Tracking the Maturity of Industry 4.0: The Perspective of a Real Scenario

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Abstract. In order to track industry 4.0 status, readiness models can be used to analyze the state of industry 4.0 technologies' implementation allowing the quantification and qualification of its readiness level, focusing on different dimensions. To this matter, there are companies unable to relate the industry 4.0 with their business models, leading to a lack of a correct self-assess in order to understand the reached readiness level. Not all companies are adopting these new technologies with the same ease and with the same pace. Into this purpose, it is important to understand how to assess the industry 4.0' readiness so far and what are the barriers on the adoption of these enabling technologies by the industry. This paper aims to assess the industry 4.0' readiness level of companies, understand the perception of companies due to the barriers on the adoption of industry 4.0 enabling technologies and bring new barriers for discussion on academic community. To this end, empirical data was collected on a sample of 15 companies belonging to an important industrial cluster in Portugal.

Keywords: Industry 4.0, Readiness Models, Readiness Level, Implementation barriers, Company perception.

1. Introduction

High energy costs, constrains on the acquisition of raw materials and qualified workforce, aligned to a weak internal demand, the rigid of the regulatory and administrative processes also labor markets, low investment in Research and Development (R&D) and innovation, have tended on shifting to date the industrial sector to developing countries. Therefore, it is well known the importance of increasing the competitiveness on the manufacturing environment for the survival of each company. This new vision is enabling companies to look at the real value-added that can be created by themselves. Companies that in recent past followed the trend to relocate activities (looking for low-cost labor), are now pathing to recover their competitiveness.

Germany played a key rule on this paradigm shifting, launching public and private initiatives to maintaining and promoting its importance as a "forerunner" on the industry [1]. Industry 4.0 (I4.0) concept was first appeared in a German government article in November 2011 and was intitled as the "High-Tec strategy for 2020". The fourth stage of industrialization was called I4.0. The I4.0 term will appear again in Germany at Hannover industrial fair in 2013 and rapidly emerged as the German national strategy. As one of the most competitive global manufacturing industries, Germany developed a strategic plan to implement I4.0, helping on the transformation from de Industry 3.0 [2], with the heading of Industrie 4.0 [3].

The urgent need for the I4.0 implementation leads to a growing demand for this research topic in order to provide insights into the issues, challenges, and solutions for the design and implementation of the I4.0 [4].

The urgent need for the I4.0 implementation leads to a growing demand for this research topic in order to provide insights into the issues, challenges, and solutions for the design and implementation of the I4.0 [4]. Also, this demand is reflected on the acceptance among industry that I4.0 paradigm is an indispensable concept to shift manufacturing environments into a valuable asset and that there is no way to survive without I4.0 implementation. Up to date, I4.0 is on the early stage of implementation in industry, human environment, and scientific research [5]. This makes I4.0 a no longer "future trend" [4].

Since it is still in an early stage of implementation, not all industries are adopting these enabling technologies with the same ease and it is necessary to understand what the reasons behind these differences are. On the one hand, companies are unable to relate I4.0 with their business models and, on the other hand companies are not able to self-assess in order to understand the reached readiness level. For companies to overcome uncertainty and discontent, it is necessary to use new tools to guide and support them [6]. Thus, to analyze I4.0 into different states, maturity or readiness models can be used. According to Schumacher et al. [6], a maturity model measures the maturation process as the readiness model measures how company is ready to the development process.

As the implementation of I4.0 takes place at different pace around the world, it will be very important to understand what the barriers on I4.0 enabling technologies adoption are. The academic community has been presenting some studies not only regarding the maturity or readiness levels of I4.0 in companies, but also about the perception of the barriers associated with the implementation process.

I4.0 is considered the fourth industrial revolution [7] and different from previous revolutions because it was declared before it happened, and we are currently experiencing its evolution. In this way, the academic and industrial community have a great opportunity to be part of this revolution. In this sense, this paper presents a study carried out on a region of great industrial importance in Portugal allowing the possibility to compare it with other studies in other regions and/or countries. Through this study, it is also intended to bring to the scientific community new barriers on I4.0 enabling technologies adoption and, to the best of our knowledge, have not yet been identified in previous studies.

The rest of this paper is organized as follows: section 2 presents a brief overview over the enabling technologies to reach the I4.0 environment achieving the smart factory, introduces maturity and readiness models to measure the I4.0 status and barriers on the I4.0 enabling technologies adoption, section 3 exposes the research methodology followed on this paper, section 4 presents the results and drawn the discussions, and the section 5 outlines the conclusions, the research limitations and ongoing research.

2. The Path Leading to the Smart Factory

The first industrial revolution started after the introduction of mechanical manufacturing factories on the second half of the 18th century [8]. Steam engines were gradually inserted on the production sector, then on the transport sector and, finally, on energy production. This change was slow and took decades [9]. Since 1870, with the electrification and division of labor, the second revolution began [8]. This revolution began on the United States of America with the rapid expansion of industries, with new factories linked together and to a central power plant. It was during this revolution that Henry Ford developed the manufacturing system without interruption at the Detroit auto plant. The line operators were semi-qualified, and the parts produced were standardized, that is, it was a type of mass production [9].

The third revolution, also called the digital revolution, originated from electronic advances and computer technologies in 1970, which provided production automation increase [8]. Traditional industries based on oil, fossil fuels and mass production could no longer be considered a complete solution to economic or social problems and, therefore, a cluster of innovative communication and energy technologies was created [9]. Figure 1 shows industrial progress from a historical perspective.

Currently, on fourth industrial revolution or I4.0, higher level of automatization achieving a higher level of operational productivity and efficiency is the aim of I4.0 [11, 12], connecting the physical world to the virtual world [13, 14], bringing into the traditional industry computerization and inter-connection [10]. Several authors [11, 15, 16] assumed I4.0 as Cyber-Physical production, founded on knowledge integration and heteronomous data using Big Data (BD) and advanced technologies such as Internet of

Things (IoT) and Services (IoS), Cybersecurity (CS), Cloud Computing (CC) and Intelligent Robotics [11, 12, 14].

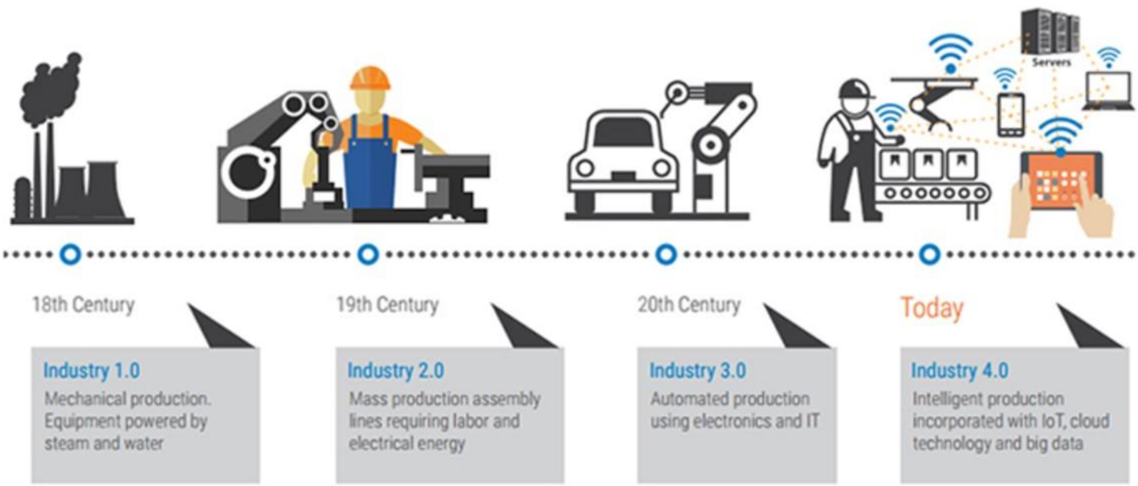


Fig. 1 Industrial Progress from a Historical Perspective [8].

The framework of the I4.0 is the development of the Smart Factory (SF) [12, 13, 15–19]. Gilchrist [19] assumed in conceptual terms that the Cyber-Physical Systems (CPS) are the heart of the I4.0. Complementing, Hofmann and Rüsch [1] assumed the SF main components as CPS, IoT and IoS. These components built the decentralized concept of production system with a social network connecting resources, machines, and humans [1]. When SF use cloud-based manufacturing, CPS and IoT, the SF converge to IoS in order to create, publish and share manufacturing processes on a form of services that can be supplied by virtual enterprises [20].

The fundamental aspect to deal with this new generation of SF is the systems integration where three types of integrations take place. The vertical integration occurs inside the SF, the horizontal integration occurs in the value network of the SF and across several SF's, allowing the end-to-end systems integration across the entire value chain [21].

Figure 2 shows the approach of I4.0 for manufacturing systems based on SF concept whit IoT, IoS, the systems integration and Cyber-Physical Production System (CPPS) that can be consisted by several CPS linked on a network. Depending on the purpose, the CPS component can use the key enabling technologies such as: IoT, BD, CC, CS, horizontal and vertical integration, Additive Manufacturing (AM), Augmented Reality (AR), Autonomous Robots and Simulation. This approach can be seen in detail on a literature review of Alcácer et al. [7].

The importance of I4.0 is clearly assumed around the world. The fourth industrial revolution is the essential path for the industrial sector competitiveness. Having this into account, it is obvious that companies who will not follow this trend are doomed to be erased from the industrial scenario.

2.1. Measuring with Readiness Models

I4.0 and its concepts can be difficult to understand. The I4.0 implementation process will be different for all companies. Therefore, it is necessary to analyze each one in particular to better define their objectives. The need to measure the progress and success as well as the need of comparisons with competitors is part of the industrial environments. Thus, in order to evaluate the I4.0 adoption, methodologies are needed to support companies. Assessment tools have been developed by academia and practitioners aiming the self-assessment within analytical frameworks to evaluate conditions or analyze it on an interactive form with the framework developers [22]. Several authors proposed models to address guidance and support on strategies and operations regarding I4.0 implementation. A model is an assessment tool and basically outcoming a formal description of a given system, e.g., an organization, a manufacturing system, a manufacturing process, or a machine.

Depending on the definition of the representation and application purpose, models can be descriptive (reproduction of some reality aspects), explanatory (casual connection relations are investigated to better understand the reality) or predictive (efficient solution suggestions to face the future reality). At the end, all model approaches depict the current state of a given system [23]. Models also can be used as a comparative purpose, enabling maturity benchmarking across companies by similar practices within different industries [24]. Maturity models are a subcategory of models, arising on the software development field, used on an enterprise' assess the quality of implemented processes. The Capability Maturity Model Integration (CMMI) or Software Process Improvement and Capability dEtermination (SPICE) are examples of these models [25]. The maturity of an enterprise is seen by Schumacher et al. [6] as the state of progression of internal and external conditions under the concepts of horizontal, vertical, and end-to-end engineering integration of I4.0 on manufacturing systems.

Commonly, maturity models are used to measure the maturity of a given system regarding to a specific target state. Maturity models captures the "as-it-is state" [6].

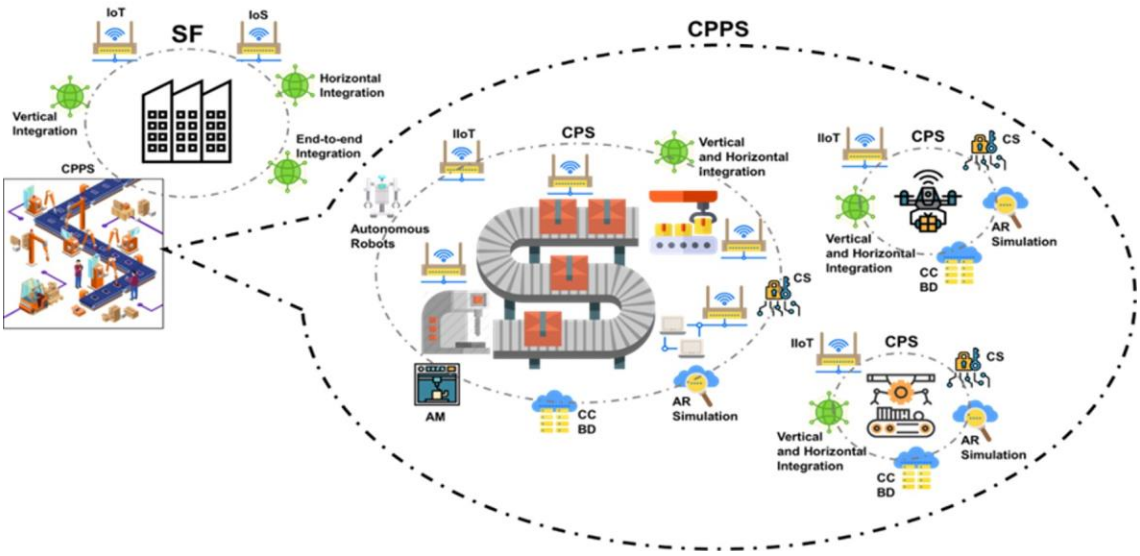


Fig. 2 The Development of the SF Concept.

Reaching a given maturity level is the foundation for the evolution to the next maturity higher level that can be planned and further implemented. Thus, the maturity models quantify activities and make them mature along time. To assess maturity systems through levels, maturity models are based on the idea of "state of being complete, prefect, or ready" and it can be addressed as qualitative or quantitative, in a discrete or continuous manner. As a close approach to maturity models, in order to assess readiness systems through levels, readiness models are based on the idea of "this is the starting point for", allowing the preparation for the development process of the measured given system. The "readiness" term induces a tendency for change in the given system. Readiness models intends to assess the state of the system before the engagement into the maturity transformation process [6]. Readiness models to assess I4.0 on companies are based on self-assessment mostly on the collection of information via internet surveys or via phone interviews [26].

Maturity and readiness models are mostly feeding by dimensions that represents thematic groups, constructed with numerical indicators, and extracted from the collected information from the given system [26]. As it can be seen on Table 1, some I4.0 maturity and readiness models were identified through a literature review, which will be described as follows.

Both "Industrie 4.0 Maturity Index" [28] and "Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises" [6] analyze more than six dimensions which makes them quite complete and may be a negative aspect as respondents need to have extensive knowledge about I4.0 technologies. “The Connected Enterprise Maturity Model” [29] and “Smart Manufacturing System Readiness Level (SMSRL)” [30] model has only four dimensions that includes technical aspects of I4.0 implementing, such as information technologies, but it does not consider aspects related to human resources and the strategy adopted by the company.

Tab. 1 Maturity and Readiness Models and Respective Dimensions.

Model	Dimensions	
IMPULS Industrie 4.0 Readiness [27]	• Strategy and Organization • Smart Factory • Smart Operations	• Smart Products • Data-Driven Services • Employees
Industrie 4.0 Maturity Index [28]	• Computerization • Connectivity • Visibility	• Transparency • Predictability • Adaptability
Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises [6]	• Strategy • Leadership • Customers • Products • Operations	• Culture • People • Governance • Technology
The Connected Enterprise Maturity Model [29]	• Information Infrastructure • Controls and Devices	• Networks • Security policies
Smart Manufacturing System Readiness Level (SMSRL) [30]	• Organizational Maturity • Information Technology Maturity	• Performance Maturity • Information Connectivity Maturity

After analyzing different maturity and readiness models on Table 1, the chosen model to be used on this research is the IMPULS [27] because it is based on well-defined dimensions, sub-dimensions, and their details, which greatly facilitates its application. Another reason for this choice was the existence of an online questionnaire of this model [31]. The questions from the IMPULS model were adapted regarding to the Portuguese reality.

This model was funded by the IMPULS Foundation of the German Engineering Federation (VDMA) and developed by the IW Consult and the Institute for Industrial Management at RWTH Aachen University. Other studies use this model, from dissertations [32–34], scientific articles [35–37] and by the Institute of Welding and Quality, with an online questionnaire available for companies to obtain a self-diagnosis of their I4.0 readiness level [38].

The IMPULS model consists of six dimensions that are represented on Table 2, as well as the sub-dimensions that were analyzed. The readiness score of each company was calculated using a weighted arithmetic mean, represented on Table 2. This percentages were discussed with companies in order to understand what their perception about the relative importance of each dimension was [6]. The readiness level on each dimension was attributed to companies based on the lowest score in any sub-dimension. For example, if on "Smart Products" dimension a company reaches a score of 5 on "ICT add-on functionalities" sub-dimension, and a score of 1 on "Use of Data" sub-dimension, then the final score of "Smart Products" dimension is readiness level 1. The company’s readiness level can be measured using a scale from 0 to 5, as seen in Table 3. These six levels can be grouped into three categories as: “newcomers” that describes companies that have adopted little or no I4.0 technologies, “learners” that characterizes the companies that have already taken the first measures to implement I4.0, and “leaders” that represents companies that have made various efforts to implement I4.0.

Tab. 2 Relative Dimension and Sub-dimension Weight. Adapted from [6].

Dimension	Weight (%)	Analyzed Sub-dimensions	
Strategy and Organization	25	• Degree of Strategy Implementation • Definition of Indicators	• Investments • Innovation Management
Smart Factory	14	• Equipment Infrastructure (current) • Equipment Infrastructure (target) • Digital Modeling	• Data Collection • Data Usage • IT Systems
Smart Operations	10	• System-integrated Information Sharing • Autonomously Guided Workpieces • Self-reacting Processes	• IT Security • Cloud Usage
Smart products	19	• ICT Add-on Functionalities	• Use of Data
Data-driven Services	14	• Data-driven Services • Share of Revenue	• Level of data Usage
Employees	18	• Employee Skills	

The I4.0 implementation is very important from a strategic point because it allows companies to develop entirely new business models. The "Smart Factory" dimension describes an intelligent, interconnected factory that can communicate directly with the Information Technologies (IT) systems. This can be achieved though the placement of sensors across the factory, including machinery and systems, on critical data collection points. This process can generate large quantities of data (Big Data) which may be a problem if the IT infrastructure is underdeveloped. Another possible barrier related to this dimension is the high investment cost. The dimension "Smart Operations" focuses on the integration of systems as a key element for horizontal and vertical integration of the value chain, which provides the potential to improve productivity, flexibility, and quality. This dimension is highly dependent on the collection, analysis, and usage of data of the highest resolution possible which is why IT security is so important. Smart products supply the data required for the data-driven services such as a predictive maintenance plan based on the usage level of the equipment. This "smart products" dimension includes the Information and Communication Technologies (ICT) add on functionalities that allow the data collection and whether the data is used or analyzed. Dimension "data-driven services" represents the paradigm shifting from selling products to providing solutions. This change grants companies the opportunity to upgrade their business models and direct their attention to enhance the benefit to their customers. Nowadays, manufacturers are moving past selling machinery and are creating a new business with the maintenance of said machinery. The combination of products and services increases the added value to the final customer. All the dimensions described so far are more focused on the technicalities of I4.0 but employees are the ones affected by the implementation of the I4.0 enabling technologies in their digital workplace. Dimension "employees" focuses on the skills and qualifications that companies require their employees to have.

2.2. Barriers to I4.0 Implementation

Despite the advantages associated with the I4.0 implementation, companies may not use the appropriate technologies for their company as there are some barriers that hinder its implementation. A 2014 study carried out by the World Economic Forum [39] on the implementation of IoT, concluded that, of all the identified barriers, the most important ones are the "lack of standards (difficult interoperability)" and "data security". Müller et al. [40] conducted a study on emerging technologies and their impact on business models. This study was carried out on Germany, in 2015, and focused on Small and Medium Enterprises (SMEs). About two thirds of participants consider that one of the most important barriers is the "high effort for coordination" in order to implement the enabling technologies. Some participants affirmed that the I4.0 implementation implies high costs that their customers are not willing to pay. Despite these barriers, some participants mentioned that they consider the I4.0 technologies implementation for fear of losing customers to more technologically advanced competing companies.

Tab. 3 Readiness Levels and Their Description. Adapted from [6].

Level		Description
Newcomers	0 (Outsider)	Companies that do not meet the necessary requirements and have done little to no planning for implementing I4.0.
	1 (Beginner)	Companies that have pilot initiatives related to I4.0 in some departments and investments in one of them. Just a few of the production processes are supported through IT systems, and the existing equipment infrastructure only partially fulfils the requirements for future integration and communications. IT security solutions are still in early planning or starting to be implemented.
Learners	2 (Intermediate)	Companies that integrate I4.0 in their strategic orientation and already has a developed method with the appropriate indicators to measure the implementation status. Some data is already being collected automatically and being used to a limited extent. Information sharing is integrated within the company and the first steps to integrate information sharing with business partners are being taken. Companies are already producing some items with initial IT-based add-on functionalities.
Leaders	3 (Experienced)	Companies that already have a I4.0 strategy developed with investments made in several departments. Data is being collected automatically in key areas and the IT systems in production are connected using interfaces to support the production processes. Information sharing is partially integrated to the system within the company and their business partners. The needed IT security solutions are already enabled, and cloud computing solutions are outlined to adapt to future expansion. Companies already provide items with IT-based add-on functionalities which are the basis for data-driven services that not yet integrated with their customers.
	4 (Expert)	Companies that are already using an I4.0 strategy and using the pertinent indicators to monitor its status. IT systems support most of the production processes and the data collected from them is used for optimization. Companies that are starting to adopt autonomously guided workpieces and self-reacting processes. The items provided by these companies have IT-based add-on functionalities that combine data collection and targeted analysis during the usage phase, which allows for data-driven services that feature direct integration between the customer and producer.
	5 (Top Performer)	Companies that have a well-defined I4.0 strategy and regularly monitor its implementation status. The requirements for integration and system-integrated communications are already satisfied. Information sharing systems are already fully integrated within the company and with its business partners. Exhaustive IT system support is implemented in production and automatically collects all the important data and autonomously guided workpieces, and self-reacting processes are already in use. Companies provide products with IT-based add-on functionalities that supplies data for data-driven services such as product development, remote maintenance, and sales support.

Stentoft et al. [41] conducted a study on I4.0 barriers and drivers on Denmark in 2018. The study focused on SMEs and identified three groups of barriers on a literature review: "economic / financial", "skills / resources" and “high effort for coordination”.

Müller conducted another study [42], in which he interviewed 68 German managers between May and June 2016. On this study, he concluded that the barriers that most participants mentioned was “lack of trust between business partners” due to the lack of “data security” and the “high effort for coordination”. Li et al. [43], Beqqal and Azizi [44] and Yang et al. [19] focused on barriers associated with the implementation of certain technologies associated with I4.0. Li et al. [43] identified barriers related to the implementation of IoT, focusing mainly on more technical aspects such as the “lack of standards” or the “concern with the reliability of systems”. Some barriers related to the implementation process were mentioned such as the “lack of an implementation methodology” and the “need to create new business models”. Beqqal and Azizi [44] mainly refer barriers related to technical aspects, as well as the legal aspect of data security in relation to Radio Frequency Identification (RFID) technology. Yang et al. [45] mentions the same categories of barriers, regarding BD and CC, and adds the need for large investments.

Türkes et al. [46] conducted a study, in 2018, in Romania in order to understand the perspective of SMEs about I4.0 barriers and drivers, using a survey where respondents expressed whether they agreed or disagreed with the presented barriers. The 176 companies that have participated were from areas such as: automotive, pharmaceutical, chemical, insurance or health. One of the objectives of the study was to understand which would be the barriers that companies could encounter when implementing the technologies associated with I4.0. All the six barriers used on the study of Türkes et al. [46] were considered important by the respondents. These barriers were: “lack of clarification of economic benefits”, “lack of technical knowledge”, “insufficient workforce”, “need for continuous formation”, “lack of regulations and procedures” and “high effort for coordination”.

As it can be seen on Table 4 the I4.0 implementation barriers can be divided into 6 categories [47]. Most studies focus on SMEs and do not target a specific technology.

Based on this list of barriers, it was elaborated a guide that served as support during the semi-structured interviews. In order to simplify this guide and not prolong the interviews for too long, not all barriers were selected. This selection considered the number of authors who referred each barrier, as showed on Table 4 in “Total” column, including the most referred barriers in each category. On regards to "implementation process" category, this logic was not directly applied, where the selected barrier was the second most referenced, as it would be better understood by companies. All the selected barriers can be seen on Table 22.

3. Research Methodology

The adopted methodology on this study was divided into two phases: first it was carried on a survey to measure the I4.0 readiness levels and, subsequently, a questionnaire to assess the perception that companies have about the barriers on the adoption of I4.0 enabling technologies. The framed research questions established for this study are:

Q1: What are the I4.0 readiness levels founded so far on an industrial cluster?

Q2: What is the perception of the barriers’ importance to implement I4.0?

To answer both research questions, the followed methodology used a survey according to the IMPULS model and each the company’s response was analyzed using an Excel document, coded to automatize the attribution of the readiness level for each dimension and respective sub-dimensions.

Based on the literature review it was formulated a questionnaire to better understand what the company’s perception is regarding to each barrier. Semi-structured interviews were conducted using a questionnaire as a guide.

Tab. 4 Main Barriers to I4.0 Implementation. Based on [47].

	Authors	**[41]**	**[46]**	**[39]**	**[40]**	**[42]**	**[43]**	**[44]**	**[45]**	
	Analyzed Technology	N/A	N/A	IoT	N/A	N/A	IoT	RFID	BD+CC	
Barriers	*Focus*	SME	SME	SME	SME	SME	N/A	N/A	N/A	***Total***
Economic / Financial	Need for large investments	T		E	E	E			T	**5**
	Lack of clarification of economic benefits	T	T	E						**3**
Cultural	Lack of support from top management			E						**1**
	Workers demotivation					E				**1**
Skills / Resources	Lack of employees' skills	T		E	E					**3**
	Lack of technical knowledge	T	T	E	E	E				**5**
	Insufficient workforce	T	T							**2**
	Need for continuous formation	T	T							**2**
Legal	Lack of regulation and procedures	T	T	E	E		T		T	**6**
	Concern about data security	T		E	E	E	T	T	T	**7**
Technical	Lack of standards (interoperability and compatibility)			E			T	T	T	**4**
	Concern with the reliability of systems						T		T	**2**
	Underdeveloped IT infrastructure			E			T	T	T	**4**
	Data Storage							T	T	**2**
	Underdeveloped technologies			E						**1**
Implementation Process	Need to create new business models			E		E	T			**3**
	Lack of an implementation methodology						T			**1**
	High effort for coordination	T	T		E	E				**4**

Note: T – Theoretical; E – Empirical; N/A – Not Applicable

3.1. Survey Methodology

In order to answer the first framed research question (Q1) a survey was conducted. A survey is described as "a systematic method for gathering information from (a sample of) entities for the purposes of constructing quantitative descriptors of the attributes of the larger population of which the entities are members" [48]. The steps followed on this phase were as showed in Figure 3.

Fig. 3 Survey Methodology Steps.

The first step was the identification of the objectives and definition of the sample. This study is focused on companies located in Portugal, more specifically on Setúbal peninsula, which has an area of 1 421 km² and covers nine counties, where 782 044 people live. There are 27 788 companies registered across the 9 counties on the Setúbal peninsula.

According to "*Directório Empresas Portugal*" [49], companies on Setúbal peninsula mainly have an activity area of "wholesale and retail trade, repair of motor vehicles and motorcycles". A company can have more than one activity area, one being the primary and the other the secondary, Table 5 does not make this distinction, since both are accounted for.

Tab. 5 Activity Area of Companies on Setubal Peninsula. Adapted from [49].

Activity Area	%
Wholesale and retail trade, repair of motor vehicles and motorcycles	31,0
Construction	15,6
Accommodation, catering and similar	9,5
Manufacturing industries	8,4
Other service activities	5,2
Consulting, scientific, technical, and similar activities	4,9
Real estate activities	4,2
Agriculture, animal production, hunting, forestry, and fishing	4,1
Administrative and support service activities	4,0
Transport and storage	3,0
Human health and social support activities	2,8
Artistic, show, sports and recreational activities	2,1
Information and communication activities	1,7
Financial and insurance activities	1,7
Education	1,2
Water collection, treatment, and distribution; sanitation, waste management and remediation	0,20
Public administration and defense; social security	0,14
Extractive industries	0,11
Electricity, gas, steam, hot and cold water and cold air	0,055
Activities of international organizations and other extraterritorial institutions	0,0024
Activities of households employing domestic staff and production activities of households for own use	0,0012

The target population considered on this study were companies associated to an industry association located in Setúbal peninsula named as AISET – "*Associação da Indústria da Península de Setúbal*" [50]. Currently, AISET is considered a national reference and an active voice not only on the region, but also in Portugal. Since December 2014, this association aims to combat the lack of representativeness of industrial companies on Setúbal peninsula [50]. The choice to partnership with AISET was based on the fact that some associated companies operate together and form value chains, leading to the creation of synergies among themselves which leads to the development of the ecosystem itself. The partnership with AISET on this study enhances the possibility of comparing the readiness levels between the companies involved on the same value chain.

AISET is an association with 55 very diverse members, from large companies (with more than 3 500 employees) to micro companies (with only two employees) [50]. The distribution of members, according to their activity area is shown in Table 6. The activity area of most companies is the manufacturing industry, followed by education area. These two activities represent more than half of AISET members.

Tab. 6 Activity Area of AISET Member Companies [50].

Activity Area	%
Manufacturing industries	43,6
Education	10,9
Water collection, treatment, and distribution; sanitation, waste management and remediation	9,1
Wholesale and retail trade, repair of motor vehicles and motorcycles	9,1
Consulting, scientific, technical, and similar activities	9,1
Transport and storage	7,3
Real estate activities	3,6
Administrative and support service activities	1,8
Information communication activities	1,8
Construction	1,8
Other service activities	1,8

This study makes use of a sample and therefore, there are associated errors present. One of them is the sampling error. This type of error is statistically well understood and is related to the sample size [51]. A sampling error can be summarized as the fact that the chosen sample is not representative of the population. To decrease this error, it is necessary to randomly choose a sample as large as possible [52]. The measurement error occurs when the answers are imprecise and differ from the "true" value [51]. Finally, the nonresponse error, which, as the name implies, refers to the lack of response from some respondents [51]. To reduce this error, follow-up procedures can be scheduled or elaborate an intuitive questionnaire with a simple design [52].

On the first step, the "Mapping the Adoption of Industry 4.0 Technologies in the Setúbal Peninsula" survey was adapted, as a part of the "Driving Industry 4.0" project [53]. The survey was conducted using the LimeSurvey software, with the questions from the IMPULS model.

The next step was collecting survey data that was initially made and available to companies on the beginning of July 2020. Under the General Data Protection Regulation (GDPR), AISET contacted its associates in order to identify which ones would be interested on participating on this study. As companies are protected by GDPR, it is not possible to identify them, having been assigned a number to each one. After this collection, 17 companies accepted to participate in the study, representing 30,9% of the associates.

Due to the Covid-19 pandemic, the first contact was made by email and only two companies have responded to entire survey. Since the response rate was insufficient (11,8%), it was necessary to send the survey a second time. This second contact was made on the first half of September 2020. Some companies were contacted by email, but the phone contact was more efficient in order to request the survey conclusion. On this phase, 13 responses were collected, adding to a total of 15 and, thus obtaining a response rate of 88,2%. After compiling all the answers, it was necessary to organize and analyze them. For this purpose, an Excel document was coded to carry out a statistical analysis. Based on this document, conclusions were drawn on the final step of this methodology.

3.2. Identification of Barriers to I4.0 Implementation

To answer the second framed research question established for this study (Q2), the methodology used to identify some barriers on the I4.0 enabling technologies adoption is similar to the one used by Türkes et al. [46], where only six barriers were selected through a literature review and the resulting survey was sent via email to the selected companies.

To generalize the obtained conclusions, it was necessary to choose more than one case to analyze. The selection of cases represents an opportunity, allowing a better understanding of the cases and provides a holistic view of them [54]. It is necessary to consider the available resources to expand the investigation and cover as many cases as possible. The choice of a small number of case studies may impact the quality of the results obtained and the ability to generalize them, as an unrepresentative sample of case studies can result in unreliable conclusions [54].

The methodology chosen for this study was the polar type method, selecting companies that were on extreme and opposite situations, this is the companies that obtained a maximum and minimum readiness level on the first research step. This approach makes possible to identify contrasting patterns [55]. This selection method was used due to the limited number of responses to better represent the population [56].

Using the methodology described and to ensure that responses from both extremes existed, two companies were selected from each extreme. After the selection, respondents from companies were contacted and, due to the Covid-19 pandemic situation, it was not possible to schedule in-person meetings. Therefore, and to reduce possible errors while filling out the questionnaire, it was decided to conduct these interviews by phone. Before the interview took place, the questionnaire was sent to the four companies by email, on the 23rd of October 2020. The mentioned barriers on the questionnaire were discussed during these interviews to understand which ones were considered most important and whether there were any other relevant barriers beyond those already listed. Each interview lasted approximately thirty minutes.

4. Results and Discussion

All readiness levels mentioned on this section are between 0 and 5, using the criteria defined on Table 3. The best readiness level for a company is readiness level 5, which represents a “top performer” company and belongs to “leaders” category, which also includes readiness level 3 as “experienced” and readiness level 4 as “expert” companies. A company classified as readiness level 2 is called “intermediate” and belongs to “learners” category. Finally, companies that reach readiness level 0 as “outsider” or readiness level 1 as “beginner” belong to the “newcomers” category.

The last part of this section is focused on the impacts of the current pandemic scenario. Some companies took it as a chance for implementing new technologies in order to ease remote working and others viewed it as a barrier to new investments due to the decrease of its turnover.

4.1. Survey Answers

The online survey was sent and analyzed according to the methodology proposed by Lichtblau et al. [27]. This survey was completed autonomously, and the answers are a company’s self-assessment. Help was offered to the companies for answering the survey in order to decrease the possibility of answers that deviated from the companies’ reality. Although the help was offered there is still a possibility that the answers do not depict their reality due to lack of knowledge of the I4.0 thematic. Each company of this survey was numbered from 1 to 17. Since companies 3 and 14 did not answer to this survey, these companies will not be referred on this analysis.

4.1.1. Characterization of Companies

The 15 surveyed companies can be classified according to the number of employees and business volume, and accordingly classified as micro, small, medium, or large companies. The companies' characterization regarding their business volume is represented on Figure 4. According to the established parameters on Table 7, only one company is defined as micro, four companies as medium and large and small companies are in equal number, five of each. This distribution can be seen on Figure 5.

Fig. 4 Characterization of Companies According to Their Business Volume.

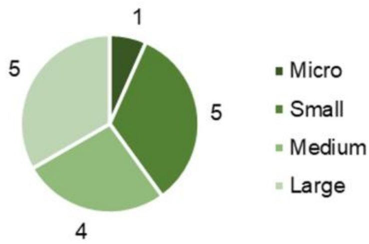


Fig. 5 Characterization of Companies According to Their Dimension.

Tab. 7 Criteria to Characterize the Dimension of Companies.

Number of Employees	Business Volume	Classification
Up to 9 employees	Less than 2 million euros	Micro
Between 10 and 49 employees	Between 2 and 10 million euros	Small
Between 10 and 49 employees	Between 2 and 10 million euros	Small
Between 50 and 249 employees	Between 10 and 50 million euros	Medium
Between 50 and 249 employees	Between 2 and 10 million euros	Medium
Between 50 and 249 employees	More than 50 million euros	Large
250 employees or more	More than 50 million euros	Large

Another way to characterize companies is through the activity area. Most respondents belong to the manufacturing industry, as can be seen on Figure 6.

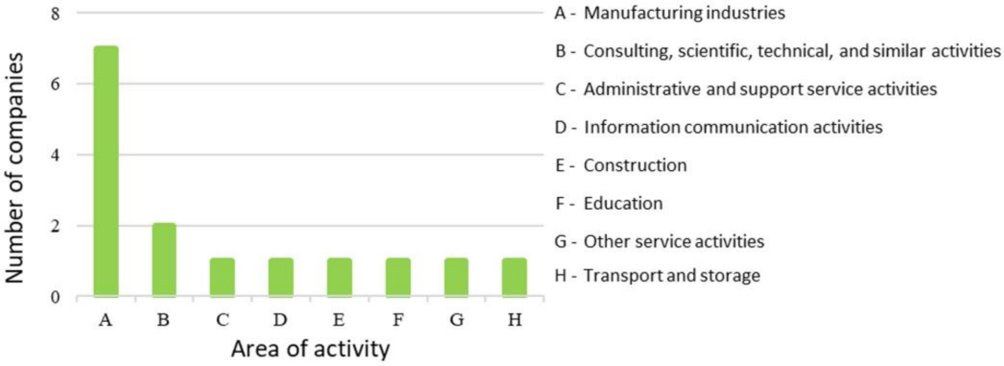


Fig. 6 Characterization of Companies According to Their Activity Area.

4.1.2. Overall Sample Results

The answers obtained through the survey can be grouped according to the readiness level, as seen on Table 8. Only "Employees" dimension has no companies with a readiness level 0 or 1, and, along with "Smart Products" dimension, are the only dimensions with companies in readiness level 5.

Tab. 8 Number of Companies in Each Readiness Level According to the Dimensions.

Readiness level		Strategy and organization	Smart factory	Smart oper-ations	Smart products	Data-driven services	Employees
0	Outsider	7	8	1	9	11	0
1	Beginner	2	5	2	3	1	0
2	Intermediate	1	2	4	1	3	2
3	Experienced	2	0	6	0	0	4
4	Expert	3	0	2	0	0	8
5	Top performer	0	0	0	2	0	1

Table 9 shows the average readiness level obtained on each sub-dimension. The lowest average was readiness level 0,6 and was obtained on "Level of Data Usage" sub-dimension on "Data-driven Services" dimension. The highest average was readiness level 4,2 and was obtained on "Cloud Usage" sub-dimension which belongs to "Smart Operations" dimension.

Each dimension will be analyzed in more detailed on next sections, based on Table 8 and Table 9.

Figure 7 shows that on four out of six analyzed dimensions, there are no companies reaching the highest readiness level: "Strategy and Organization", "Smart Factory", "Smart Operations", and "Data-driven Services". Only "Employees" dimension is reach by companies achieving readiness levels exclusively above readiness level 1.

As described previously, companies can be grouped according to their readiness level into three categories. Companies categorized as "Newcomers" (readiness level 0 and 1) represent 53,3% of the sample. About 26,7% of the sample belongs to "Learners" category (readiness level 2) and the remaining 20% belong to "Leaders" group (readiness level 3, 4 and 5). On "Leaders" group, there are no companies with readiness level 4 (Expert) or readiness level 5 (Top Performer), with the maximum readiness level being seen by companies as a long-term objective.

Through the analysis of Figure 8, it is possible to conclude that only less than 20% of companies do not use any technology from those mentioned on the survey and more than 70% already use sensors, which is the most used technology.

Tab. 9 Average Readiness Level on Each Sub-dimension.

Dimension	Sub-dimension	Average Level
Strategy and Organization	Degree of Strategy Implementation	1,7
	Definition of Indicators	2,8
	Investment	2,8
	Innovation Management	3,4
Smart Factory	Equipment Infrastructure (current)	2,1
	Equipment Infrastructure (target)	1,4
	Digital Modeling	2,2
	Data Collection	2,3
	Data Usage	1,8
	IT Systems	1,7
Smart Operations	System-integrated Information Sharing	3,3
	Autonomously Guided Workpieces	3,4
	Self-reacting Processes	3,9
	IT Security	4,1
	Cloud Usage	4,2
Smart Products	ICT add-on Functionalities	1,7
	Use of Data	2,1
Data-driven Services	Data-driven Services	0,9
	Level of Data Usage	0,6
Employees	Employee Skills	3,5

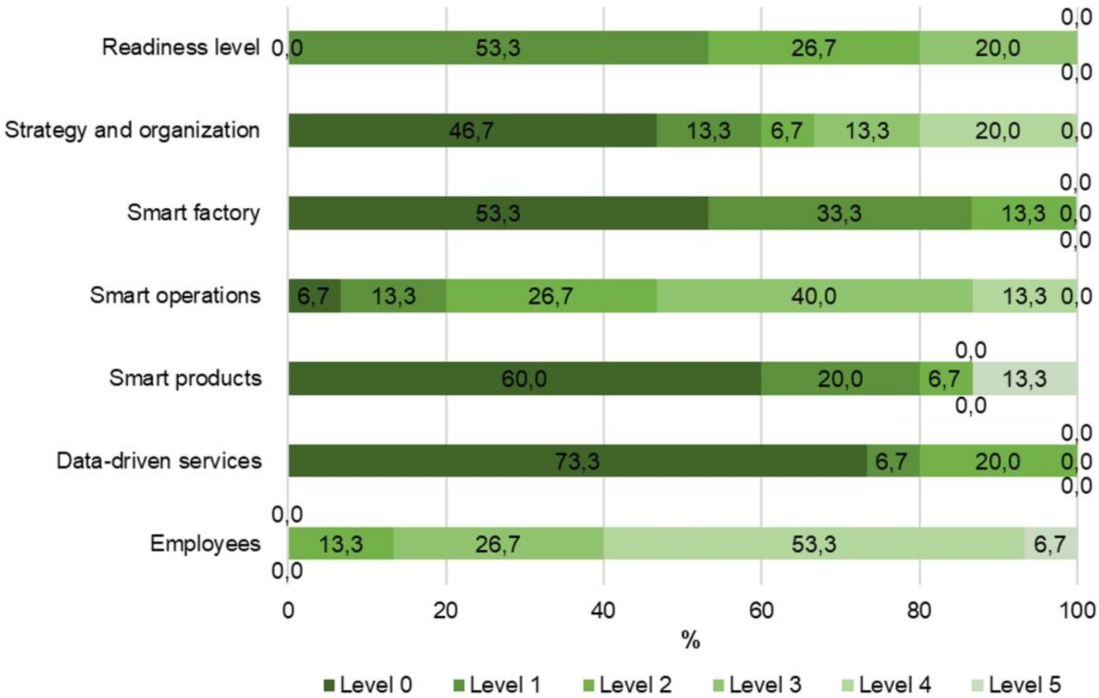


Fig. 7 Readiness Level Distribution on Different Dimensions.

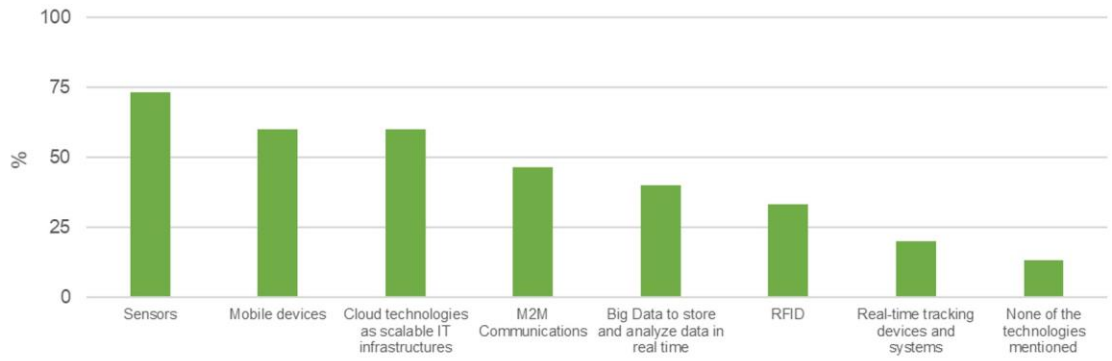


Fig. 8 Used Technologies by Surveyed Companies.

By looking at Figure 9, it can be seen that more than half of the companies (60%) obtained a readiness level below the average. There is a discrepancy of 2,71 between the readiness level of the company with the highest and lowest rating, with no apparent relationship between the rating and the size or activity area of the companies.

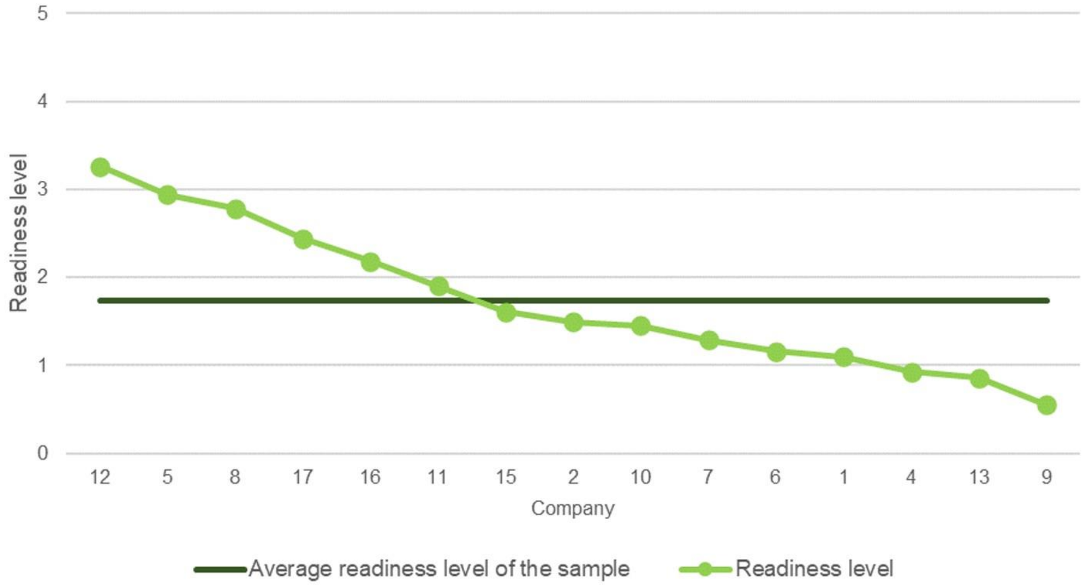


Fig. 9 Distribution of Companies' Readiness Level and Comparison with Sample's Average Readiness Level.

Depending on the product or service type offered by each company, it may be difficult to introduce certain I4.0 technologies, which may negatively impact their readiness level. For example, on "Smart Factory" dimension there are companies obtaining the minimum level on a sub-dimension because it is not a concept that can be applied on their reality in which they are inserted. For example, a company that manufactures electronic-based products and equipment will find it easier to use digital modelling than a transport and storage company. Using this example, and according to Lichtblau et al. [27], this dimension has a weight of 14% on the final readiness level. If a company reaches the maximum readiness level on all other dimensions and the minimum readiness level on this dimension (readiness level 1), it will have a maximum readiness level of 4,44, which translates to a final readiness level of 4.

On average, companies reached a readiness level of 1,73, which is a relatively low readiness level value, despite being higher when compared with the readiness value obtained by Lichtblau et al. [27]. This difference can be explained by the characterization of the chosen sample of companies. Lichtblau et al. [27] conducted the study exclusively with companies with more than twenty employees located across Germany, focusing on manufacturing companies. The chosen sample on this study includes companies of different sizes and does not include exclusively companies on manufacturing sector. Companies represented on decreasing order on Table 10 are the companies with highest and lowest readiness levels.

Tab. 10 Companies with highest and lowest readiness levels.

Company	Activity Area	Employees	Business volume	Dimension	Readiness Level	Final Readiness Level
12	Information and communication activities	10 to 49	Less than 2 million euros	Small	3,26	3
5	Manufacturing industries	More than 250	More than 50 million euros	Large	2,94	3
13	Manufacturing industries	50 to 249	More than 50 million euros	Large	0,86	1
9	Manufacturing industries	10 to 49	Less than 2 million euros	Small	0,55	1

Figure 10 shows readiness level of two companies with the highest and two companies with the lowest readiness level achieved in the different sub-dimensions and its comparison with sample' average level.

4.1.3. Analysis of "Strategy and Organization" Dimension

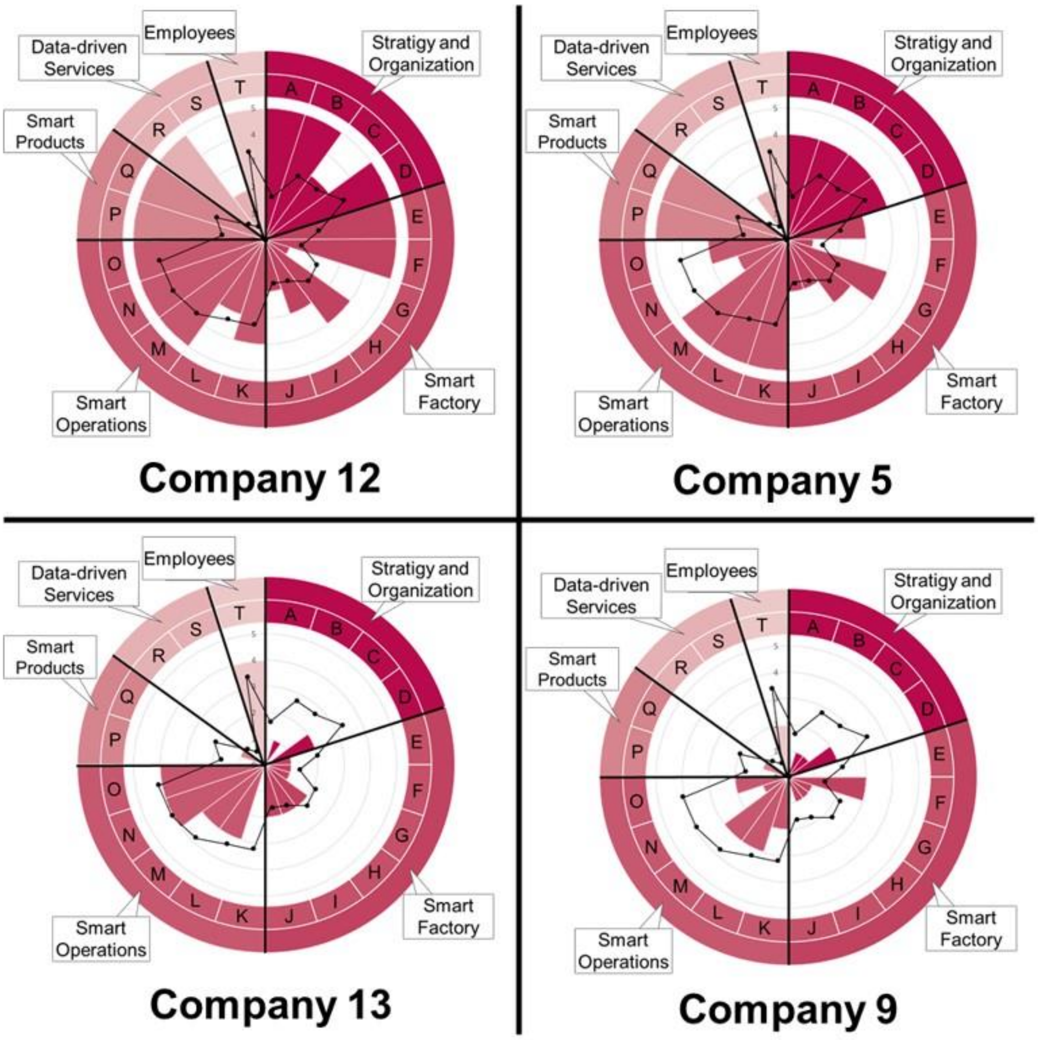
The average readiness level obtained was 1,5 on the corresponded scale from readiness level 0 to 5. Thus, 46,7% of companies obtained a readiness level 0, which means that they are considered "Outsiders" because they do not reach the necessary requirements. On this dimension, no company reached readiness level 5.

One aspect that may contribute to such a low average readiness level is the fact that almost half of the respondents (46,7%) have no I4.0 strategy implemented or under development. As shown in Table 9, the sub-dimension that has the lowest average level is "Degree of Strategy Implementation", and the sub-dimension with the highest average level was "Innovation Management", on which the readiness level most often obtained by companies was readiness level 3, which means that there is only innovation management in one company area.

The three companies that obtained the highest readiness level 4 on this dimension are the companies 5, 8 and 17. Companies 5 and 8 have a similar characterization, whose activity area belongs to manufacturing industries and are considered large companies, with a business volume of more than € 50 million and more than 250 employees. Company 17 has a very different characterization with an activity area of construction and is considered a small company, with a business volume of less than € 2 million and a number of employees between 10 and 49.

4.1.4. Analysis of "Smart Factory" Dimension

On this dimension, companies obtained an average readiness level of 0,6 on the corresponded scale from level 0 to 5, with the most common value of readiness level 0 (53,3% of respondents), as can be seen in Table 8. A company that has a readiness level 0 on this dimension means that it has not met the necessary requirements.



Subtitle:

A – Degree of Strategy Implementation
B – Definition of Indicators
C – Investments
D – Innovation Management
E – Equipment Infrastructure (current)
F – Equipment Infrastructure (target)
G – Digital Modelling
I – Data Collection
J – Data Usage
K – System-integrated Information Sharing
L – Autonomously Guided Workpieces
M – Self-reacting Processes
N – IT Security
O – Cloud Usage
P – ICT add-on Functionalities
Q – Use of Data
R – Data-driven Services
S – Level of Data Usage
T – Employee Skills
–•– – Average Readiness Level

Fig. 10 Comparison of Obtained Readiness Levels on Dimensions and its Sub-dimensions for Best and Worst Performers.

Table 9 shows that sub-dimension with the lowest average readiness level is “Equipment Infrastructures (target)”, in which seven respondents obtained readiness level 0, that is, 46,7% of the companies report their systems and machines cannot be updated. The sub-dimension with the highest average readiness level is “Data Collection”, in which 40,0% of companies answered that they do not collect data from machines and processes.

Through the surveyed questions it was not possible to apply directly the criteria described on the IMPULS model. After the adaptation, the level of “Data Usage” sub-dimension has a maximum assigned as readiness level 3, which could decrease the final readiness level of each company on this dimension. This limitation does not exist on this sample since all respondents had obtained a lower readiness level on at least one other sub-dimension. As an example, company 5 is displayed on Table 11, which is not affected by this limitation as it has a lower readiness level on sub-dimension “Equipment Infrastructure (target)”.

Tab. 11 Obtained Readiness Levels by Company 5 on "Smart Factory" Dimension.

Company	Equipment Infrastructure (current)	Equipment Infrastructure (target)	Digital Modeling	Data Collection	Data Usage	IT Systems
5	3	1	4	3	2	2

The two companies that obtained the readiness level 2 on this dimension were companies 8 and 11. Company 8 is a large company and has an activity area of manufacturing industries. Company 11 is considered medium size and belongs to the activity area of consultancy, scientific, technical, and similar activities.

4.1.5. Analysis of “Smart Operations” Dimension

On this dimension, companies obtained an average readiness level 2 on the corresponded scale from level 0 to 5. Only one company obtained readiness level 0, most companies (40,0%) obtaining readiness level 3 and none achieving readiness level 5, as shown in Table 8. A company at readiness level 3 is considered experienced and it can be said that there are initial solutions for CC, data storage and data analysis, it already has IT security solutions partially implemented and there are some information sharing systems.

As it can be seen on Table 9, the sub-dimension where companies obtained, on average, a lower readiness level was “System-integrated Information Sharing”, where most companies obtained readiness level 5, which means that these companies have integrated sharing information systems between departments on all areas and between customers and suppliers in more than five areas. The sub-dimension on which most companies obtained a higher average readiness level was “Cloud Usage”, where only two companies do not use CC, one of which is planning on starting to use it. On this sub-dimension, most respondents reached readiness level 4, stating that there is some use of CC services on the company.

Most companies (80,0%) do not use autonomously guided workpieces, 53,3% do not have self-reacting processes and 53,3% of the companies have implemented all IT security solutions mentioned on the survey.

Companies that obtained readiness level 4 on this dimension were the same ones that obtained the highest readiness level on the previous dimension (company 8 and 11).

4.1.6. Analysis of “Smart Products” Dimension

On this dimension, companies obtained an average readiness level 1 on the corresponded scale from level 0 to 5. As it can be seen on Table 8, most companies (60,0%) obtained a readiness level 0, being placed on “outsider” category because they do not meet the necessary requirements.

As showed on Table 9, the sub-dimension on which companies reached the highest readiness level on average was “Use of Data”. Despite having a higher level than the other sub-dimension (ICT add-on Functionalities), it is still a low value due to the lack of data analyzed during the usage phase, being that ten companies (66,7%) do not collect or analyze them, which represents a readiness level 1 on this sub-dimension.

The two companies that have reached the maximum readiness level on this dimension, companies 5 and 12 have different activity areas and sizes. Company 5 has already been described on section 4.1.3. Company 12 is considered small because it has between 10 to 49 employees and its business volume does not exceed € 2 million. This company belongs to the information and communication activity area.

4.1.7. Analysis of "Data-driven Services" Dimension

On this dimension, companies obtained an average readiness level 0,5 on the corresponded scale from level 0 to 5. As it can be seen on Table 8, the most frequently readiness level assigned was readiness level 0, which means that these companies do not meet the necessary requirements.

The most frequently assigned value on "data-driven services" sub-dimension was readiness level 0, as showed on Table 9, which leads to a low average value. A company on readiness level 0 does not provide data-driven services, which may be due to their activity area. Some companies may integrate data-driven services in an easier way due to the product or service type they offer. For instance, a company that offers electronic-based products and equipment will find it easier to introduce a data-driven service than an ink manufacturing company.

Through the surveyed questions it was not possible to obtain the readiness level of "Share of Revenues" sub-dimension thus, this sub-dimension was not considered. On this study it was not possible to apply directly the methodology proposed by the IMPULS model. According to the suppression of "Share of Revenues" sub-dimension, the "Level of Data Usage" sub-dimension reached a maximum of readiness level 2. This limitation affects four companies that have a higher level on the other sub-dimension, as it can be seen on Table 12.

Tab. 12 Companies Affected by the Limitation Imposed on "Level of Data Usage" sub-dimension.

Company	Data-driven Services	Level of Data Usage
2	3	1
8	3	2
12	5	2
17	3	2

The maximum level reached on this dimension was readiness level 2 and only three companies (8, 12 and 17) reached it, all of which were affected by the limitation described above. Throughout section 4.1 these companies were characterized. The only common factor is the size of companies 12 and 17, both considered small.

4.1.8. Analysis of "Employees" Dimension

On this dimension, companies obtained an average readiness level of 3,5 on the corresponded scale from level 0 to 5. This was the dimension that obtained the highest average readiness level which is justified by the fact that no company obtained a readiness level 1 or lower and the most frequent value was readiness level 4, as Table 8 shows. The eight companies (53,3%) on readiness level 4 fall into "Expert" category which means that they consider that their employees have the adequate qualifications on most of relevant areas.

Only company 12 reached the maximum of readiness level 5 on this dimension.

4.2. Results of Identifying the Barriers to I4.0 Implementation

Based on the surveyed companies' readiness level, the four companies represented on Figure 10 were selected to carry out the second phase of this study.

Based on the barriers to I4.0 implementation present on Table 4 and using the criteria described on section 2.2., it was elaborated a questionnaire to serve as guide during the semi-structured interviews. This questionnaire contained the barriers displayed on Table 13 and the respondents had to evaluate their importance by attributing a number between 1 and 5, meaning 1 being not important and 5 being extremely important. The general perception of each barrier's importance was obtained by adding the importance values that each company attributed. The sum of the importance values is represented on the "Total" column of Table 13 and the higher the total the more important the barrier was considered.

Tab. 13 Perception of the Barrier's Importance on I4.0 Implementation.

	Company				
Barrier	**12**	**5**	**13**	**9**	**Total**
Need for large investments	4	3	4	3	14
Lack of clarification of economic benefits	4	5	2	5	16
Lack of support from top management	2	2	5	5	14
Demotivation of workers	3	2	2	5	12
Lack of employees' skills	4	2	4	5	15
Lack of technical knowledge	4	2	4	4	14
Lack of regulation and procedures	4	2	1	3	10
Concern about data security	5	2	1	4	12
Lack of standards (interoperability and compatibility)	4	5	2	5	16
Concern with the reliability of systems	3	4	4	4	15
Underdeveloped IT infrastructure	5	3	4	4	16
Need to create new business models	2	2	4	3	11

Both companies with a lower readiness level considered that one of the most important barriers is "lack of support from top management". This barrier is not related to the size of these companies as one is large and the other small. Company 9 (small) also states that "lack of employees' skills" is a very important barrier, which is on agreement with the readiness level obtained on the dimension "Employees" being lower than the average of the AISET associates. Company 13 considers "lack of employees' skills" an important barrier, despite having a higher readiness level than average readiness level on this dimension.

Regarding the "Lack of support from top management" barrier, there is a clear distinction between companies with a higher and lower readiness level. The same is not true on any other category. Barriers that companies perceive to be the most important are "Lack of clarification of economic benefits", "Lack of standards (interoperability and compatibility)" and "Underdeveloped IT infrastructures". During the interviews, other barriers that companies consider to be important were mentioned.

Company 12 is a business solutions provider through software development, which allows them to have both the company's point of view as well as the customers' point of view. The respondent from company 12 affirmed that it is necessary to invest on the implementation of I4.0 enabling technologies, but that this will not be the biggest barrier. Also believes that the biggest barrier to I4.0 implementation on companies is "Underdeveloped IT infrastructures". The respondent of company 12 also add that the vision of companies is short-term and, therefore, there is no well-defined long-term strategy.

Unlike company 12, the respondent of company 5 does not consider that "Underdeveloped IT infrastructures" barrier is a very important barrier. It was mention that Return of Investment (RoI) analysis is used to understand the economic benefits. This RoI analysis makes it possible to analyze “Need for large investments” and “Lack of clarification of economic benefits” barriers together. Despite emphasizing the importance of “Concern about data security” barrier, the respondent of company 5 do not consider it to be a very important barrier. This concern implies that employees of company 5 are not allowed to use clouds, although there is already data that is collected into a private cloud, but it is only on experimental stage. It was also mentioned by the respondent of company 5 that another barrier not specified on the questionnaire is “Delay on allocation of public funds”, which are a great help on I4.0 implementation regarding its enabling technologies.

The respondent of company 13 considers “Lack of support from top management” barrier the most important, adding that this barrier would be equally important on any area because if there is no support from top management, it is quite difficult to introduce new concepts. Also considers “concern about data security” and “lack of regulations and procedures” as minor barriers. The respondent of company 13 affirms that there is no effective dissemination of the theme of I4.0 among potential users (companies).

The respondent of company 9 states that the concept of I4.0 is not clear and, therefore, there should be a certified entity that could perform a diagnosis helping companies on their digital transformation. This company has a clear perception of the need for innovation and the importance of constant evolution on a competitive market. The respondent of company 9 owns two other companies, one of which is being created incorporating some I4.0 enabling technologies.

4.3. Impact of the Covid-19 Pandemic

On the last group of this survey was included a question to understand how the current pandemic scenario has influenced companies on the use of I4.0 enabling technologies and how will they be used on the future.

Eight companies affirmed that this pandemic has had little to no impact. The tools that allow collaborative work already existed and it was only necessary to learn how to get the best out of what was already implemented.

Due to the decrease on turnover, four companies mention that they had to freeze or postpone planned investments. The uncertainty associated with the pandemic scenario is also a factor that led to the cancellation or postponement of new projects.

Company 2, in addition to intensifying the use of communication and online meeting software, also began to develop products to support the fight against Covid-19 pandemic. The development of these products will be continuing on in accordance with the market´s necessity, and company 2 is contemplating the possibility of continuing developing other products. The respondent of company 16 also claims that the pandemic had created an opportunity to develop some technologies. This company accelerated the use of analysis and remote assistance to its customers.

An interesting point is the respondent of company 17 mentioning the Covid-19 pandemic impact so far has been none. Company 17 has not stopped activity and even developed the following actions that they consider to be of a very significant relevance, as follows:

1) Fully implementation of an IT structure integrated among all resources (hybrid solution);
2) Implementation of an entirely new installation based on an integration perspective;
3) And a full-time contract of five hired new employees.

5. Conclusions

The I4.0 implementation is based on the adoption of advanced information and communication technologies, in order to increase the companies’ efficiency and effectiveness. The interest on these technologies has been increasing in recent years [4]. Some experts estimate that the progress of I4.0 will boost the industry allowing to meet the increasingly demanding requirements of its customers and thus preserve its competitive advantage [8]. Despite the advantages associated with its implementation, companies may not use as many technologies as there are some barriers that hinder their implementation. These barriers can be divided into six categories as: “economic / financial”, “cultural”, “skills / resources”, “legal”, “technical” and “implementation process”.

To assess the readiness levels founded so far on Setúbal peninsula companies, regarding the I40. enabling technologies, a survey was sent to AISET members, developing synergies among them, and promoting their ability for digital transformation. Through "Mapping the Adoption of Technologies for Industry 4.0 on Setúbal Peninsula" survey it was possible to conclude that the responding companies have an average readiness level of 1,73, with the most frequently attributed readiness level 1. A company inserted on this readiness level is part of “Newcomers” category and it is considered that it is involved on I4.0 through pilot initiatives on several departments, has investments on a single area, and IT security solutions are still on the planning or implementation phase.

On this study, companies that are not AISET members were excluded, that is, it is not a representative sample of Setúbal peninsula. The discrepancy between the readiness level of the company with the highest and lowest readiness level is 2,71 and most companies (60%) are below the average readiness level of the sample. One of the factors that can negatively impact the readiness level of companies is the type of products or services that companies offer.

To assess what is the perception of the barriers’ importance to implement I4.0, semi-structured interviews were conducted among the four selected companies to understand what the most important barriers from the companies’ perspective. It was concluded that the barriers considered most important were: “Lack of clarification of economic benefits”, “Lack of standards (interoperability and compatibility)”, and “Underdeveloped IT infrastructure”.

The surveyed question related to the impact of the Covid-19 pandemic shows that more than half of the companies in the sample, 53,3% affirm that the necessary tools for working remotely already existed, being only necessary to learn how to make the best of them. On the opposite direction, four companies reported that the pandemic scenario has negatively affected their turnover, which has led to a freeze on I4.0 investments. Only one company claims that they were not affected, and all previously planned actions were implemented. One of the companies started to use communication software for remote working more often and claims that changed its production in order to develop products to support the fight against Covid-19 pandemic.

It should be noted on this study that the sample size is quite small. The sample was taken from a companies’ population located on Setúbal peninsula. Only AISET associates were selected, of which it was only possible to contact seventeen and obtain a total of fifteen responses. It was not possible to divide this sample into different categories according to their activity area because the number of companies in each group would be very different, some with almost half of all companies and some with just one company. On the second phase, the sample size was also small with only four companies. In addition to sample sizes, another limitation of this study is that IMPULS model was developed for the industrial sector and this study include companies from other sectors such as education. This difference could bias results on this survey.

As a recommendation for future research, a new assessment of companies' readiness level is suggested to evaluate the impact of the Covid-19 pandemic on I4.0 enabling technologies adoption. On the one hand, companies may have postponed the implementation of some I4.0 enabling technologies due to lack of financial resources, human resources or even lack of time. On the other hand, companies may have been driven to consider new ways of manufacturing with less human resources due to the increase on remote work. Knowing that the most affected companies by this crisis associated with the Covid-19 pandemic are SMEs [57] and that 66,7% of respondents on this study belong to this category, it would be interesting to see if this trend is verified with these companies and understand its impact.

Some AISET member companies operate together, forming value chains and creating synergies with each other. An opportunity created through the partnership with AISET would be to compare the readiness levels between the companies involved in the same value chain. It was not possible to achieve this goal because AISET member companies that were available to be surveyed unfortunately do not form value chains.

One of the mentioned barriers by the surveyed companies is the “Lack of clarification of economic benefits” and some add that they would be interested in being assessed in this area by an accredited entity.

On this way, it would be beneficial to conduct a study on the added value, not only economic but also competitive, of I4.0 enabling technologies adoption.

Ethical Approval

All surveyed participants have given their consents to participate on this study under the General Data Protection Regulation (GDPR).

Consent to Participate

All surveyed participants have agreed on participating and they have understood the aim of the project. All participants have given their consents to use surveyed data on this study on an anonymous manner. All surveyed participants as protected under the General Data Protection Regulation (GDPR).

Consent to Publish

All authors give their consent for the publication of the manuscript, which include all its details such as figures, tables, or all relevant information to be published on The International Journal of Advanced Manufacturing Technology.

Authors Contributions

Vítor Alcácer designed, coordinate this study, Carolina Rodrigues drafted the manuscript, Helena Carvalho supervised and revised the manuscript, and Virgílio Cruz-Machado supervised the project and the manuscript. All authors read and approved the manuscript.

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Competing Interests

The authors declare they have no competing interests.

Availability of data and materials

All datasets and datasheets used to support the discussion and conclusions on this study are available upon request to the corresponding author.

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Figures

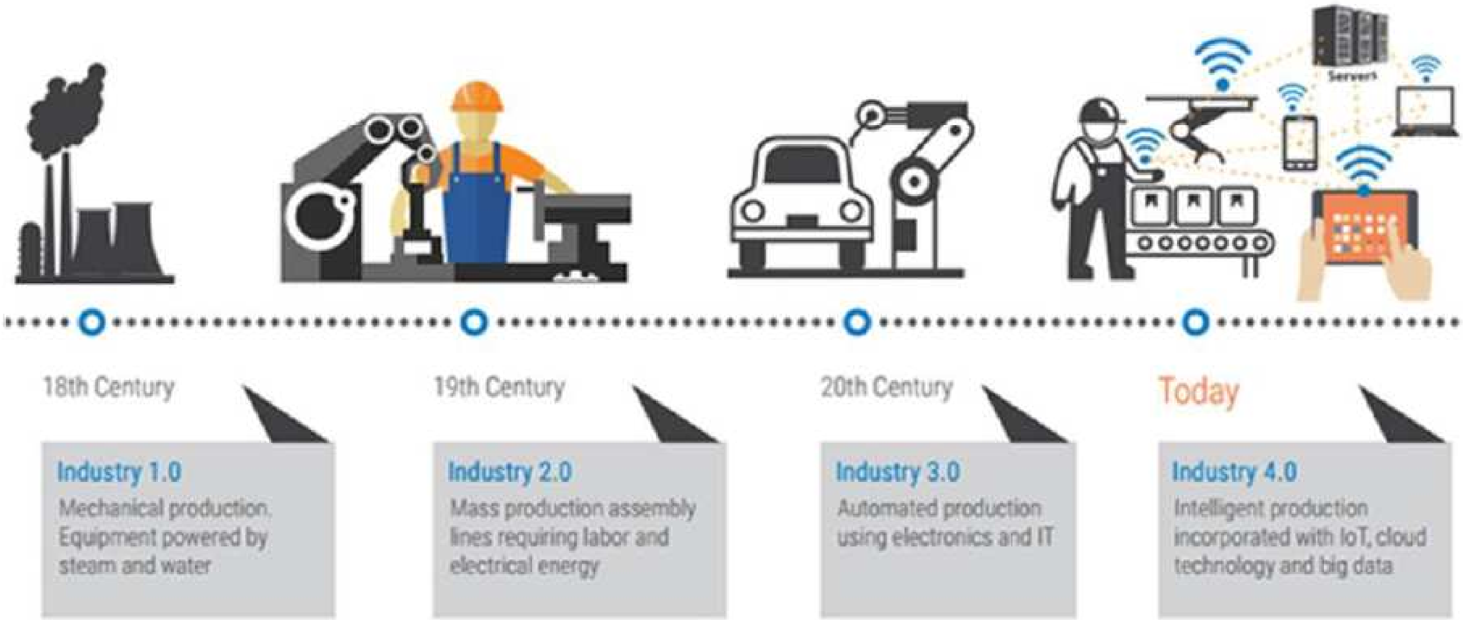

Figure 1

Industrial Progress from a Historical Perspective [8].

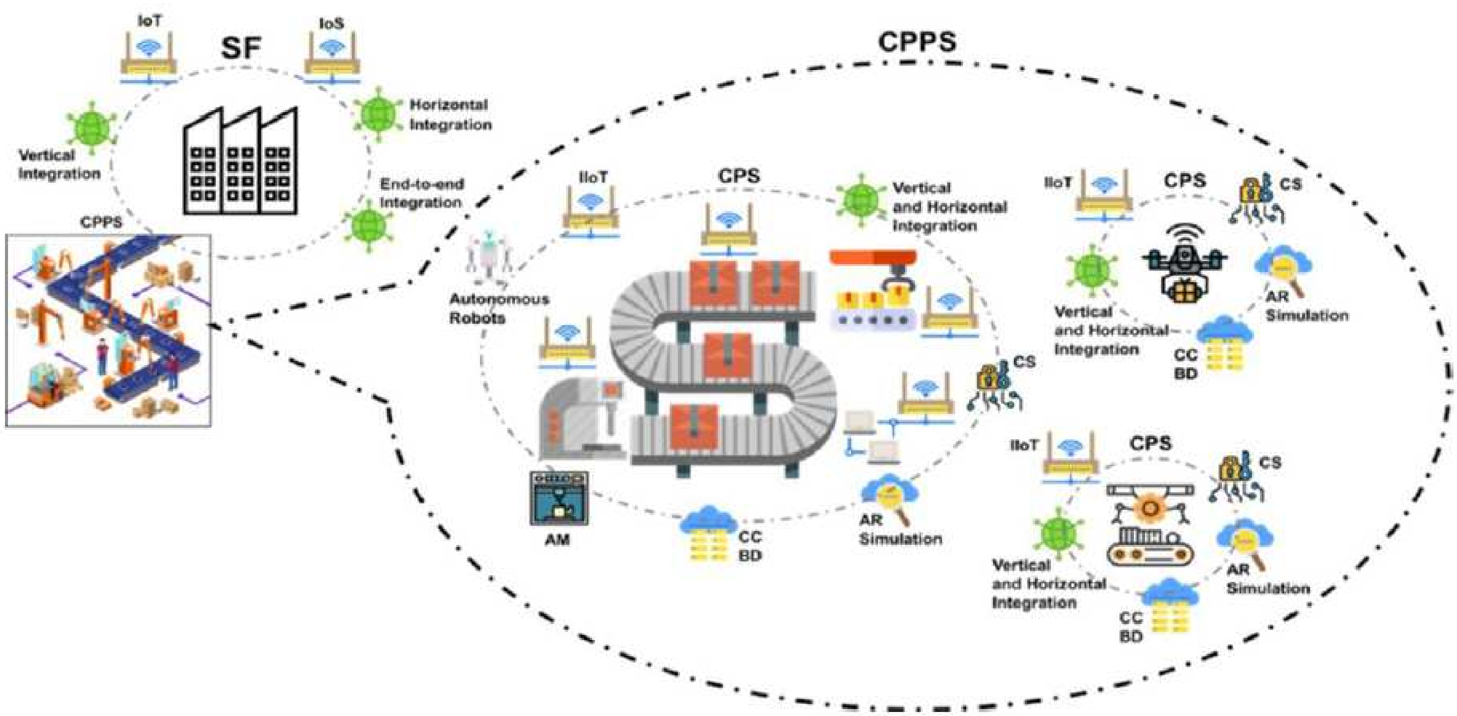

Figure 2

The Development of the SF Concept.

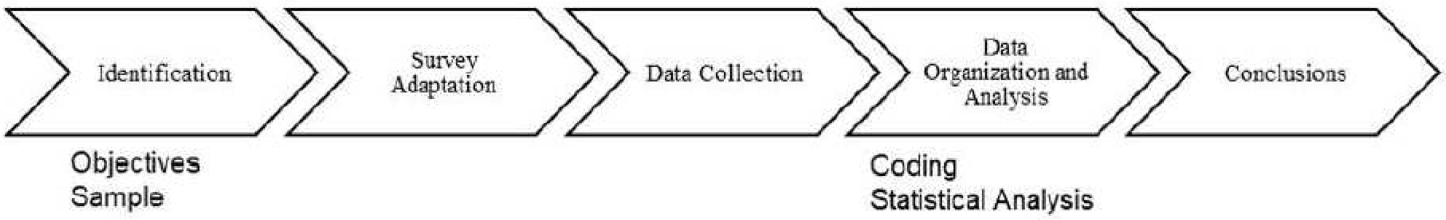

Figure 3

Survey Methodology Steps.

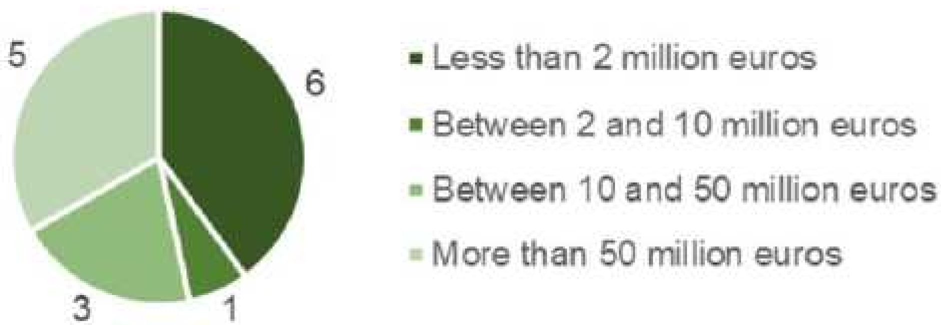

Figure 4

Characterization of Companies According to Their Business Volume.

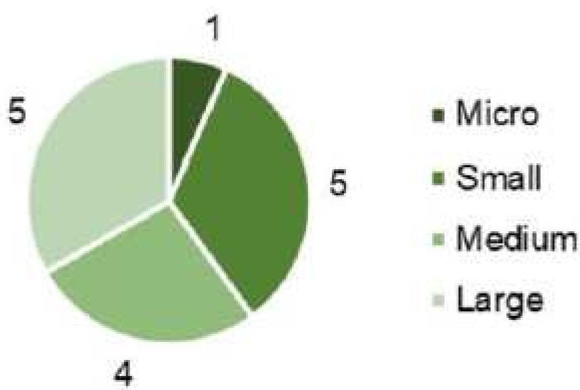

Figure 5

Characterization of Companies According to Their Dimension.

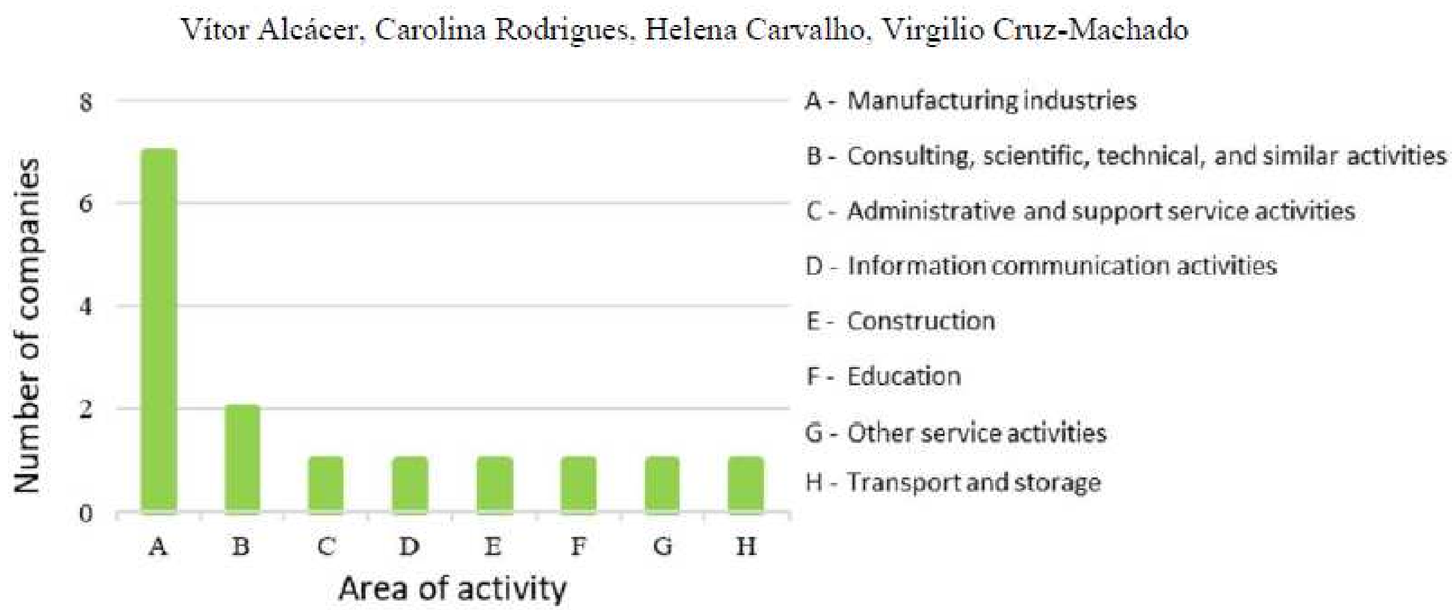

Figure 6

Characterization of Companies According to Their Activity Area.

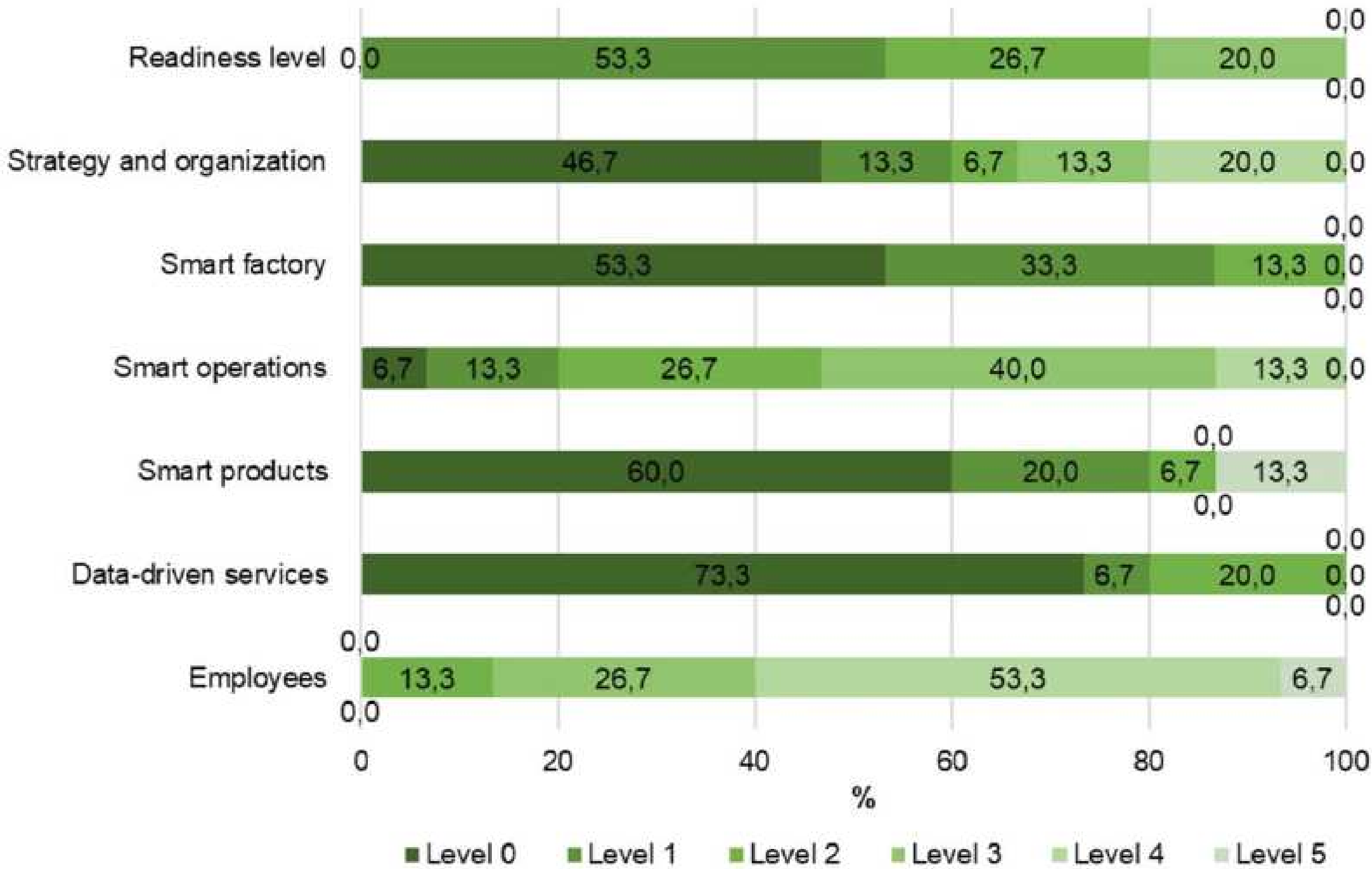

Figure 7

Readiness Level Distribution on Different Dimensions.

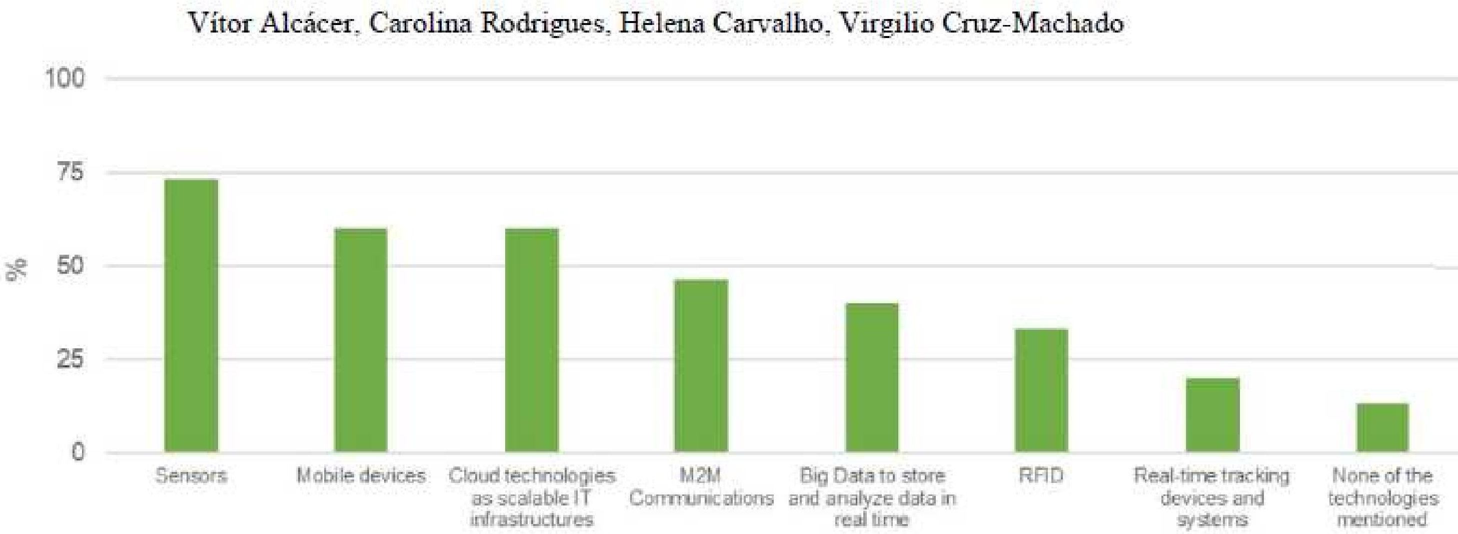

Figure 8

Used Technologies by Surveyed Companies.

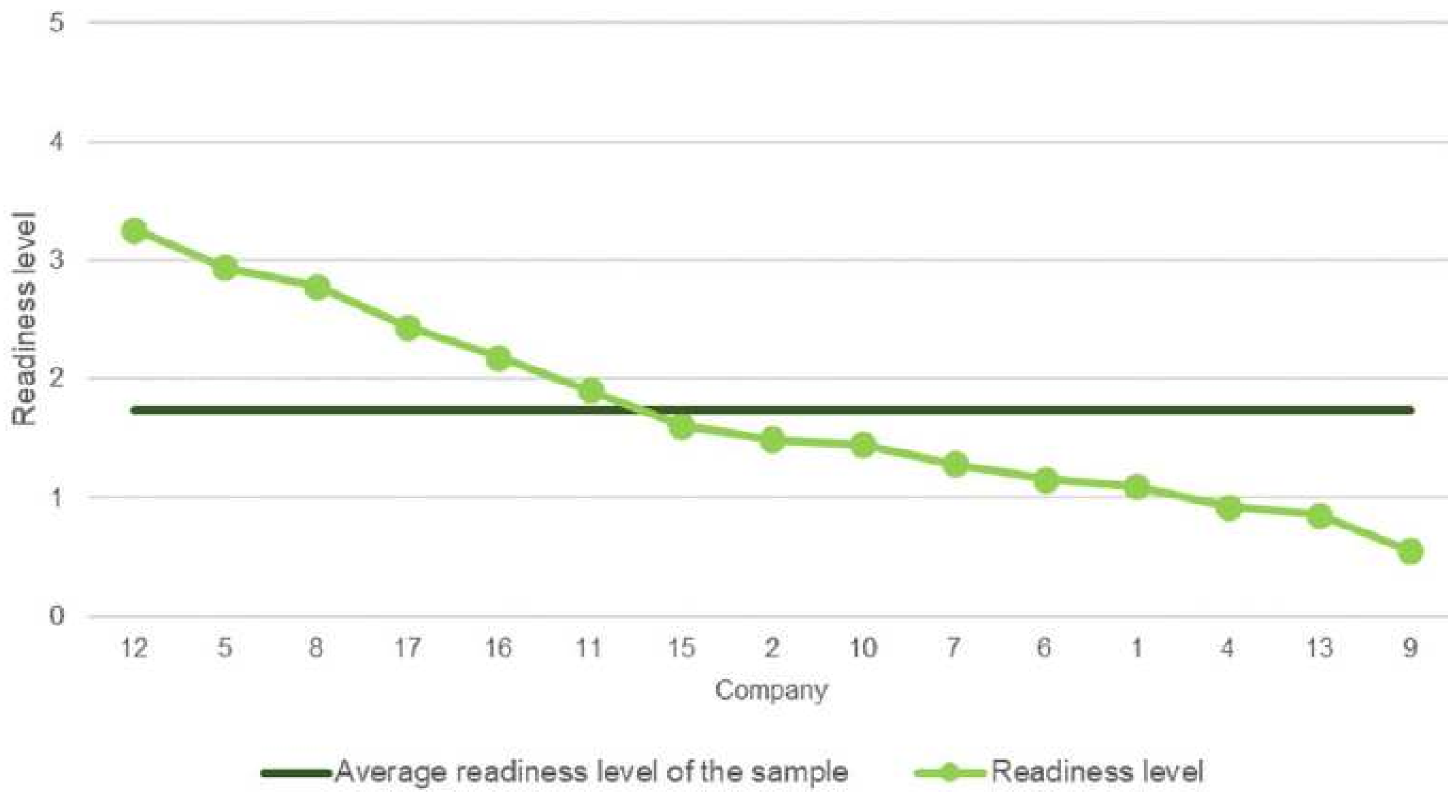

Figure 9

Distribution of Companies' Readiness Level and Comparison with Sample's Average Readi-ness Level.

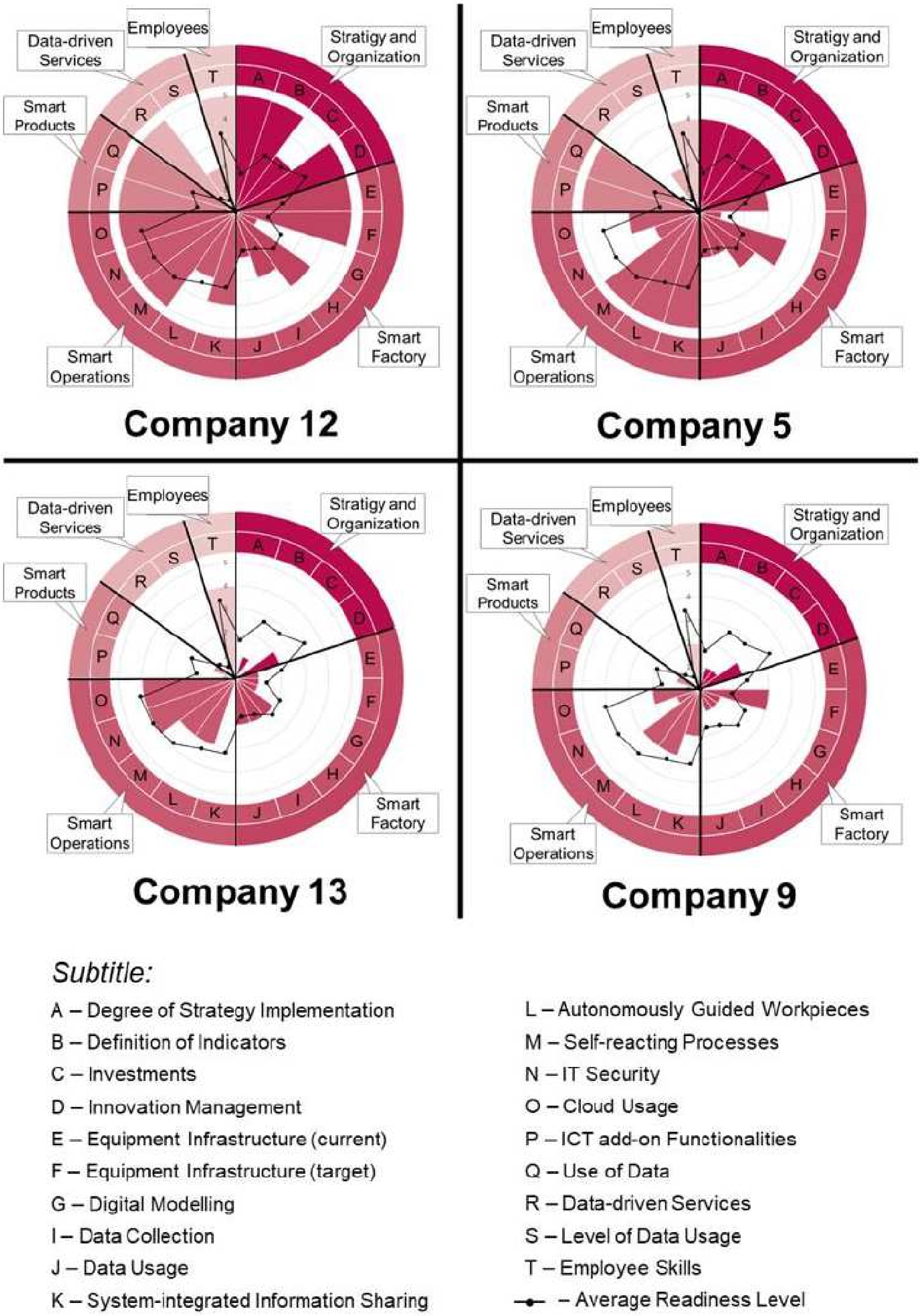

Figure 10

Comparison of Obtained Readiness Levels on Dimensions and its Sub-dimensions for Best and Worst Performers.