): Own elaboration

Figure 11. Comparison of responses for the operations dimension between two groups

Customers

The customer dimension focuses on utilizing customer data and digitizing services (Schumacher *et al.*, 2016). Both groups mentioned “enhance response to customer needs,” “increases customer satisfaction” and “seamless communication with customers” (Figure 12). This suggests that participants may view E.4.0 as an opportunity to foster customer orientation and flexibility. Most frequently, both groups emphasized the theme “enhance response to customer needs” ($n = 4$), which could indicate that E.4.0 technologies are perceived as tools to strengthen customer relationships and build loyalty. The below-average group exclusively highlighted the themes “order tracking becomes easier” and “enhances customer perception,” reflecting a focus on more fundamental operational benefits. On the other hand, the above-average group emphasized the theme “maintain traditional customer relations,” mentioning it four times.

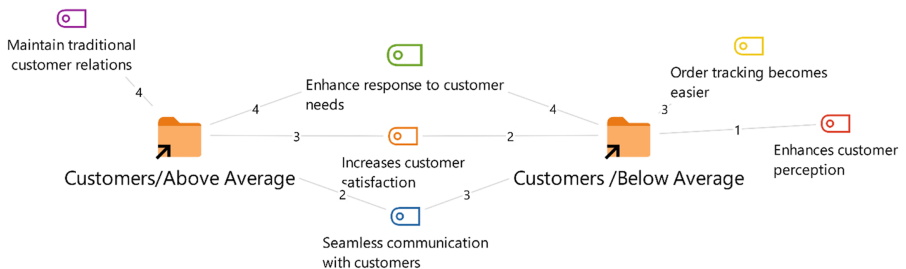
Both groups frequently mentioned the “enhance response to customer needs” theme, which suggests that enterprises may consider responding to customer demands a key priority. This observation could indicate that E.4.0 technologies have the potential to support customer-focused approaches and enhance enterprises’ competitive advantage. Furthermore, both group’s emphasis on “increases customer satisfaction” and “seamless communication with customers” implies that participants might view E.4.0 as a valuable tool for improving customer satisfaction and communication.

However, differences between the groups may point to variations in their approaches to E.4.0 technologies based on their maturity levels. The prominence of “order tracking becomes easier” and “enhances customer perception” themes among below-average groups could indicate a greater focus on fundamental operational benefits in these businesses. In contrast, the above-average group’s sole emphasis on the “maintain traditional customer relations” theme may suggest that these enterprises view E.4.0 technologies as a means to sustain and enhance existing customer relationships.

Products

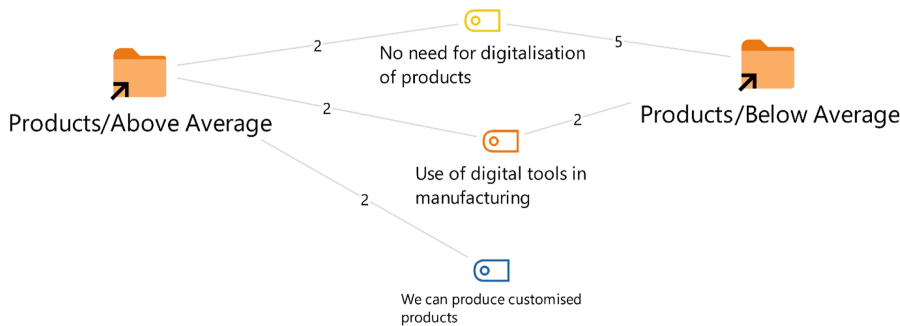
The products dimension focuses on products equipped with information and communication technologies to communicate with other systems. This dimension involves the use of digital tools in manufacturing, the integration of digital controls for quality assurance, and the creation of smart, functional products (Schumacher *et al.*, 2016).

The below-average group emphasized the theme of “no need for digitalization of products” five times, while the above-average group mentioned this theme twice. Both groups referred to the theme “use of digital tools in manufacturing” equally frequently ($n = 2$). Only the above-average group stated that personalized products could be produced within the scope of the product dimension (see Figure 13).



Source(s): Own elaboration

Figure 12. Comparison of responses for the leadership dimension between two groups



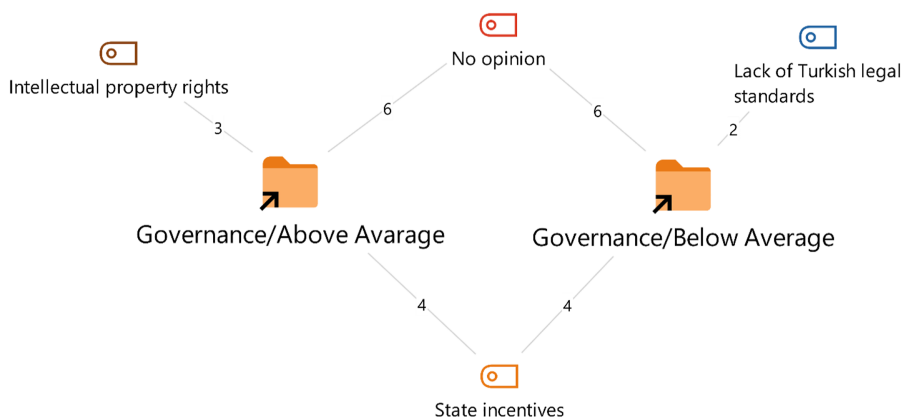
Source(s): Own elaboration

Figure 13. Comparison of responses for products dimension between two groups

Enterprises with above-average maturity scores emphasized more I4.0 technologies in products' dimensions, stating that they can produce personalized products tailored to customer needs and expectations. Both groups interpreted I4.0 technologies as the use of digital tools in their production processes. On the other hand, enterprises with below-average maturity scores indicated that they either do not need or are not capable of digitizing their products. The responses from the below-average group suggesting no need for product digitization might indicate a lack of sufficient awareness in this area.

Governance

The topic of Governance in I4.0 encompasses issues such as labor laws, technological standards and intellectual property rights. This dimension emphasizes the importance of supporting investments in digital technologies and fostering international collaborations in manufacturing. According to Figure 14, both groups stated six times that they did not have knowledge about legal regulations related to I4.0. Therefore, both groups expressed that they lacked detailed information on incentives and general legislation, but they each mentioned government incentives four times. This indicates that these enterprises were more familiar with the legal and financial aspects of E.4.0 technologies. The group with below-average



Source(s): Own elaboration

Figure 14. Comparison of responses for the governance dimension between two groups

maturity, believing there are deficiencies in legal regulations for I4.0, suggests a deeper and more comprehensive need in the “legal regulations” dimension. The below-average group also mentioned twice that they thought the legal standards for E.4.0 technologies in Türkiye were insufficient or that they had no knowledge about them.

According to Figure 14, the group with above-average maturity stated that they understood and applied intellectual property protection laws. From this, we can infer that the above-average group was more aware of intellectual property rights compared to the below-average group, as they mentioned intellectual property rights three times, while the below-average group did not mention them at all.

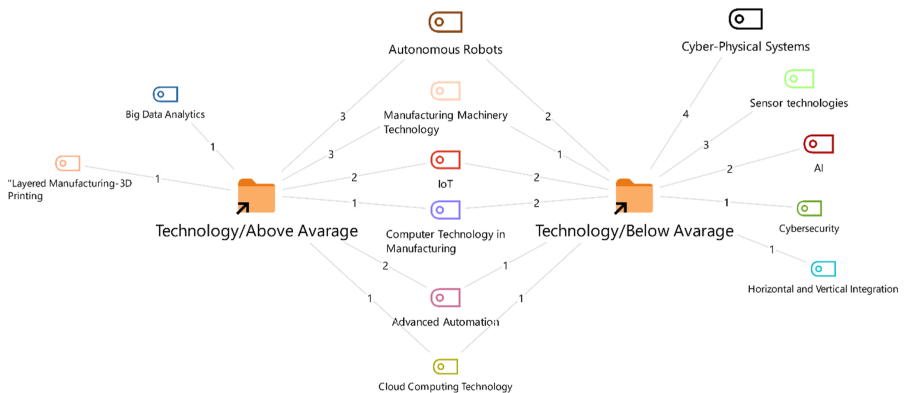
Technology

The themes shown in Figure 15 generally reflect the participants’ awareness of the core technologies of I4.0 and their approaches to these technologies. Participants mentioned the themes “cyber-physical systems,” “sensor technologies,” “AI,” “cybersecurity” and “horizontal and vertical integration” in the below-average group. Despite a lower maturity level, this group addressed a significant majority of the core components of I4.0 technologies. On the other hand, only enterprises with above-average maturity mentioned the themes “big data analytics” and “layered manufacturing – 3D printing.” These themes are associated with more advanced I4.0 applications. This suggests that the above-average group may have had a more integrated approach to technology and decision-making based on data.

The themes emphasized by both groups occurred similarly frequently. Both groups had knowledge of the core technologies of Industry 4.0. However, the above-average group more frequently highlighted more advanced and sophisticated technologies, such as autonomous robots, advanced automation and cloud computing, while the below-average group focused on more fundamental technologies, such as sensor technologies, cyber-physical systems and AI.

Conclusions and discussions

This study emphasizes the need for a holistic approach to assess I4.0 readiness. In the first stage, we determined the I4.0 maturity levels of 21 manufacturing enterprises located in a developing industrial zone (Bartın-OIZ) in the city of Bartın, situated in the north of Türkiye, where 53% of the population lives in rural areas. In the second stage, we conducted qualitative research to measure the participants’ perspectives on I4.0 and maturity criteria. We conducted data collection, including interviews, in 2023. This study provided the opportunity to



Source(s): Own elaboration

Figure 15. Comparison of responses for the technology dimension between two groups

determine the I4.0 maturity levels of enterprises of different sizes in Bartın OIZ and to reveal the perspective and perceptions of these enterprises on the I4.0 maturity dimensions. Combining both methods provides a comprehensive analysis, revealing insights and patterns beyond standardized scales. Therefore, supplementing quantitative research with qualitative methods strengthens the research and emphasizes the importance of a mixed methods approach.

The semi-structured interviews showed that the awareness of I4.0 has formed and that I4.0 realizes its potential early and adapts quickly to the transformation process. Although some enterprises have understood the importance of I4.0, they have not yet entered a complete transformation process. Some enterprises are still not sufficiently aware of the concept and potential of I4.0 and continue to adhere to traditional production methods.

The expectations of the enterprises regarding I4.0 opportunities are production-oriented, and the expectations for other enterprises' processes or organizational structures are limited. Enterprises emphasize operational aspects such as production and technology rather than their institutional structures in both I4.0 maturity level measurement and semi-structured interviews.

Some enterprises believe that digital transformation will not bring a disruptive change, that only the technological infrastructure will improve, processes will continue in the same way and only the need for people will decrease. Instead of waiting for a disruptive change, they think that there will be a transformation in which existing processes will become optimized, and technology will only serve in certain areas. The fact that digital transformation is a costly and risky process for enterprises may have led some enterprises to think that it is a more ideal step to improve their technological infrastructure instead of changing their existing enterprises' processes to a great extent, considering these costs and risks. In this way, they may tend to resist change and thus follow a less costly and risky path.

Many participants, especially enterprises operating in the textile sector, have claimed that being a contract manufacturer or producing for enterprises selling products to the end consumer prevents the transition to I4.0. Contract manufacturing enterprises concentrate only on producing and fulfilling customers' requests. They take less account of other enterprises' processes or technological developments. Therefore, they may not feel the need to invest in I4.0 technologies. The effort of contract manufacturing enterprises to realize low-cost production to offer a cost advantage to their customers may have caused them to avoid turning to new technologies or processes that require investment costs to increase their profitability.

Respondents primarily view I4.0 as enhancing production through technology use, automation and productivity gains. This perception highlights the importance of technology but does not necessarily signify a comprehensive understanding. I4.0 encompasses digitalization, data analytics, AI, automation and smart factories. To grasp I4.0 fully, one must consider all components and implement them together, beyond a sole focus on technology in production. Few enterprises focus on using data in the execution of this process and see it as better decision-making and use of data for better operations. Therefore, very few enterprises see this new industrial revolution as collecting and analyzing data and integrating the findings into processes.

Going beyond the current roles of Bartın-OIZ management, providing consultancy to enterprises on technology or developing projects to improve their technology infrastructure can support the processes of increasing the competitiveness of enterprises and adapting to the I4.0 transformation. In this context, raising the I4.0 maturity levels of enterprises can strengthen knowledge and skills in the field of technology and digitalization by providing training to enterprises on I4.0. The OIZ management could establish networks that encourage cooperation and information sharing between enterprises. It could also create a collaborative platform where enterprises could share the challenges and opportunities, they face in the digital transformation process. This platform can allow enterprises to learn from each other, transfer their experiences and develop joint solutions.

This study has some possible limitations. One of them is that although the criteria are for the manufacturing industry, the criteria have different weights because each enterprise has different priorities within its own industry. Therefore, separate studies for each industry will be effective in achieving more effective results.

Implications and contributions

The findings have implications for enterprises and researchers on I4.0 maturity assessment in SMEs. Issues such as a lack of qualified personnel in industrializing regions, questions misinterpretation and a tendency to overly positive responses suggest that standardized scales may not fully capture the complexity of I4.0 maturity. These challenges underline the need for a mixed-method approach that integrates qualitative insights to provide a more comprehensive understanding of I4.0 readiness.

The study revealed that the I4.0 maturity levels of enterprises in Bartın-OIZ differ. In the interviews, there was a common view that Industry 4.0 transformation requires high costs (Figures 6 and 7). Thus, large-scale enterprises can adapt to this transformation process more easily since they have the capacity to allocate capital for technological investments. On the other hand, small-scale enterprises are likely to tend to maintain traditional production methods due to their limited financial resources. Moreover, we revealed the level at which enterprises are in the I4.0 adaptation process and what difficulties they may encounter.

We observed that enterprises prefer to improve their technological infrastructure instead of changing their existing processes to a great extent due to the high costs and risks of digital transformation. This revealed a resistance to change and a tendency to optimize existing processes.

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