Manufacturing Companies Industry 4.0 Maturity Perception Level: A Multivariate Analysis

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Abstract:

Purpose: This research investigates Portuguese manufacturing companies' Industry 4.0 (I4.0) maturity perception level and proposes an index to measure that aim.

Design/methodology/approach: This study uses a survey method to gather the companies' perceptions of their I4.0 maturity level and applies subsequent exploratory factor analysis to propose a global I4.0 measurement index.

Findings: The research results show that the most critical factors in evaluating the perception level of I4.0 Perception Maturity (IPM) are strategy, leadership, and customer experiences. The result for the Global Index was 53.50%. Hence, the global Index companies' perception of the level of maturity of I4.0 in Portugal is medium.

Research limitations/implications: This study encompasses only Portuguese manufacturing organisations (50 valid responses). Moreover, the research is subject to the limitations of the survey methodology, such as possible respondent bias.

Originality/value: This study provides a valuable tool for manufacturing companies to identify the factors that need to be improved to create significant growth in the I4.0 Perception Maturity (IPM) index. Therefore, it can support companies in establishing a roadmap for successful I4.0 adoption and improving their performance and competitive position accordingly.

Keywords: Industry 4.0, I4.0, maturity model, perception level; Portugal

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1. Introduction

The technologies that help write the story of Industry 4.0 (I4.0) are diverse and so are the areas of intervention of this profound transformation of business processes. Digital transformation is entering the lexicon of industry in Portugal. At various paces and with priorities that fit distinct strategies and concerns, the changes are coming. Industrial revolutions contributed to significant enhancements in the output and productivity of the manufacturing industry. I4.0 is transforming the manufacturing firm business models and can support production flexibility, efficiency, and productivity (GTAI, 2014; Ibarra, Ganzarain & Igartua, 2018; Rüßmann, Lorenz, Gerbert, Waldner, Justus, Engel et al., 2015), fostering innovation, competitiveness, and improved industrial system sustainability (Müller, Kiel & Voigt, 2018; Stock & Seliger, 2016).

The I4.0 technologies adoption in companies and industries is a highly relevant topic (Luthra & Mangla, 2018; de Sousa-Jabbour, Jabbour, Foropon & Godinho-Filho, 2018; Kiel, Müller, Arnold & Voigt, 2017). However, it is unclear how I4.0 technologies can be integrated into existing production systems and what processes they can support (Kolberg, Knobloch & Züehlke, 2017). Technological development over time has brought significant changes to the world scenario. First, worldwide manufacturing companies, followed by all types of organisations, started to address how to catch the I4.0 wave and use digital technologies to support the digitalisation of their business processes. Therefore, I4.0 can foster competitive advantage and more efficient and sustainable businesses (Fonseca, 2017; Galati & Bigliardi, 2019) and support knowledge intensive business services, which have significant impact in terms of countries growth rate, especially for the economies of emerging countries (Busu & Busu, 2019). According to Oztemel and Gursev (2020) I4.0 will have an enormous effect on social life. It is assumed that the robots will be more dominant in manufacturing, implanted technologies, cooperating and coordinating machines, self-decision-making systems, autonomous problem solvers, learning machines, 3D printing etc. will dominate the production process. Wearable internet, big data analysis, sensor-based life, smart city implementations or similar applications will be the main concern of the community. Hence, this social transformation will naturally trigger the manufacturing society to improve their manufacturing suits to cope with the customer requirements and sustain competitive advantage. Furthermore, Singh, Goyat and Panwar (2023) concluded that "the emerging technologies such as IoT, blockchain, artificial intelligence, augmented reality, 3D printing, big-data analytics, and cloud-computing" support I4.0 in reducing human interference for effective and efficient systems. Finally, a thorough review of relevant articles integrating I4.0 technologies with Operational Excellence (OPEX) strategies (Pansare, Yadav & Nagare, 2022) concluded that advanced I4.0 technologies were the most prominent factor for improving organizational performance.

Concerning Portugal, I4.0 arrives at different speeds. The Portuguese strategy for I4.0, "Indústria 4.0", was launched in January 2017. The Portuguese vision is oriented around three axes: digitalisation, innovation, and training. In comparison with other countries strategies, it is a bottom-up approach, initiated by the Ministry of Economy (but is managed by a private association, COTEC) that mainly targets small and medium-sized enterprises and has a strong focus on upskilling the workforce (COTEC, 2020; Yang & Gu, 2021). According to COTEC (2020), Portugal is above average. It is ranked as the 23rd most prepared economy to adopt I4.0 in 45 countries analysed, highlighting its infrastructure, general skills, and innovation capacity. Moreover, in the last few years, a select group of companies in Portugal has started pulling ahead in their efforts to implement I4.0 across their manufacturing networks (Deloitte Insights, 2019).

The high expectations from I4.0 concepts motivate companies to adopt I4.0. However, not all firms adopt I4.0-enabling technologies with the same ease. Some cannot relate I4.0 with their business models, while others cannot self-assess to identify their I4.0 maturity level and identify priority actions. Companies need to I4.0 progress and success. Therefore, they should apply proper methodologies and tools for guidance and support (Schumacher, Erol & Sihn, 2016) in evaluating I4.0 adoption and identifying their present situation concerning I4.0 (situation "as it is") and where to focus on improving the process and achieving the intended benefits (situation "as it should be"). According to Schumacher et al. (2016), a maturity model measures the maturation process, and the readiness model measures the company's readiness for the development process. Maturity can be defined as the current state of an organisation's specific process, area, or domain as it evolves through the several stages of learning concerning the extent to which the process is explicitly defined, managed, and controlled (Archie & McCormack, 2004). Moreover,

the maturity level increase translates into upgrading knowledge and problem-solving capacity concerning the related processes (Fraser, Moultrie & Gregory, 2002). Higher levels of maturity contribute to improved effectiveness and results control, enabling managers with enhanced ability to propose more ambitious targets of performance (McCormack, Willems, Van den Bergh, Deschoolmeester, Willaert, Stemberger et al., 2009). The Likert-type scale survey is a tool commonly applied to assess maturity levels, with the "five" answer in the Likert scale corresponding to the high maturity level (Fraser et al., 2002).

Maturity models measure a given system's maturity regarding a specific target state. The topic can be traced back to the concept of the quality management process maturity grid introduced by Crosby (1979) with five levels (1- Uncertainty, 2- Awakening, 3- Enlightenment, 4- Wisdom, 5- Certainty) and Dale and Lascelles (1997) for Total Quality Management (TQM). The Capability Maturity Model Integration (CMMI) or Software Process Improvement and Capability Determination (SPICE) are examples of well-disseminated maturity models (Stefan, Thom, Dominik, Dieter & Bernd, 2018). Maturity models can support enhancing a company's processes and business process management (BPM) capabilities. However, Röglinger, Pöppelbuß and Becker (2012) concluded that they provide limited guidance for identifying desirable maturity levels and implementing improvement measures. Hence, companies need maturity models that they can understand and apply.

Consequently, companies should perform an I4.0 maturity assessment to clarify those issues and overcome uncertainty and potential problems as maturity models describe the current scenarios of the organisations and offer improvement guidelines. Furthermore, maturity models need to be easy to understand and apply by the companies.

Due to the need for more research on adopting I4.0 in Portugal, this research aims to assess and discuss the I4.0 perception level of Portuguese companies building an Index through multivariate analysis by proposing the following Research Questions (RQ):

RQ1. What are the contributions of Investments in I4.0 tools to the organisation business?

RQ2. What are the perceived benefits and obstacles of adopting I4.0?

RQ3. What is the level of application of the I4.0 pillars and technology?

RQ4. What are the current perceptions of Portuguese manufacturing industries concerning their I4.0 adoption maturity?

RQ5. Can companies self-assess their I4.0 Maturity level with an aggregated index to identify their I4.0 maturity level, benchmark with others, and identify priority actions and progress?

The paper is structured as follows: After the introduction, section 2 outlines the state of the art and related work. The third section presents the research methodology, and the subsequent section 4 outlines the results and discussion. Finally, in section 5, the paper closes with conclusions and suggestions for future studies.

2. State of the Art

I4.0 is a revolution that requires technology and national strategies, and Yang and Gu (2021) summarised the updated national strategies and plans of over 14 countries for I4.0.

The convergence of technologies in support of digital transformation can be grouped into nine pillars (see Table 1) supporting the Internet of Things (IoT) oriented, augmented decision-making, and advanced automation (Oks, Jalowski, Lechner, Mirschberger, Merklein, Vogel-Heuser et al., 2022).

The I4.0 technologies adoption in companies and industries is a highly relevant topic (Luthra & Mangla, 2018; de Sousa-Jabbour et al., 2018; Kiel et al., 2017). Hermann, Pentek and Otto (2016) defined I4.0 as a collective term for technologies and concepts of value chain organization. I4.0 includes horizontal integration of information flows among all the stakeholders involved in the supply chain and vertical integration within the industry environment (Pérez-Lara, Saucedo-Martínez, Marmolejo-Saucedo, Salais-Fierro & Vasant, 2020), with digital technologies representing the common feature of I4.0 initiatives (Zheng, Ardolino, Bacchetti & Perona, 2023). These technologies fundamentally transform the traditional value chain, open new revenue flows, and drive a shift in business performance and even new business (GTAI, 2014; Ibarra et al., 2018; Rüßmann et al., 2015; Hanelt, Bohnsack, Marz & Antunes-Marante, 2020). According to Galati and Bigliardi (2019), this paradigm obliges the manufacturing industry to understand the increasing complexity of their processes and allows for effective

integration and visibility across the entire supply chain (Pérez-Lara et al., 2020; Tiwari, 2020). The use of digital technologies also fosters innovation, competitiveness, and improved industrial system sustainability (Müller et al., 2018; Stock & Seliger, 2016).

I4.0 Pillar	Description
Big Data	This technology acts as an extensive database and allows the generation and storage of a large volume of data at high speed and variety to understand better decision-making and process automation, quantities that cannot be processed in traditional software/technologies (Ching, Lau, Ghobakhloo, Fathi & Liang, 2022). The big challenge is ensuring that users get the most value from the data, increasing the probability of making quick and correct decisions with this vast volume, variety of data types and structures, and considerable data processing velocity.
Autonomous robots	The autonomous/intelligent robot can perform specific tasks and interact with other machines without human supervision. Organizations, through the implementation of autonomous robots, achieve a gain in performance and availability, leaving the production to the machines. With this, they reduce labour costs since they run quickly (Çınar, Zeeshan & Korhan, 2021).
Internet of Things (IoT)	It is an extension of the Internet, allowing objects (with computational and communicative capacity) to connect. The IoT enables intelligent operations, contemplating the exchange of information in real time between production systems and operators. With this, it is possible to obtain quality and productivity gains, providing robustness, autonomy, self-organization, self-maintenance, transparency, predictability, efficiency, interoperability, and traceability (Alcácer& Cruz-Machado, 2019).
Simulation	It is a crucial technology for developing planning and exploratory models to optimize complex production systems' decision-making, design, and operations (Bertolini, Esposito, Neroni & Romagnoli, 2019). Simulation allows testing and optimizing products and processes early, avoiding unnecessary expenses. The main advantage of simulation in I4.0 is to avoid losses. Instead of investing in an idea that may or may not be helpful, resources are allocated only to actions that have already been validated.
Integrated systems	They consist of evaluating systems to identify crucial areas that need to be assisted differently, aiming that all parties involved in the supply chain are appropriately integrated and connected cohesively. The I4.0 paradigm is essentially delineated by two dimensions of integration: horizontal and vertical (Gazdik, 2022).
Cybersecurity	It is a technology designed to detect, protect, and respond to cyberattacks, so it is essential to develop strategies that prevent these threats (Flamini & Naldi, 2022). It was not a concern in the traditional industry, as communication between sensors, networks, and clouds was virtually non-existent. One of the biggest challenges faced by this new industrial reality is the security of information systems.
Cloud computing	It is a technology that provides computing systems, including data stores, systems, software, and analysis over the Internet, to provide faster deployment, flexible resources, and economies of scale (Çınar et al., 2021). The most relevant feature of this technology is that any user can access documents and other materials anywhere on the globe (if you have an internet connection). Moreover, the user does not need to have a concrete physical structure nearby, as this physical structure exists somewhere in the service provider, with security guarantees that are obviously included.
Additive manufacturing	It is a revolutionary technology and an alternative to production. The junction of industrial production and 3D printing allows the creation of prototypes and the production of individual components. 3D printing follows a digital model created on a computer to produce a physical objective accurately. Then, with the three-dimensional model projected in software, usually in CAD, the printer prints the 3D design and offers advantages to the organization, such as accelerating the product development process (Silva & da Rocha, 2020).
Augmented reality	It is a computer graphics technology that allows the user to monitor the process data in real-time interactively. This means a significant advance, especially in reducing worker risks, increasing production line capacity, and optimizing resources. Furthermore, in augmented reality, the user is provided with additional computer-generated information within the data collected from real life that enhances their perception of reality (Voinea, Girbacia, Dugulean, Boboc & Gheorghe, 2023).

Table 1. I4.0 Pillars

Hence, from a theoretical point of view, I4.0 successful adoption can support the development of companies' capabilities that can foster the intelligent development of enterprises helping organisations enhance performance and integrate with stakeholders (a unique resource) and respond to their demands, and ultimately achieve superior competitive position, as posited by the Resource Based View of the firm (Barney, 2001). Moreover, in the present volatile environments, dynamic capabilities, such as using I4.0, are critical for organisations' survival (Fonseca, 2022). The Institutional Theory can predict that more companies will follow the I4.0 path as they follow models from successful organisations, thereby converging and becoming similar because of societal influence and the search for organisational legitimacy (DiMaggio & Powell, 2000).

Current literature has investigated the I4.0 phenomenon from different perspectives by adopting various approaches: studying the current state of I4.0 (Oztemel & Gursev, 2020; de Sousa-Jabbour et al., 2018; Kiel et al., 2017) and the company's maturity level of I4.0 (Ortt, Stolwijk & Punter, 2020; Bertolini et al., 2019; Çınar et al., 2021; Flamini & Naldi, 2022).

Several authors investigate the state-of-the-art of I4.0 in their countries. For example, Zheng et al. (2023) investigated the state-of-the-art I4.0 adoption in Italian manufacturing firms. They tried to understand variations in technologies implemented and business functions involved, benefits perceived, and obstacles encountered in I4.0 implementation by comparing results from a previous survey to that one conducted after three years. Their paper presents a descriptive survey of 102 Italian manufacturing companies. Survey findings demonstrate that Italian manufacturing companies still have limited awareness of I4.0 technologies and adopting I4.0 technologies differs per technology. Additionally, company size and information system coverage level are the two factors that impact the company's technology adoption level. companies are still seeking I4.0 solutions to reduce costs and lead times primarily, and the benefits perceived by companies are shown to be related to the number of I4.0 technologies in use. Finally, when companies put the I4.0 technologies into practice, competence is constantly considered the most significant barrier.

Overwhelmingly, the study of geographical areas characterised by most SMEs helps to understand the maturity level of SMEs in adopting I4.0 and the actual advantages that can be achieved (Galati & Bigliardi, 2019).

Gökalp, Şener and Eren (2017) compared seven maturity models for I4.0 assessment, namely Rockwellautomation, Geissbauer, Vedso and Schrauf (2016), Schumacher et al. (2016), Lanza, Nyhuis, Ansari, Kuprat and Liebrecht (2016), Menon, Kärkkäinen & Lasrado (2016), Leyh, Schäffer, Bley and Forstenhäusler (2016).

Bertolini et al. (2019) developed a qualitative review of the models applied in I4.0, for six dimensions (dimensions, key indicators, maturity measurement, calculation tool, presentation of results and maturity stages) and proposing future perspectives to improve existing models and develop new ones.

Schmitt, Schmitt and Engelmann (2019) conducted a literature review of I4.0 maturity models and evaluated them according to their applicability to SMEs.

Hizam-Hanafiah, Soomro and Abdullah (2020) focused on the main dimensions of I4.0 maturity models. Six main dimensions (technology, people, strategy, leadership, process and innovation) are identified as commonly used ones.

Silva and da Rocha (2020) evaluated the maturity level of a Strategic Defense Company (EED) from the perspective of I4.0 concepts.

Alcácer and Cruz-Machado (2019) referred that it is essential to understand how companies are facing the digital transformation challenges, what is their perception of the enabling technologies towards the I4.0, assess the I4.0's readiness so far, and what are their perception of the barriers to the adoption of these technologies. Therefore, they did an empirical study for assessed the I4.0 readiness level of companies and discuss the perception of companies about the barriers to the adoption of I4.0 with the reached readiness level of companies, based on the data collected on a sample of 15 companies belonging to a significant industrial cluster located in Portugal.

Çınar et al. (2021) reviewed the research related to existing I4.0 maturity models (MMs). They proposed a readiness framework (F/W) integrated with technology forecasting (TF) to evaluate the growth of I4.0 adoption and provide

a roadmap for implementing I4.0 for smart manufacturing enterprises. The proposed modular MM has four dimensions, five levels, 60 second-level dimensions, and 246 sub-dimensions, and proposed a generic F/W with four layers and seven hierarchy levels. Case study findings show that the enterprise's overall maturity score is 2.73 out of 5.00, and the forecasted year of full integration of I4.0 is between 2031 and 2034, depending upon the policy decisions.

Gajdzik (2022) developed an I4.0 maturity study carried out in Poland on steel companies. The model is based on assessing key technologies or pillars of I4.0. The research was carried out with 79 selected steel enterprises in Poland for the pilot study. The research established that the segment of enterprises in the Polish steel market is at the third maturity level in the model's five-level scale, where level 1 is the "preliminary" level, and 5 represents the optimal maturity level. Furthermore, within pillars of I4.0, according to all respondents, the most significant changes in implementing the industrial concept occurred in connection with the use of the Internet and mobile technologies in customer service, including EDI, an e-invoicing system.

Finally, Elibal and Özceylan (2021) performed a systematic literature review for I4.0 maturity modelling: state-of-the-art and future challenges. They conclude that there are limited review studies about I4.0 maturity modelling with many challenges and research gaps. Moreover, the author(s) posits the need for SME-focused, agile, and easily implementable I4.0 maturity assessment models.

3. Methodology

This research aims to innovate by creating a multivariate Index of companies' perception of the level of maturity of I4.0 in Portugal, which the authors of this paper named IPM, using exploratory factor analysis based on the Knowledge level of the Manufacturing Companies. In essence, the authors introduce a novel approach to assessing Industry 4.0 maturity perception, adding a distinctive perspective to the current body of knowledge in the field. Specifically, the research aims to innovate by crafting a multivariate Index, termed IPM, that gauges companies' perceptions regarding the maturity of Industry 4.0 in Portugal.

Considering the present study's focus on SMEs and the need to apply a model that can be easily understood and implemented by these types of companies and promotes possible roadmaps for future improvement, after reviewing the different maturity models, the chosen model to be used on this research is the Leyh et al. (2016) I4.0 maturity model. It encompasses six companies' dimensions (Strategy and Leadership (SL), Customer Experience (CE); Operations (O); Products and Innovations (PI); Information Technology (IT); Human Resources (HR)) and it be used as support to build an Index of companies' perception of the level of maturity of I4.0 (IPM) through multivariate analysis. Moreover, it is based on well-defined dimensions, which enables its successful application.

A quantitative research strategy was adopted, a survey was developed, and data was collected through a questionnaire. The participants were informed about the scope of the research, and their identities were kept anonymous.

The questionnaire was designed based on the framework of Leyh et al. (2016), to calculate the company's maturity level for six dimensions.

The survey featured distinct parts: Company characterisation (6 questions: industrial sector; localisation; the number of employees, sales volume; position held by the respondent; contact for further clarifications); I4.0 investments (1 question), I4.0 benefits and obstacles (3 questions); I4.0 pillars and technology level of application (2 questions); I4.0 maturity with five related companies' dimensions (25 questions): Strategy and Leadership (SL; 5 questions), Customer Experience (CE; 5 questions); Operations (O; 7 questions); Products and Innovations (PI; 4 questions); Human Resources (HR; 4 questions).

Each statement was rated on a five-point (1 to 5) Likert scale, with a high score of 5 reflecting the five related companies' dimensions.

The survey content validity was assessed through an I4.0 experts' pretest. Subsequently, an email was sent to a total of 700 companies identified through a ranking of the largest companies in Portugal in 2020 and contacts made

available by this research author(s). The data collection period was active between July and August 2021, and 50 valid answers were obtained (response rate of 7.1%).

Furthermore, the survey results were monitored to check for possible non-respondent bias using "wave analysis" (Armstrong & Overton, 1977). No significant differences were found by comparing late and early respondents' responses, minimising possible bias errors. Additionally, the analysis of the survey results suggests that it is representative since the sample distribution is consistent with the population.

A statistical analysis of the collected data was carried out with the IBM SPSS STATISTICS V21 software. Cronbach's Alpha Internal consistency measure (Pestana & Gageiro, 2014) was applied to assess the reliability of the questions. Exploratory factor analysis (EFA), one of a family of multivariate statistical methods, was used to discover the factor structure of a measure. This study proposed a factor analysis to identify the factors underlying the variables of a questionnaire to measure the perceived level of I4.0 maturity.

Two assessment techniques are usually used to verify the adequacy of factor analysis: the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity to assess the factorability of the data (Pestana & Gageiro, 2014). The determinant score is calculated to examine the multicollinearity among the variables. Kaiser's Criterion and Scree test are examined to determine the number of factors to be extracted. Finally, the Varimax orthogonal factor rotation method is applied to minimise the number of variables with high loadings on each factor (Hair, Black, Babin, Anderson & Tatham, 2006).

The above tests facilitated the verification of the research hypotheses and made it possible to demonstrate the existence of statistically significant relationships between the variables.

The multivariate index produced in this study was based on the methodology used by Cunha, Borges and Fachel (1998).

The appraisal of the factors results from the weighted averages of the individual variables included in each dimension, using the weights obtained from the application of factor analysis as weights. On the other hand, for the global calculation, the results of each dimension are applied using the eigenvalues of the corresponding factors as weights.

To calculate the global IPM, the eigenvalues will be used as importance weights (Hair et al., 2006). The weighted perception level dimension index calculation allows for an interpretation with more precision and rigour since it includes the relative importance of the factors. Concerning the evaluation of the level of global IPM, the impact of the eigenvalues is considered, where the first factor has greater importance than the second, and so subsequently.

Factor analysis allows obtaining two appropriate indicators to calculate the IPM: (i) factor load of the variables, which indicates how much each of them explains the variance of the respective factor; (ii) explanatory potential of each factor (eigenvalue), that is, how much each factor explains of the total variance.

The multivariate indicator of PERCEPTION makes it possible to analyse the level of PERCEPTION of each factor and identify which factors are more influential in the analysis result.

The IPM will be presented in percentage form ranging from 0% (when respondents say very low, score 1) to 100% (when respondents say very high, score 5).

Quantitative values are translated into qualitative outputs, as follows: [0-20%[- very low; [20-40%[- low; [40-60%[- medium; [60-80%[- high; and [80-100%] - very high. There are 5 points by analogy with the Likert scale.

In the first step, the IPM will be produced for each factor, where for each variable, the weighted average between the answers of the Likert scale values performed is used, weighted by its factorial load. Then, Equation [1] presents the IPM calculation of factor k.

$$IPM(F_{kn}) = \frac{\sum_{i=1}^{j}(|p_i|\bar{x}_i) - \sum_{i=1}^{j} p_i}{(L_u - L_l) \cdot \sum_{i=1}^{j} p_i} \cdot 100\% \qquad i=1,...,j \qquad (1)$$

where,

IPM (F_{kn}), Index perception maturity on factor k (based on n companies);

n, number of companies;

j, number of variables in the factor k;

$|p_i|$, absolute value of the factorial loading for variable i on factor k;

$\bar{x}_i$, average of the score of variable i on factor k;

L_u, upper limit of the Likert scale;

L_l, lower limit of the Likert scale.

In second step, after the factor results are obtained, the global IPM for the companies is calculated, using the final eigenvalues as weights, according to Equation 2 (Cunha et al., 1998).

$$IPM_G(n) = \frac{\sum_{i=1}^{k}[\Lambda_i.IPM(F_{kn})]}{\sum_{i=1}^{k}\Lambda_i} \qquad\qquad i=1,...,k \qquad\qquad (2)$$

where,

IPM$_G$ (*n*), Global Index perception maturity;

Λ_i, factor k final eigenvalue;

IPM (F_{kn}), Index perception maturity for the Company n on factor k.

4. Results and Discussions

4.1. Respondents' Characterisation

Of the companies surveyed, it was possible to observe a wide range of business branches, such as Services (20%), Metalworking (16%), and Automobile (12%). More than 75% of the companies employ more than 50 employees. Companies employing more than 200 employees represent around 50% of the companies that collaborated, and in total, 30% of the companies that participated in the research employ more than 500 employees. Companies with more than 1000 employees represent 10% of the companies surveyed (see Figure 1).
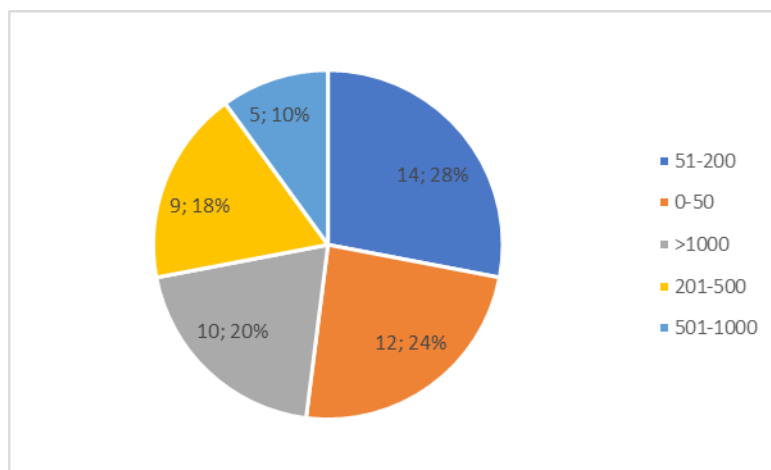

Figure 1. Company size in number of employees

Around 78% of the companies participating in the survey had a turnover of more than €1 million in 2019, of which 60% exceeded €5 million.

Concerning the position held in the company by the respondent, 30% of respondents hold Administration positions. These positions are closely followed by Owners who represent 20% of respondents and Operations

Manager with 18%. It should be noted that the positions of Lean Manager and i4.0 Manager only individually represent 2% and 4% of respondents respectively.

4.2. Contributions of Investments in I4.0 Tools to the Organisation Business

Regarding the second part of the questionnaire "What are the contribution of investments in I4.0 tools", from the 50 surveyed companies, a high percentage (60%) considers that will improve Production, and less than a quarter (22%) considers that they may have a contribution in IT. It should also be noted that although 18% of respondents consider that the impact will be in all sectors, 10% of respondents state that it will have no impact in their organisation (see Figure 2).
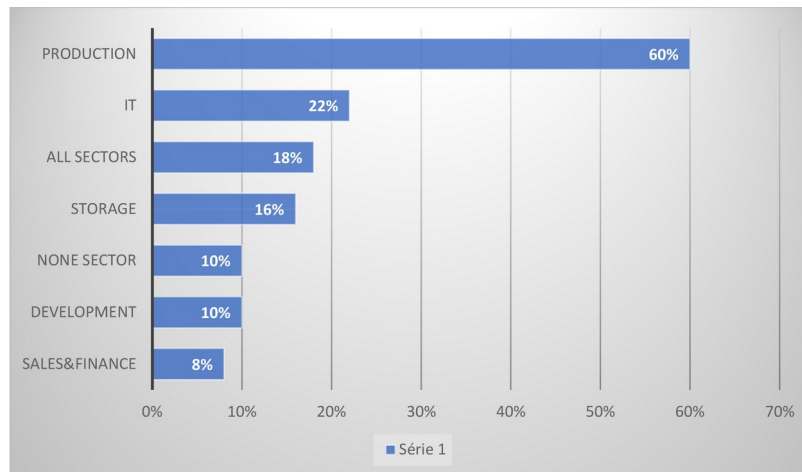

Figure 2. Contribution of investments in I4.0 tools

Likewise, more than 68% of the companies said that they use IT tools in Production Planning, Quality Management, Accounting and Finance, and Purchasing and Inventory Management, the latter having the highest usage rate (82%).

4.3. Potential Benefits and Obstacles of Adopting I4.0

Concerning the potential benefits of applying I4.0, Increased Agility in Operations with 76% was chosen as the main benefit, followed, with 64%, by companies considering Improved Services to be offered to customers, and Reduced Production Costs as the second most significant benefit (see Figure 3).
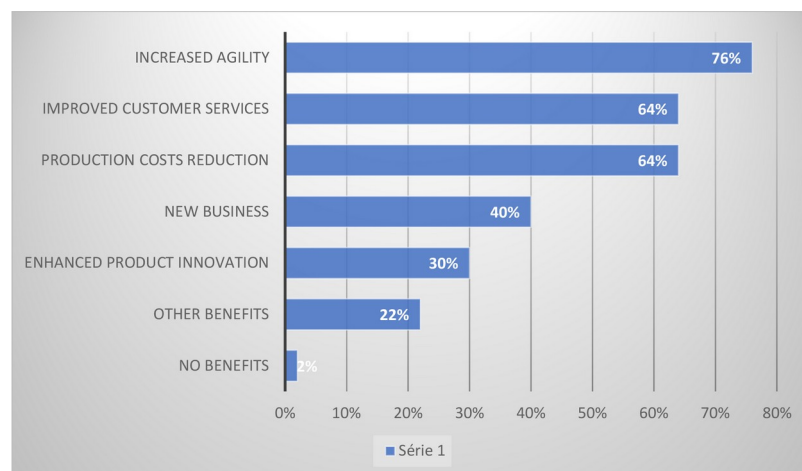

Figure 3. Potential I4.0 benefits for the organisation

Conversely, 76% of the respondents reported the need for additional investments as the major obstacle to I4.0 successful implementation, followed by the time-consuming activities (64%). The difficulty in accessing collaborators with the necessary knowledge to apply the changes implicit in the digitalisation of processes concerns 43% of the respondents (see Figure 4).
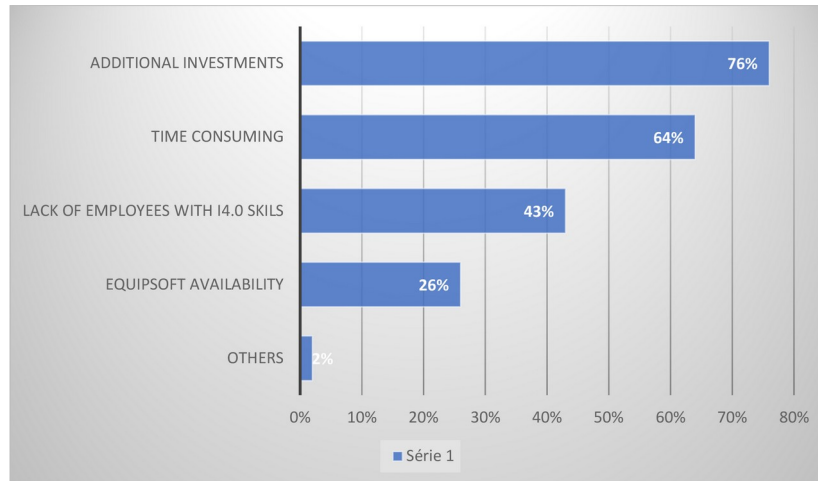

Figure 4. Obstacles for I4.0 adoption

4.4. I4.0 Pillars and Technology

The next survey section aimed analyse the level of use of I4.0 main pillars/technologies by the respondents' organisations. The results highlight that the pillars Augmented Reality, 3D Printing, Autonomous Robots and Virtual Simulation, are the least used in the companies participating in the study, with percentages of non-use of 74%, 68%, 58% and 56% respectively. Conversely, IoT/IoS (26%), Cloud Computing (24%), Cybersecurity (20%) have the highest percentages of high usage (see Figure 5).
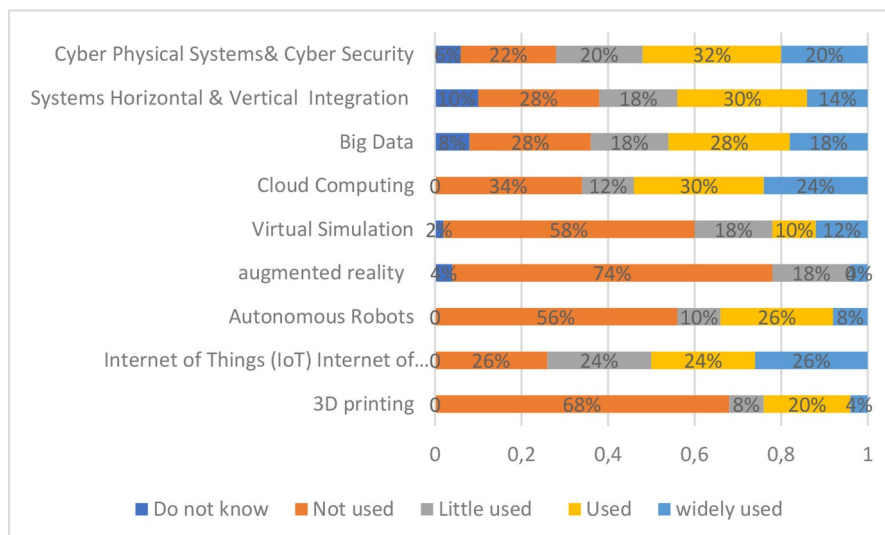

Figure 5. Level (%) of use of the tools of the I4.0 Pillars

4.5. Organisation I4.0 Perception Level

When asked to self-assess their level of perception about the subject of this work more than 50% of the companies surveyed assume a Medium/Above Average level (1 to 5 scale, 1 - very low and 5 - very high). Conversely, only one company considers it to have a high level (Figure 6). Ferreira, Fonseca, Pereira and Ferreira (2022) compared the Portuguese' self-assess level of maturity perception of I4.0 with the results of a New Zealand

survey (Hamzeh, Zhong & Xu, 2018). Although both companies of countries reported a similar Medium/Above Average (approximately 50%), the number of companies with the highest level is much lower in Portugal, with only 2% of domestic companies reaching this level while in New Zealand it is reached by 16%.
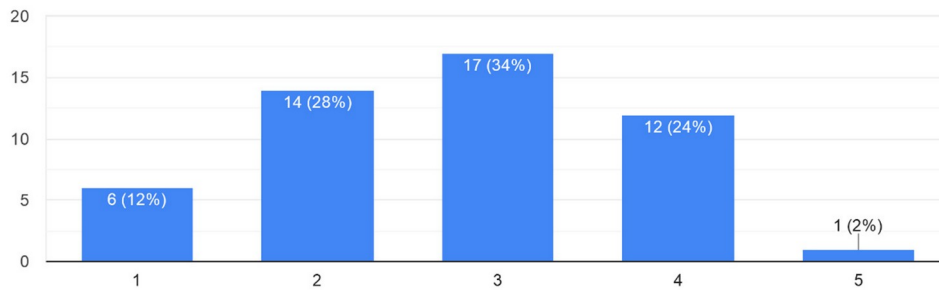

Figure 6. I4.0 Perception Level

4.6. Organisation I4.0 Maturity Level Descriptive Statistics

The concept of I4.0 implementation will be measured according to the five dimensions (Leyh et al., 2016): 1 - Strategy and Leadership; 2 - Customer Experience; 3 - Operations; 4 - Products and Development; and 5 - Human Resources. To calculate the I4.0 perception level, the questions were categorised according to these five dimensions with a Likert 1 to 5 type scale (1- very low; 2- low; 3-medium; 4-high; 5-very high).

The aggregation of the results provides a possible value to frame the average maturity degree of the sample concerning each of the dimensions studied to the phenomenon of industrial digitalisation. Thus, according to Leyh (2016), the assessment of maturity in I4.0 goes up to five levels from basic to complete and optimised integration of the digitalisation of organisations.

The weighted average was then determined based on the summation of the answers to each question by dimensions. Subsequently, the average of all questions for each dimension studied was calculated, and finally, the average of all dimensions was taken. To increase the accuracy of the classification of maturity levels, value ranges with the precision of 2 decimal places were adopted to determine the respective levels, thus assessing their maturity level clearer (Table 2).

Dimensions	Average
Strategy and Leadership	2.88
Customer Experience	3.29
Operations	3.12
Products and Development	2.91
Human Resources	3.67
Total average	3.174

Table 2. Average for each dimension

After determining the average for each dimension and the total average, it is possible to classify each dimension individually, and make an overall classification (Table 3).

Maturity value		Maturity levels
Less than 2	1	Initial
Greater than 2 and less than 3	2	Integration
Greater than 3 and less than 4	3	Digitisation implemented
Greater than 4 and less than 5	4	Digitisation complete
Equal a 5	5	Digitisation optimised

Table 3. Perception/maturity levels assessment

Figure 7 shows the distribution of the dimensions studied by their maturity. As also emphasised Table 2, for the surveyed companies, Human Resources has the most positive result (3.67), while strategy and leadership (2.88) and products and development (2.91) have the lowest average results.

It should be noted that the average value of the question where companies self-assessed their perception would place them at the integration level (2.76). However, after the previous analysis, it is possible to see that the sample is at the implemented digitalisation level (3.17).
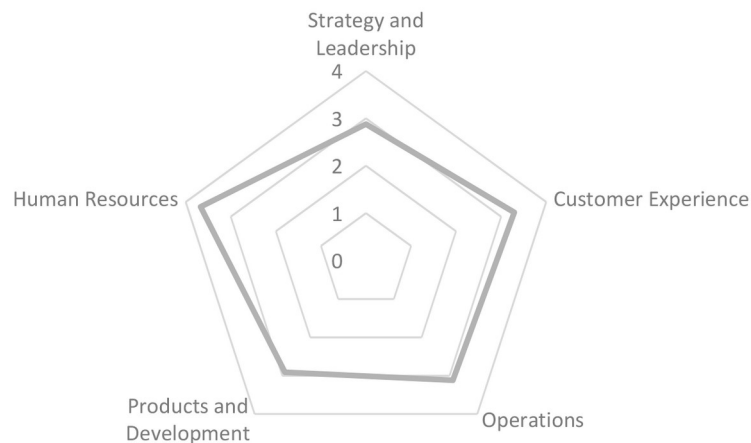

Figure 7. Final average in each dimension

Table 4 presents the descriptive statistics of the results.

Variable description	1	2	3	4	5	$\bar{x}$	SD
What is the level of perception of I4.0 in the company? (n=50)	6	14	17	12	1	2,76	1,01
	12%	28%	34%	24%	2%		

Table 4. Descriptives statistics

The results of the detailed questions for each dimension, highlight the following conclusions (see Table 5 for the detailed questions):

- *Strategy and leadership:* To determine the level of management commitment to the implementation of new tools and methodologies, from the analysis of the questions, it can be observed that the budget allocation and prioritisation in digital investments have the most level 1 responses (34% and 24% respectively) in the participating companies followed by the allocation of human resources (22%). The digital vision and the effort to implement it are the categories where the leadership of the companies studied is at the highest

level, with both components having an above-average level (4 and 5 level responses) in more than 52% of the cases observed.

- *Customer experience*: The companies studied have an above-average concern with customer experience, with the impact of customer demands on the market being the point most valued by them, thus being valued at a high and very high level by 72% of the companies (see Figure 2). However, in the opposite direction, it is possible to observe that about 32% of the companies still reach a low level in using customer data to improve their processes.

- *Operations:* Most companies surveyed have a Medium/High level of automation and digitalisation. The areas where companies encounter the most significant difficulty are in defining and updating KPIs. It is also evident that most companies surveyed have an integrated platform. This issue will be even more visible in the next section.

- *IT Tools:* We also inquired the organisations about the Organisational Information Systems they currently have available. The vast majority, 82%, have an enterprise resource planning system (ERP), as well as 46%, have relationship management control (CRM), 18% have production data acquisition (RFID), and 16% have warehouse management (WMS). The remaining answers were grouped in the category Other. 80% of the companies only use one or two different software, and only 6% of the companies surveyed use 4 different software throughout their value chain.

- *Products and Innovations: A*lthough many participating organisations can collaborate easily between departments, this collaboration does not translate into harnessing technologies to innovate products. Despite this, the organisations have a medium/high level of analysis and innovation per market changes. The implementation of new service models is also at a similar level.

- *Human Resources:* The companies were asked to answer questions on digitalising their HR management processes. After analysing the data, it is possible to determine that although most companies do not have a dedicated team to foster the organisation's digitalisation, this fact is compensated with a medium/high level of incentives for the sharing of ideas by their employees. These incentives are supported in a Medium/High manner by skill management tools and remote connectivity.

4.7. Constructing of the Index of Companies' Perception of the Level of Maturity of I4.0 (IPM)

The structured questionnaire was designed to collect primary data. For the applicability of factor analysis, tests were necessary to measure the quality of the correlations between the variables. To identify the factors, it is necessary to understand the concept and steps to apply factor analysis for the questionnaire survey.

The original questionnaire from Leyh et al. (2016) comprehends the following dimensions: 1 – Strategy and Leadership (5 questions); 2 - Customer Experience (5 questions); 3 – Operations (7 questions); 4 - Products and Development (4 questions); and 5 - Human Resources (4 questions). Hence, with a total of 25 questions. The principal component analysis was applied to analyse the main components and select the components that explain most of the total variation, reducing the size of the data.

For the applicability of factor analysis, tests were necessary to measure the quality of the correlations between the variables, i.e., to check whether the data characteristics were adequate to apply the statistical technique. In this study, it was used the Kaiser-Meyer-Olkin measure of sampling adequacy and Bartlett's test of Sphericity were used to assess the factorability of the data. A value of 0.816 was obtained for the KMO, indicating the sampling is adequate. The Bartlett's test of Sphericity is highly significant at $p < 0.001$, which shows that the correlation matrix has significant correlations among at least some of the variables (Pestana & Gageiro, 2014). After analysing the anti-image matrix and the commonalities, it was found that 5 of the 24 variables under study had a Sampling Adequacy Measure of less than 0.50, showing the need to eliminate them.

The application of Principal component analysis (PCA) is justified with the aim to analyse the data to obtain the minimum number of factors required to represent the available data set (Hair et al., 2006). Kaiser's Criterion and Scree test were examined to determine the number of factors to be extracted. In addition, the Varimax orthogonal factor

rotation method is applied to minimise the number of variables with high loadings on each factor. The internal consistency is confirmed by calculating Cronbach's alpha and composite reliability to test the instrument's accuracy.

Convergent validity is established when the average variance extracted is greater than or equal to 0.5. Five factors were extracted, accounting for a combined 72.3% of the total variance. Factor 1 (Strategy and leadership) explains 18.624 of the data. Factor 2(Customer experiences). The first component (Strategy and leadership) has explained 18.62% % of the total variance with an eigenvalue of 3.139. The second component (Customer experiences) has explained a 15.99% variance with an eigenvalue of 2.695. The third component (Products and Innovations) has explained a 13.75% variance with an eigenvalue of 2.318. The fourth component (Human Resources) has explained a 12.33% variance with an eigenvalue of 2.078, and the fifth component (Operations) has explained an 11.61% variance with an eigenvalue of 1.957.

To verify the reliability of the grouping of the variables, Cronbach's Alpha coefficient was calculated for each of the five factors (Table 5), which confirmed the reliability of the survey instrument.

Table 5 presents the averages and standard deviations for each variable and the set of 19 variables, analysed using a 5-point Likert scale.

Factors	Variable Description	Descriptive		Factorial loading p_i	% Variance explained	Alpha Cronbach	Final Eigenvalue	IPM (F_{kn})
		Mean	Standard Deviation					
Factor 1 Strategy and leadership	X_1. Does the organisation have a digital vision to transform itself due to new market needs?	3.56	0.793	0.793	18.624	0.851	3.139	47.31%
	X_2. Has the leadership made an effort to translate the digital vision at all levels of the organisation?	3.40	0.839	0.839				
	X_3. Is there a team dedicated to the digital transformation and change of the organisation?	2.64	0.837	0.837				
	X_4. Is there a prioritised business area for digital investments?	2.44	0.768	0.768				
	X_5. There is a separate budget allocated for the adoption of digital technologies	2.34	0.717	0.717				
Factor 2 Customer experiences	X_6. Does the organisation experiment with various digital channels to engage customers?	3.18	0.913	0.913	15.990	0.834	2.695	53.59%
	X_7. Is digital technology used to stay in touch with customers and solve their challenges?	3.08	0.886	0.886				
	X_8. Are inputs from customer usage data used continuously to improve solutions and services?	3.14	0.748	0.748				
	X_9. Can the organisation offer customised solutions to capture greater market segment share?	3.18	0.719	0.719				

| Factors | Variable Description | Descriptive | | Factorial loading p_i | % Variance explained | Alpha Cronbach | Final Eigenvalue | IPM (F_{kn}) |
		Mean	Standard Deviation					
Factor 5 Operations	X_{10}. Level of digitisation of operations?	3.02	0.766	0.766	11.611	0.733	1.957	58.03%
	$X_{11.}$ Is there an integrated platform that provides complete visibility and can be accessed by multiple users?	3.50	0.834	0.834				
	$X_{12.}$ Can all production information be accessed remotely?	3.42	0.821	0.821				
Factor 3 Products and Innovations	$X_{13.}$ Can departments collaborate easily through digital channels?	3.70	0.785	0.785	13.753	0.758	2.318	53.36%
	$X_{14.}$ Is the organisation able to innovate quickly according to changing market requirements?	3.30	0.728	0.728				
	$X_{15.}$ Have new service models, enabled by digital technology, been introduced?	2.86	0.746	0.746				
	$X_{16.}$ Can product usage information be analysed based on real-time data flow?	2.64	0.728	0.728				
Factor 4 Human Resources	X_{17}. Can employees leverage digital tools for collaboration and remote connectivity?	3.64	0.777	0.777	12.329	0.776	2.078	58.60%
	X_{18}. Are employees' digital transformation ideas encouraged?	3.24	0.862	0.862				
	X_{19}. Are digital tools used for knowledge management and skills improvement?	3.18	0.855	0.855				

Note. Likert scale: 1-very low; 2-low; 3-medium; 4-high 5-very high

Table 5. Descriptive values, factor loading, Alpha Cronbach and IPM for each factor

The PCA analysis allowed the reduction of the 25 initial questions to the 19 presented in the above Table 5. After calculating the I4.0 Perception Maturity (IPM) for each factor, it is possible to evaluate the Global perception of I4.0 maturity, pondered by the values obtained from the final eigenvalues, using Equation 2. According to the result, the IPM for the surveyed companies is satisfactory since it displays a value of 53.50%, indicating that companies are medium with Strategy and Leadership; Customer Experience; Operations; Products and Development, and Human Resources.

5. Conclusions

Overall, the research objectives were fulfilled by analysing the perception and knowledge about I4.0 by companies operating in Portugal, ascertaining the benefits, obstacles, and state of application of its tools and methods in the national panorama, and determining the essential factors for defining the maturity level of the implementation of I4.0. Furthermore, the research objective was achieved by creating a multivariate Index of companies' perception of the level of maturity of I4.0 in Portugal and evaluating the Global perception of I4.0 maturity. The IPM is

satisfactory since it is 53.50%, indicating that companies are medium with Strategy and Leadership; Customer Experience; Operations; Products and Development, and Human Resources.

Specifically concerning RQ1, "What are the contributions of investments in I4.0 tools to the organisation business?" 60% of the respondent organisations emphasise the improvement in the Production area. While 18% of respondents consider that the impact will be in all sectors, 10% state that it will not impact their organisation.

Concerning the next RQ2, "What are the perceived benefits and obstacles of adopting I4.0?", "Increased Agility in Operation" (76%) and Improved Services to be offered to customers, and Reduced Production Costs (both with 64%) are considered the second most significant benefits. Conversely, 76% of the respondents the need for additional investments as the major obstacle to I4.0's successful implementation, followed by time-consuming activities (64%). These results are in line with Alcácer and Cruz-Machado (2019), that also advance that companies could be postponing I4.0 investments due to a lack of financial resources, human resources, or even lack of time. A high workload and the lack of qualified people were suggested as possible explanations for the limited application of improvement methodologies within Portuguese companies (Fonseca & Domingues, 2018). On the other hand, financial support and continued specialized skills training have also been reported as significant enablers of I4.0 in a study of the manufacturing industry in India (Jain & Ajmera, 2021). Furthermore, Türkes, Oncioiu, Aslam, Marin-Pantelescu, Topor and Căpușneanu (2019) confirmed the existence of a high level of desire to implement I4.0 in the Romanian SMEs; however, there are scarce resources to implement it.

IoT/IoS (26%), Cloud Computing (24%), and Cybersecurity (20%) have the highest percentages of high usage, while Augmented Reality, 3D Printing, Autonomous Robots and Virtual Simulation are the least used in the companies participating in the study, with percentages of non-use of 74%, 68%, 58% and 56% respectively (RQ3. What is the level of application of the I4.0 pillars and technology?).

Proceeding with RQ4 (What are the current perceptions of Portuguese manufacturing industries concerning their I4.0 adoption maturity?), 50% of the companies surveyed assume a Medium/Above Average level, and the average value of the question where companies self-assessed their perception would place them at the integration level (2.76). However, with the application of the proposed IPM methodology, it is possible to see that the sample is at the implemented digitalisation level (3.17). These results align with those of Gajdzik (2022) in Poland steel companies and Hamzeh et al. (2018) in New Zealand and are more favourable than those previously reported by Türkes et al. (2019) with Romanian SMEs (72.2% of the respondents' indicated level 0 for the level of preparation for implementing I4,.0 specific technologies).

Human Resources has the most favourable result in a more detailed analysis of the five studied maturity dimensions (3.67). In contrast, strategy and leadership (2.88) and products and development (2.91) have the lowest average results. The respondent companies need better results concerning budget allocation, prioritisation in digital investments, and assigning human resources for I4.0 adoption. This indicates the need to strategically manage I4.0, aligning with the company strategy, goals, and actions, as posited by Fonseca, Amaral and Oliveira (2021). Secondly, the impact of I4.0 on customer experiences is of high regard to the surveyed companies. Most (82%) companies have an enterprise resource planning system (ERP), as well as 46% have relationship management control (CRM), 18% have production data acquisition (RFID), and 16% have warehouse management (WMS). However, approximately 32% of the companies still need to reach a higher level in using customer data to improve their processes, highlighting the need for standards of interoperability and compatibility) and develop IT structure, as emphasised by Alcácer, and Cruz-Machado (2019). Concerning operations, companies report a Medium/High level of automation and digitalisation. However, there are significant difficulties in defining and updating KPIs. Hence, the need to properly define and deploy the strategy through the overall value chain, namely adopting novel business models that support innovation and new product development (Fonseca, 2022). Furthermore, Naeem and Garengo (2022) concluded that within the context of I4.0, a strong interaction exists between the maturity of manufacturing processes and performance management and measurement (PMM). Hence the adoption of I4.0 can foster PPMs and enhanced performance. Finally, although the need for more human resources with the right I4.0 skills is regarded as a significant obstacle to I4.0 adoption, it is acknowledged that employees actively contribute with suggestions and manage the proper tools for remote connectivity. Nevertheless, adopting I4.0 might create job loss

fear in employees (Pasi, Mahajan & Rane, 2021) and most respondent companies need a dedicated team to foster the organisation's digitalisation.

To conclude with RQ5 (Can companies self-assess their I4.0 Maturity level with an aggregated index to identify their I4.0 maturity level, benchmark with others, and identify priority actions and progress?) The PCA analysis and the proposed I4.0 Perception Maturity (IPM) can support companies in evaluating their present I4.0 situation and identifying improvement actions. The research results indicate an overall satisfactory (53.50%) value for the IPM, indicating that companies are performing at a medium level with Strategy and Leadership; Customer Experience; Operations; Products and Development, and Human Resources.

This research provides valuable information on the I4.0 Maturity level of Portuguese manufacturing companies, which is crucial to support the bottom-up approach of the Portuguese I4.0 strategy, mainly targeting small and medium-sized enterprises. The research objectives cover the perception, knowledge, benefits, obstacles, and maturity levels of I4.0 adoption. The use of a multivariate index (IPM) to assess the maturity level and the comparison between the self-assessment results and the IPM, provide an in-depth evaluation highlighting possible strategies for Portuguese I4.0 manufacturing companies (especially for small and medium-sized enterprises) strategy and where to focus on improving the process and achieving the intended benefits. The study identifies specific areas for improvement, such as strategic focus on I4.0, integrated IT structure, employee skills, and transformational leadership. Moreover, practical methodologies and tools are suggested for companies to evaluate and improve their I4.0 adoption. Top Management commitment is also essential to create a favourable organizational culture for adopting I4.0 (Samanta, Virmani, Singh, Haque & Jamshed, 2023). In addition, managers must adopt a transformational leadership style for employees to accept I4.0 (van Dun & Kumar, 2023).

Concerning this research's limitations, this study presents certain limitations that provide avenues for further investigations. The first limitation of this study is the low response rate to the questionnaire (7.1% combined with a small sample size (50 valid answers), which falls short compared to similar studies. Secondly, it is research limited to the Portuguese industry, which prevents the generalisation of the results, and these may not be directly applicable considering different contexts.

Thus, future studies should consider a larger and more diverse sample size, and efforts should be made to increase the response rate. Furthermore, employing mixed-methods approaches could provide a more comprehensive understanding. To enhance external validity, future research could include companies from different countries or regions, providing a broader perspective on I4.0 adoption across diverse industrial landscapes by obtaining more reliable results and allowing its generalisation. In addition, introducing new variables to evaluate potential associations, such as the size of the participating companies, would allow the study of the influence of the number of employees on the maturity of I4.0 adoption. Moreover, digital transformation (I4.0) has brought new realities to the industry worldwide (Fonseca et al., 2021; Komkowski, Antony, Garza-Reyes, Tortorella & Pongboonchai-Empl, 2023). Hence, future studies should evaluate the influence of the maturity level of I4.0 adoption on the sustainability dimensions. Another suggestion would be to investigate the economic and competitive value added of I4.0 adoption. Finally, conducting longitudinal studies could provide insights into the evolving nature of I4.0 adoption and its long-term impacts on businesses.

Declaration of Conflicting Interests

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