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3D-CUBE readiness model for industry 4.0: technological, organizational, and process maturity enablers

Bruna Felippes[a], Isaac da Silva[a], Sanderson Barbalho[a], Tobias Adam[b], Ina Heine[b] and Robert Schmitt[b]

[a]Industrial Engineering Department, University of Brasilia, Brasilia-DF, Brazil; [b]Laboratory for Machine Tools and Production Engineering WZL, Chair of Production Metrology and Quality Management, RWTH Aachen University, Campus-Boulevard, Aachen, Germany

ABSTRACT

This paper proposes a new Readiness Model, 3D-CUBE, to assess the current state of manufacturing companies in the digital transformation context. Using a systematic literature review with 8-Steps-Search-Flow and a hypothetical-deductive framework (considering maturity as an 'input' enabler and not as an 'output'), the best information of 63 existing models was selected from 486 studies found in 10 databases. The 3D-CUBE was elaborated, with 3 dimensions (X = Organizational , Y = Technological , and Z = Process Maturity), 6 sub-dimensions, and 21 elements, including a scale 0-5 to assess the company readiness level. For the company's Data Collection, a 3D-CUBE Questionnaire was developed, which provides a radar graph and calculates the company's score with a readiness vector R=(X,Y,Z). Based on the existing model's shortcoming, 3D-CUBE is a new contribution to this research stream, to help companies in getting ready for Industry 4.0. .

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Industry 4.0; maturity model; readiness; technological enablers; organizational enablers

1. Introduction

The current Industry 4.0 (I4.0) can be understood as a relevant process of merging the physical, digital, and biological worlds through digital transformation technologies and cyber-physical systems (ISCOOP, 2022). I4.0 has technological enablers for new production systems, like Big Data, Cloud Computing, Artificial Intelligence (AI), Industrial Internet of Things (IIoT), and Cybersecurity (Jazdi, 2014). It represents a new stage in the organization and control of the industrial value chain since new technology paradigms and market pressure have transformed production processes and business models (Zhong et al., 2017).

Besides, there is an increasing number of authors advocating that companies must have a certain degree of maturity to succeed in a smart manufacturing environment (Renteria et al., 2019; Tortorella et al., 2020). Maturity Models (MM) are useful for both science and practice because they help systematically gather information about a company's current state and its strategies for I4.0. These data can be used to compare companies and their performance, develop better implementation methodologies, and understand current pitfalls. On the practical side, MMs are an established approach for

CONTACT Sanderson Barbalho sandersoncesar@unb.br Faculty of Technology, University of Brasilia, Darcy Ribeiro University Campus, Asa Norte District, Brasilia-DF 70910-900, Brazil

helping companies evaluate themselves within a specific interest area and for planning improvements (Chrissis et al., 2003). The application of MMs as self-assessment is currently proposed for the I4.0 endeavor (Agca et al., 2017; Canetta & Et. Al, 2018; Schuh et al., 2016; Schumacher et al., 2016; Tortorella et al., 2020; Unterhofer et al., 2018).

According to Pereira (2011), a scientific investigation is justified when there are gaps in knowledge about a subject, and there is a possibility of adding something to it with research. In this paper, a new model for the analysis of I4.0 readiness is proposed. The Model relates technological and organizational enablers and maturity to understand the gaps and possible guidelines for implementing I4.0 in companies. The Model is centered on the concept of readiness once a company must be ready to implement Industry 4.0 advancements, and this readiness must not be only on the technical side. On the other hand, the concept of maturity, derived from the quality management field, is not so appropriate to communicate the challenges a company faces when trying to implement Industry 4.0, especially in emerging countries. In fact, how can a company be mature to implement something that is evolving, and no researcher or consultancy knows exactly how it will progress? This reasoning motivated the authors to propose a readiness model where maturity is an input dimension necessary for a company to understand if it is ready to implement I4.0 technologies effectively. In our Model, maturity is derived from the excellence a company must be in the New Product Development (NPD) and Order Fulfillment (OF) processes.

The Model also addresses some pitfalls from previous MMs. To Amaral and Peças (2021), there is no tool for a systematic approach that predicts a company's hurdles in implementing I4.0. Additionally, the existing tools essentially focused on advanced technologies and occasionally on specific areas of this concept, such as technology or processes. Furthermore, not all MMs follow a concrete process model in their development, and most lack a thorough evaluation, especially regarding their usage in practice. In line with Leyh et al. (2016), however, some of the analyzed MMs contain, in part, related and relevant approaches. Still, these mostly do not cover necessarily all the required functionality and content of highly integrative and organization-wide digitization for application in the field of I4.0. After analyzing the main 17 MMs in their study, Simetinger and Zhang (2020) affirm that the existing MMs can help with I4.0, but there are still tasks that must be handled and do not require only technical excellence.

According to Renteria et al. (2019), some models don't have a description for each dimension level and do not present essential information about their enablers, structure, items, variables, dimensions, stages, layers, or evaluating levels. Hence, most of them only provide a general description for each stage and do not have their clauses mapped synergically. If a variable is too generic, its accurate assessment is difficult; if a level is too generic, a clear distinction between the levels of a dimension is jeopardized.

This research proposes the '3D-CUBE Readiness Model,' which relates technological, organizational, and process maturity enablers as dimensions for evaluating a company's readiness to implement Industry 4.0. This article compares existing maturity and readiness models, identifies the current problems and limitations in these approaches, and describes the new 3D-CUBE Model.

The relevance of research may be associated with several factors, such as the theme's importance, the approach's originality, and the results' applicability (Pereira, 2011). The importance of the theme is self-understood once Industry 4.0 is evolving, and many companies have not started their digitalization journey. The approach is original once we built a different relation between readiness and maturity, through a hypothetical-deductive approach. And the model applicability is under test and evolving as presented next.

Additionally to this section, the section 'materials and methods' presents the research methodology, and the section 'theoretical analysis' analyses the history and theoretical fundamentals of the MMs in the literature, including the previous models and the systematic bibliographic review. The section '3D-CUBE Model definition' presents the 3D-CUBE Model and its different levels and dimensions, the section 'methodology of readiness vector calculation' presents the readiness vector calculation and graphics, and the section 'discussion and conclusion' concludes the paper with a summary and outlooks.

2. Materials and methods

This research uses a hypothetical-deductive approach (Lakatos & Musgrave, 1977). This methodology includes:

(1) study of existing theories;
(2) formulation of a research problem based on discovered theoretical and empirical issues;
(3) proposed solutions consisting of conjectures or models;
(4) deduction of the consequences in the form of hypotheses suitable for testing the investigated phenomena; and
(5) falsifiability test embracing efforts to refute the hypotheses by observation, experimentation, simulation, or other procedures.

Only the first three steps are extensively presented in this article, as described below.

A systematic literature review was performed with a specific 8-Steps Search Flow. Ten of the most common scientific platforms to provide a bibliometric analysis were searched: Scopus – which presents studies from 1997 until now; Web of Science (WoS) – from 1945 until now; Science Direct (SD) – from 1992 until now; Educational Resources Information Centre (ERIC) – from 2001 until now; EBSCOhost (Academic Search Premier-ASP) – from 1887 until now; Wiley Online Library (Wiley) – from 1992 until now; American Association for the Advancement of Science (AAAS) – no information available; Springer Link – from 1991 until now; Research Gate (RG) – no information available; ACM Digital Library (ACM) – from 1908 until now. The results of analyzing these ten databases have totalized 63 MM, which will be analyzed and qualitatively discussed in this work. Common bibliometric indicators such as main authors, journals, keyword networks, highlighted countries, and institutions were also generated, but it is not in the scope of this article. The bibliometric report of part of this research is presented in Silva et al. (2021). The present paper shows the systematic analysis of the papers, i.e. a qualitative study to understand the foundation and main concepts of the gathered literature to understand its scientific.

The second step is formulating a research problem based on discovered theoretical and empirical issues. Concurrently analyzing existing models, the research team had two previous empirical interactions with MMs.

The first was a trial to use the Acatech Model (Schuh et al., 2016) to propose Industry 4.0 improvements in a large Brazilian beverage company. It is described in Barbalho and Dantas (2020) and shows that the mentioned Model was a proprietary solution. In their work, the author used the WMG Model (Agca et al., 2017), a free internet-based solution developed by Warwick University in England. This Model was analytically stressed in our research, and this interaction shows that the way it was applied tends to generate performance islands (Barbalho & Dantas, 2020).

The second was the possibility to be applied to the Acatech Model, i.e. one of the authors was the focal point in a large Brazilian energy company to which the Acatech Model was applied to evaluate Industry 4.0 possibilities. The Brazilian national industry authority has partnered with the German engineer's academy that created the Acatech Model and is applying it to Brazilian industries as a tool to propose lacks for Industry 4.0 implementation. The Acatech was deployed in question and used as an online tool to be used this way. When answering this tool, the researcher identified other lacks in the Model addressed on the 3D-CUBE. The analysis of existing models and these two empirical interactions were the main inputs to the 3D-CUBE.

The third step in the hypothetical deductive method is to propose solutions consisting of conjectures or models. The 3D-CUBE is our proposal. The meaning behind its development was to create a solution that could be used to compare Brazilian and German companies in a better way.

Because of the complexity and wide scope of a MM, the fourth step, deduction of the consequences in the form of hypotheses suitable for testing the investigated phenomena, is initially discussed with theoretical implications of the most likely business profiles in terms of the readiness that our model diagnoses. The fifth step falsifiability test is already initiated with two interactions briefly discussed in the last section, but it must be subject to future contributions.

3. Theoretical analysis

Maturity Models have been developed for almost 50 years. In 1973, Nolan (1973) presented his staged Model with the first notions of a MM for managing the computer resources in organizations. In 1993, Paulk (1993) designed the widely recognized Capability Maturity Model (CMM), which they deployed into CMMI later. This MM measures how a software development organization matures its development activities and maintenance processes (Merkus et al., 2020). The CMM describes the principles and practices underlying the software process maturity and is intended to help organizations improve it.

Since 1991, CMMs have been deployed for various disciplines, like systems engineering, software engineering, software acquisition, workforce management, and development. Although these models have proved useful to organizations, using multiple models has been problematic (Chrissis et al., 2003). The CMM Integration (CMMI) project was formed to sort out the problem of using multiple CMMs, whose combination into a single improvement framework was intended for use by organizations in their pursuit of enterprise-wide process improvement. In fact, in our thesis, more than 8 MMs have CMMI origin (such as Schumacher et al., 2016; Kerrigan, 2013; Schuh et al., 2016; De Carolis et al., 2017; Canetta & Et. Al, 2018; Sjödin et al., 2018; Pirola, Cimini, Pinto et al., 2019; Bandara et al., 2019; and Li et al., 2019 – see, Appendix A).

Around 2010, MM design became more structured with a MM design procedure model that describes possible organizational improvements by naming activities for all maturity levels. A set of maturity levels is applied to a relevant set of application area constructs, often represented in a tabular format, for maturity measurement (Merkus et al., 2020).

3.1. Maturity and readiness models' definitions

MMs are commonly used to conceptualize and measure the maturity of an organization or a process regarding some specific target state (Schumacher et al., 2016). For Büyüközkan et al. (2020) in the Digital Transformation (DT) context, some authors call MMs like 'Digital Maturity Model (DMM)'. According to Barbalho and Dantas (2020), the way a company implements I4.0 could generate a phenomenon called 'performance islands', which occur when a serious effort in improvements approaches a specific area but is limited by the poor performance of the other areas. As a whole, the system does not reach its possible excellence.

This partial and not general improvement effort is dealt with by the Capability Maturity Model Integration – CMMI (Chrissis et al., 2003), which suggests that it has two possible directions for process improvements: a sector-specific improvement approach based on capability assessment (Barbalho & Rozenfeld, 2013; Chrissis et al., 2003; Schuh et al., 2016) and a real company improvement based on maturity levels (Agca et al., 2017; De Carolis et al., 2017), which is generally more commonly applied.

Once the main reference literature discusses 'maturity' and 'capability', it is important to distinguish between 'maturity' and 'readiness' concepts because they are confused in the scientific literature, where it is possible to identify 'readiness' and 'maturity' models. For Basl (2018), i.e. the readiness models are mostly MMs in many cases. Although they are labelled synonymously, there are some differences between them. Schumacher et al. (2016) express the difference between these two concepts, putting readiness before starting the maturation process. That is, readiness assessment takes place before engaging in the maturing process. In contrast, maturity assessment aims to capture the as-it-is state during the maturing process. For them, while readiness shows if the organization is ready to start a development process, maturity demonstrates the level of organization about the analyzed process. So, readiness is 'willingness or a state of being prepared for something,' and maturity is 'a very advanced or developed form or state'.

Understanding that I4.0 is a new stretch and does not have a solid and consolidated standard, this study will be used the readiness model concepts for I4.0. So based on this concept, this paper considers that 'readiness' is related to how much the company is ready to enter an I4.0 trajectory. At the same time, 'maturity' is related to the idea that the company is already mature, at some level, for I4.0. We think no company has a mature process for Industry 4.0 once this concept and practice evolves, but the company can have mature processes. The next section presents our analysis of the 63 MMs found in the literature search.

3.2. Maturity and readiness models for industry 4.0

We analyzed the models regarding dimensions, maturity levels, and architecture. A time-frame overview of these analyzed models is given in Figure 1. Germany has published the most on this subject and has the largest number of models. Moreover, in recent years there has been an increase in the number of European countries producing scientific content on this subject. The qualitative analysis of these 63 models was also based on systematic bibliographic reviews of some of their authors, such as Zoubek and Simon (2021), Silva et al. (2021), Basl (2018), and Pirola, Cimini, Pinto et al. (2019), and Caiado et al. (2020).

As shown in Figure 1, from 2016 to 2020 were proposed 52 up to 63 MMs. Just the year 2019 concentrates 17 models. There were mainly consultancy models at the beginning of this period, and in the last years, mainly scientific publications. In general, the 'Maturity' term still appears more than 'Readiness', which is newer than the first. There were found 376 different authors and 10 clusters, and the author with the higher number of studies (4 studies) was Leyh et al. (2016), with SIMMI 4.0 MM. It is important to verify that several research groups are studying this theme, with the most recent cluster (2021) represented by Zoubek and Simon (2021) and Basl (2018).

At this qualitative stage, the 63 studies were analyzed in Appendix A, based on the following parameters: characteristics of the enterprise considered in the study, MM type, input dimensions, outputs, critical analysis, output levels, country of origin, possible shortcomings, if the MM had been empirically tested and the year of creation.

3.3. Summary of the theoretical analysis and 3D-CUBE propositions

This section summarizes the elements found in our literature review that motivate our proposed Model. First, most models miss scientific documentation and have only empirical or theoretical development. Some are not been intensively validated in real-life applications or tested to assess their usefulness as a benchmarking tool. In general, it generates a gap between a theoretical conception and a realistic view.

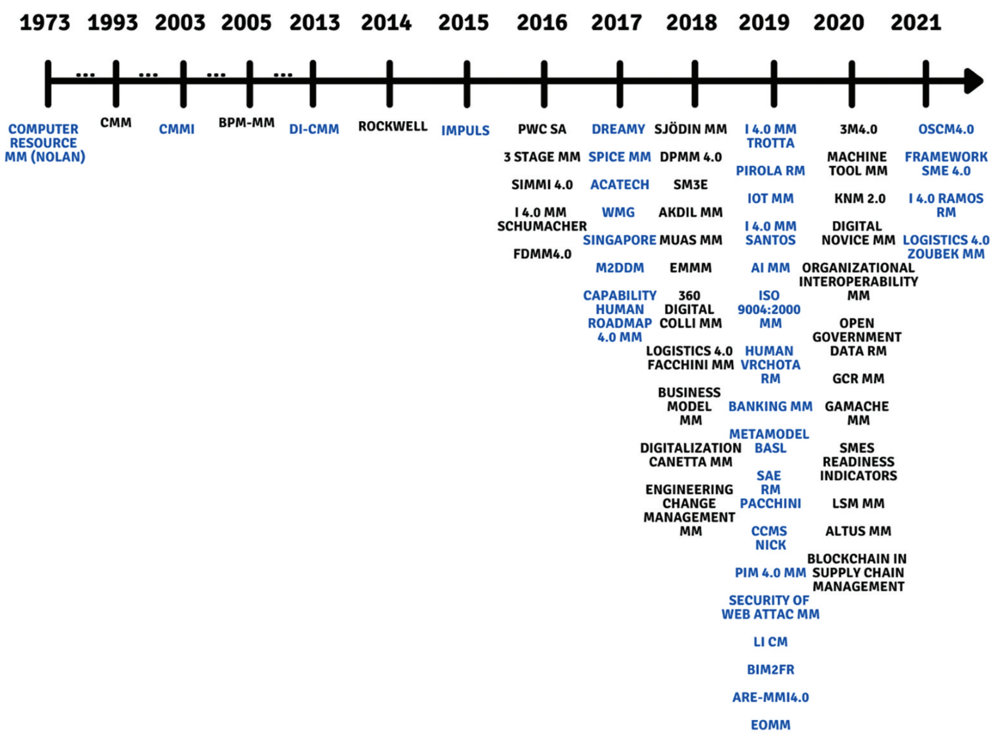

Figure 1. Timeframe of the analyzed MMs. source: authors.

For instance, some models are preliminary works lacking important elements to allow an effective company analysis (Gaur & Ramakrishnan, 2019; Unny & Lal, 2020). Nick et al. (2020), Azevedo and Santiago (2019), Basl (2018), and Amaral and Peças (2021) do not have information about output levels. Rojas et al. (2019) are just applicable for web security and don't have input dimensions. Facchini et al. (2019) and Zoubek and Simon (2021) present a tailored model for logistics processes. Ganzarain and Errasti (2016) don't have a questionnaire to implement their assessment.

Besides, models like Schumacher et al. (2016), Trotta and Garengo (2019), Nick et al. (2020), Azevedo and Santiago (2019), Rojas et al. (2019), Basl (2018), and Ifenthaler and Egloffstein (2020), and Sanabria et al. (2020), and Merkus et al. (2020), and Amaral and Peças (2021), Ramos et al. (2021), and Zoubek and Simon (2021), pp. – see Appendix A, don't present essential information about their enablers, structure, items, variables, dimensions, stages, layers, and evaluating levels. Most of them only provide a general description for each stage and have no clauses mapped with synergy (Renteria et al., 2019). So, if a variable is too generic, an accurate assessment is difficult, and if a level is poorly described, a clear distinction between the levels of a dimension is missing. In some cases, because of its large set of elements, the models presented difficulties to be implemented, especially in small enterprises. Sometimes the maturity or readiness model is so complex that it needs professional judgment to interpret the results after application in enterprises.

Another important problem is that models like Rockwell (2014) focus only on the facets of the existing IT network and inadequately address the organizational and operations-related dimensions. And still, models like Impuls (Lichtblau et al., 2015), which focus on technological enablers, don't consider a few key technologies such as AI (Artificial Intelligence), AR (Augmented Reality), VR (Virtual Reality), smart glasses, and Blockchain Technology and have a vague description of how the technologies can be used for integration and the inter-relations among them. In many cases, digital competencies and technologies outside the IT field are not discussed. Indeed, models like Schuh et al. (2016), lack technology considerations for the proposed process analysis, being difficult to comprehend the differences between the maturity analysis for I4.0 and a generic improvement analysis for increasing something in the company's performance.

Considering the validation steps, models like Felch and Asdecker (2018), limit the questionnaire respondents, only distributed to some enterprises in a specific country (regional bias) or within a specific industry, limiting the validity of their findings. About the target audience, models like Singapore (2017) do not consider people from different departments to fill out the questionnaire, others only examine manufacturing sites (not including executives and senior managers), and others like Santos and Martinho (2020) use a small number of professionals in the industry to participate in the validation phase.

In some models, such as Lichtblau et al. (2015), Rockwell (2014), De Carolis et al. (2017), Akdil et al. (2018), and Canetta and Et. Al (2018), pp. – see Appendix A, filling out the survey questionnaire is difficult because it doesn't follow the output levels number and presents a juxtaposition of dimensions. For example, among smart factories and smart operations, respondents could have doubts regarding the clarity of each dimension and their questions to answer. Besides, some model questionnaires emphasize the process view without tracking the common company functions, such as engineering, marketing, manufacturing, and finance; however, most companies are structured in these functional units. Therefore, it can be difficult to identify the right person in a company to answer the queries. Models like Ganzarain and Errasti (2016) and Weber et al. (2017), even do not have any questionnaires to be applied. Considering the final results report, models like Gajsek et al. (2019) only have general diagnostics but not a clear definition of the action plan to implement Industry 4.0 improvements.

Regarding supply-chain, MMs lack a process view connecting the whole supply-chain and didn't address the lean aspects or identify improvement opportunities or roadmap for further developments.

Therefore, based on the presented MMs shortcomings, and considering that most models have not been tested, we see the need for a model which addresses the limitations found, especially to provide a practical and easy application methodology with dimensions and levels defined and structured in an unprecedented way, geared to the readiness of a company in the context of I4.0. The new Model differentiates the enablers and a processual view. It must have a clear decomposition for each separate dimension and allow for an evaluation of less structured companies and those that already initiated their I4.0 journey. Finally, the Model needs to be clear about how new technologies can disrupt business processes but be balanced to avoid a technology-heavy approach to process improvement.

As the relationship between readiness and maturity is central to our Model, we also state the following research propositions to guide our development:

- PROP1: Maturity is different from readiness when analyzing if a company is prepared to implement Industry 4.0 technologies in its operations.
- PROP2: Process maturity is input when analyzing if a company is ready to implement Industry 4.0 technologies in its operations.

4. 3D-CUBE model definition

The 3D-CUBE Readiness Model considers the dimensions of organizational enablers, technological enablers, and process maturity as inputs (see, Figure 2). After the bibliometric review results, it can be seen that most existing MMs today use the same concept of CMMI maturity, others have no well-defined concepts, and others use readiness and maturity as synonyms. Differently, in 3D-CUBE, the relationship between maturity and readiness is clearly defined.

The proposed 3D-CUBE reflects how ready a company is to engage in an I4.0 environment, focusing on a company's level of readiness for I4.0.

4.1. 3D-CUBE readiness levels

Based on the CMMI (Chrissis et al., 2003) and incorporating elements of Schuh et al. (2016), the readiness levels are defined as follows: not initiated, initial, managed, defined, optimized, and self-adapted (Figure 3).

So, the first levels have similarities with previous I4.0 MMs, such as DREAMY Model (De Carolis et al., 2017), while the 5th level is based on Schuh et al. (2016), which follows the concept of adaptability, where continuous adaptation allows a company to delegate some decisions to IT systems, adapting to a changing business environment with self-optimization machines.

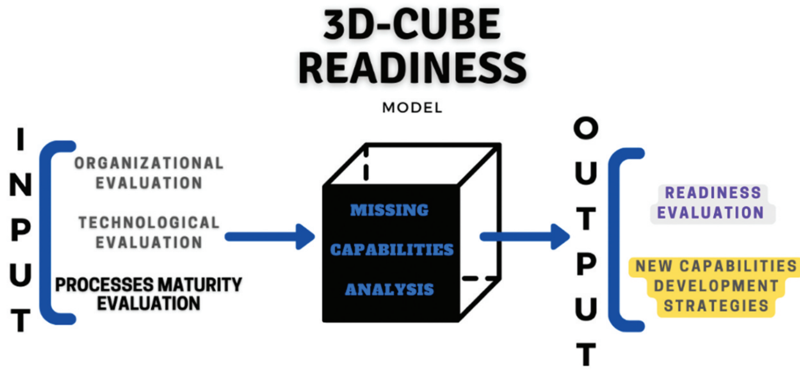

Figure 2. The framework of the proposed readiness model. source: authors.

Figure 3 shows that on level 0 (not initiated), the company does not comply with at least one of the three readiness dimensions. At the same time, level 5 (self-adapted) means that for all dimensions, sub-dimensions, and elements of the 3D-CUBE, the company has a maximum score (of five), representing complete readiness..

As a CMMI-based Model, 3D-CUBE inserts an initial step as 'level 0' to implement the concept that a company could improve separate areas with different capabilities. With the same objective of covering all possibilities within the six levels, 'level 1' of the 3D-CUBE Model (named 'initiated') replaces the CMMI level 'performed' (for continuous improvement) and 'initial' (for staged improvement). The 'optimized' level of the 3D-CUBE differs from the CMMI approach. It joins the last two CMMI levels ('quantitatively managed' and 'optimized') into just one concept.

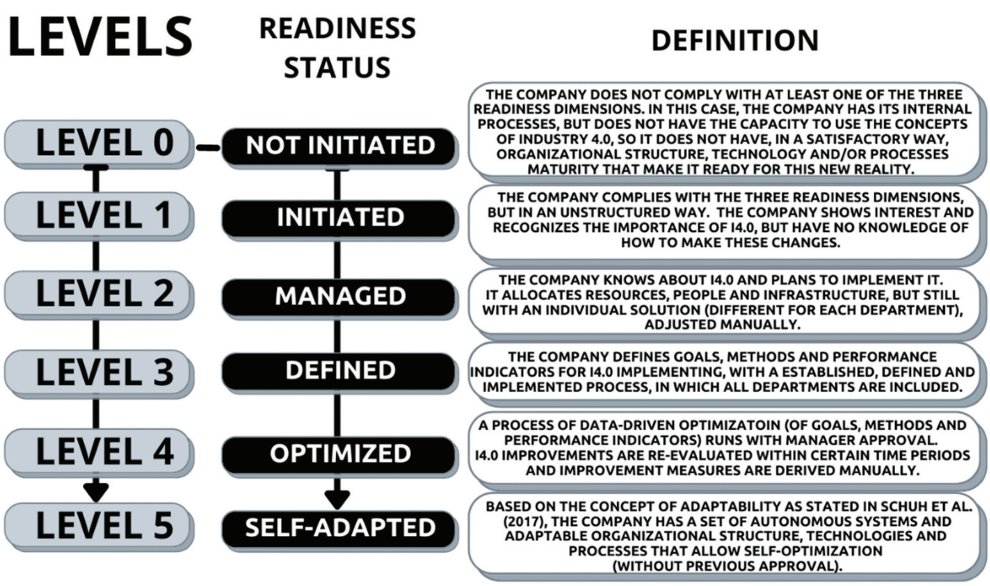

Figure 3. 3D-CUBE readiness model levels. source: authors.

For the last level, 3D-CUBE includes a 'self-adapted' as an autonomous process in which a piece of equipment, for example, can be guided by sensors and actuators autonomously, in real-time, and according to the conditions of the moment. Besides, decision-making is done using algorithms that evaluate performance and provide suggestions for a well-trained human decision-maker (Gamache et al., 2020).

4.2. 3D-CUBE dimensions

Based on the main dimensions found in the 63 existing MMs and considering the need to analyze 'process maturity' in a readiness model, the 3D-CUBE gives a tri-dimensional view of readiness, generating a three-dimensional vector as a result, which facilitates the company's understanding of its real situation through Industry 4.0. So, as a result of the evaluation process, there is a readiness vector R = (X,Y,Z), where 'X' is the organizational enabler, 'Y' is the technological enabler, and 'Z' is the process maturity enabler. When diagnosed, a company has different readiness levels in each dimension, with sub-dimensions and a third granularity named 'elements' (Figure 4).

As explained before, each dimension, sub-dimension, and element vary from level 0 to 5. The following description (Table 1) provides further details.

Next, each enabler will be explained, starting with 'organizational enablers', 'technological enablers', and, finally, the 'process maturity enablers'.

4.2.1. Organizational enablers

Organizational enablers for readiness are differentiated into two sub-dimensions, following Schumacher et al. (2016) and De Carolis et al. (2017):

(1) Organizational strategy
(2) Human Workforce

(1) Organizational strategy deals with the necessary support and philosophy that a company must have to enable organizational change. Organizational strategy requires top managers to show interest in I4.0 solutions, and the organization itself to be open to new ideas and concepts regarding its structure and processes. A digital strategy represents the improvement of products and processes through digital technologies and the opportunity to develop a brand-new business model. A good digital strategy must incorporate a long-term vision, a business model review, and a digital plan to achieve business objectives (Gamache et al., 2020). So, the Organizational Strategy sub-dimension is the adaptive organization that a company encompasses in response to or anticipating changes in its external environment (Merkus et al., 2020). The 3D-CUBE Model includes the elements: 'top-down support and governance', 'organizational structure management', 'Business Model (BM) management', and 'regulatory compliance and contractual relations'.

4.2.2. Top-down support and governance

First, a 'Top-down support for I4.0' is needed to initiate the I4.0 initiatives and projects; once when a company is trying to implement I4.0, the comfort zones are forced to be exceeded (Mintzberg et al., 2003; Tortorella et al., 2020). Only strong support from senior

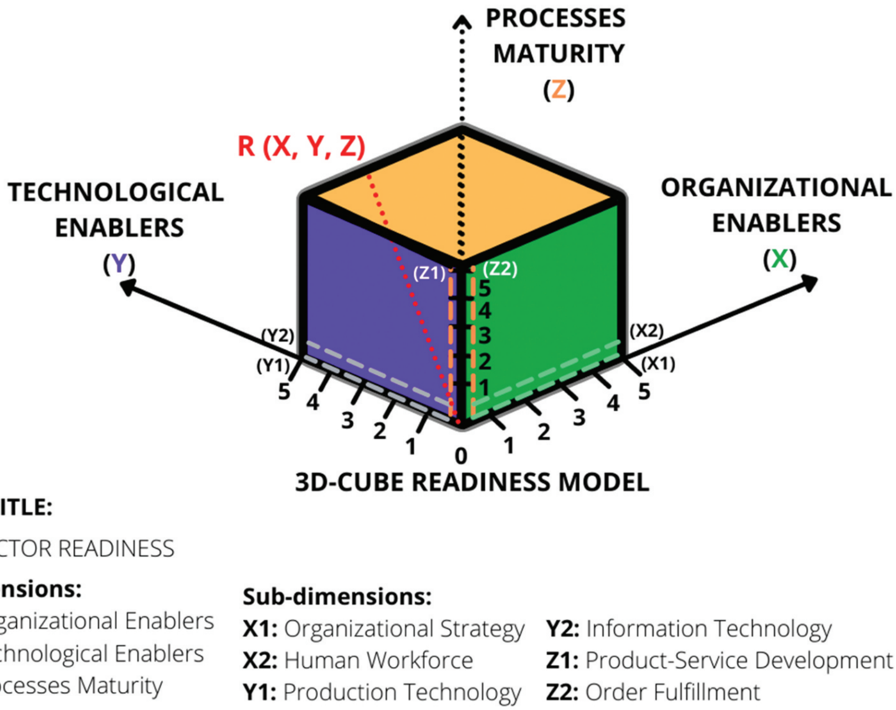

Figure 4. 3D-CUBE readiness model. source: authors.

Table 1. 3D-CUBE dimensions, sub-dimensions, and elements (source: Author).

DIMENSIONS	SUB-DIMENSIONS	ELEMENTS
ORGANIZATIONAL ENABLERS (X)	Organizational Strategy (X_1)	Top-Down Support and Governance (X_{11})
		Organizational Structure Management (X_{12})
		Business Model Management (X_{13})
		Regulatory Compliance and Contractual Relations (X_{14})
	Human Workforce (X_2)	Leadership (X_{21})
		Communication (X_{22})
		Training (X_{23})
		Culture of Innovation (X_{24})
TECHNOLOGICAL ENABLERS (Y)	Production Technology (Y_1)	Anthropomorphic Support Systems (Y_{11})
		Cognitive Support Systems (Y_{12})
		Managerial Support Systems (Y_{13})
		Driving Network Production (Y_{14})
	Information Technology (Y_2)	Data Collection, Analysis, Interconnectivity, and Transparency (Y_{21})
		Information Security (Y_{22})
		Decentralized Decisions (Y_{23})
PROCESSES MATURITY (Z)	Product-Service Development (Z_1)	Cross-company Engineering, Research, and Development (Z_{11})
		Customer-based New Product Development (Z_{12})
		Supply-Chain Development (Z_{13})
	Order Fulfilment (Z_2)	Customized-based Production System (Z_{21})
		Sales and Operations Integration (Z_{22})
		Smart Quality Management System (Z_{23})

managers with a strict mindset (Mittal et al., 2018) can sponsor the necessary changes for the transformation process. Senior management's support is necessary for bottom-up (several small initiatives begin without this support, but if it exists, they are potentiated) and top-down efforts (initiatives and projects defined by senior managers). Top-down support includes governance, which is a 'mechanism for managing complex projects and change initiatives' (Merkus et al., 2020).

4.2.3. Organizational structure management

Organizational structure management considers the analysis of impacts of the I4.0 on the company's competitiveness, the management of the I4.0 implementation, investments in the technologies of I4.0, innovation management, and use of technologies (Santos & Martinho, 2020). Organizational structure englobes 'practices, actions, business process, the flexibility, working rules, collaborations and communications, procedures that complement and accommodate activities within and between organizations' (Merkus et al., 2020).

4.2.4. Business model management

BMs are simplified and aggregated representations of the relevant activities in a company, consisting of its strategy, customer/market perspective, and value constellation (Weking et al., 2020). I4.0 BMs can be demonstrated by integrating connectivity and other I4.0 technologies in their operation. The new digital technologies can improve one's offer and relationship with the customer (Gamache et al., 2020). Industry 4.0 enables companies to associate the obstacles of BMs in one sector they actuate with solutions or obstacles in another sector. Flawed operational decisions can lead to a downward spiral if not interrupted by alert systems, such as a decrease in profit. BM is subdivided into: 'IT/cloud-based BMs', 'Service-based BMs', 'Spin-offs-based BMs', and 'Partners-based BMs':

- IT/cloud-based BMs: the result of technological enablers in I4.0, which can directly connect customers to a company (Müller et al., 2018). Knowledge creation and management are essential issues here (Dragicevic et al., 2020), as well as the use of big data (Lee, 2018) and cloud computing (Wu et al., 2020).
- Service-based BMs: BMs based on product-service systems, that is, the servitization of BMs that originally were more focused on selling products. Product-service systems and circular BMs are a current imperative (Kohtamäkia et al., 2019) since a growing number of customers are conscious of the environment when buying consumer goods.
- Spin-offs-based BMs: imply that a company follows open innovation strategies (Benitez et al., 2020), in which a small company with a small overhead starts a new promising but less profitable business (Christensen, 2006).
- Partners-based BMs: support the creation of new endeavors in its supply-chain or participate as a tier in a larger value chain on I4.0 ecosystems (Benitez et al., 2020). Partner-based business demands specific mindsets regarding horizontal collaboration and new contractual and legal considerations (Ramalho et al., 2019) involving sharing projects, knowledge, resources, and tools, and is based on willingness and the ability to cooperate (Gamache et al., 2020).

4.2.5. Regulatory compliance and contractual relations

Regulatory compliance is the 'governmental and institutional policies and procedures, standardization and security' (Merkus et al., 2020). It includes labor regulations for I4.0, suitability of technological standards, intellectual property, implementation of the I4.0 roadmap, and available resources for realization (Akdil et al., 2018), including environmental context (Merkus et al., 2020).

Internationally, there are many variations in laws and norms for employment. Work-related contracts and standards are stressed in the I4.0 context (Kurt, 2019). Concurrently, new technologies allow several off-site work environments like a home office, virtual office, and AR office (Hecklau et al., 2017). These possibilities are technologically enabled, but a remaining challenge is to align these new work environments with the employment law, which runs on another velocity.

According to Badri et al. (2021), in industrialized nations, Occupational Health and Safety (OHS) has been a growing concern in many businesses for at least two decades. Legislation, regulation, and standards have been developed to provide organizations with a framework for practicing accident and illness prevention and placing worker well-being at the center of production system design. However, the occurrence of several accidents continues to show that OHS performance evaluation is subject to interpretation. Over the years, many instruments have been developed to evaluate public and private organizations' occupational health and safety status, wherever employees are exposed to the risk of work-related injury or illness. Such tools should also be capable of guiding the choice of preventive actions implemented and measuring the effectiveness of these choices.

(2) Human Factors (HF) are probably the major enabler of I4.0 (Schuh et al., 2016), since employees are, directly and indirectly, the driver of the success of the other elements. It includes 'people ... skills: a company's crucial attributes' or 'how to hire and fire, motivate, train and educate ... Going beyond the traditional considerations such as training, salary, performance feedback, and career opportunities' (Merkus et al., 2020). With the rise of I4.0, employees will need to be empowered across all organizations and along the value chain to be agile and strategic in dealing with new challenges (Poba-Nzaou et al., 2020; Sivathanu & Pillai, 2018).

For Neumann and Dul (2010), HF is 'the scientific discipline concerned with the understanding of interactions among humans and other elements of a system ... to optimize human wellbeing and overall system performance'. According to IEA Council 2000 (International Ergonomics Association), this definition of HF spans the physical, cognitive, and psychosocial interface between the operator and the production system. It is operationally defined as synonymous with the term 'ergonomics', which is sometimes seen as a narrower issue by those outside the discipline. HF differs from Human Resource Management (HRM) in that HRM focuses more on selecting and developing people to fit them into the system. In contrast, HF focuses on adapting the system design to fit it to the people ('HF engineering'). In the 3D-CUBE Model, HF is treated as a basis for the human workforce sub-dimension and the production technology sub-dimension in the technology enabler. The human workforce includes 'leadership', 'communication', 'training', and a 'culture of innovation'.

4.2.6. Leadership

Leadership is defined by a person's process of guiding, orienting, and influencing a group of people to achieve a shared vision (Gamache et al., 2020). Any company can become smarter and closer to the I4.0 league. However, Organization and Management (OM) are often the obstacles to this development. Several MMs are introduced to assess the company's maturity toward I4.0, and leadership and people are treated as organizational aspects (Ramingwong et al., 2019). It includes a willingness to lead and managerial competencies and methods (Akdil et al., 2018), besides motivating, developing, and directing people as they work (World Economic Forum, 2016).

4.2.7. Communication

Communication is the ' . . . effective exchange of ideas and a clear understanding of what it takes to ensure successful strategies, ensuring ongoing knowledge sharing across organizations' (Merkus et al., 2020). Internal communication is a set of principles, actions, and practices designed to foster ownership, and cohesion, encourage everyone to communicate better, and promote joint work (Gamache et al., 2020). Vertical communication occurs between the hierarchical levels of the company, while horizontal communication occurs between different sectors at the same level.

Communication is probably the major concern regarding human resources in I4.0 (Zeller et al., 2018). Communication technologies alone are insufficient if people do not use them appropriately (Telukdarie et al., 2018) to gather data from customers and products, manufacturing, and logistics (Hecklau et al., 2017). While the different enterprise systems – such as Enterprise Resource Planning (ERP), Supply-Chain Management (SCM) systems, Management Information Systems (MIS), and Product Life cycle Management (PLM) – support their tasks very well, their data are often stored in separate databases and partly stored in different formats. This sub-optimal level of integration must be improved for implementing I4.0 business processes, so the information must be accessible and useable at the right time in the right 'place' along the entire supply-chain and for all business partners (Leyh et al., 2016).

4.2.8. Training

Continuous training enables people to handle new technologies, interpret data and understand its impact on the whole process (Pessl et al., 2017). I4.0 increasingly depends on highly qualified people who adapt to new business processes and respond quickly to competitive challenges (Hecklau et al., 2017). There is a need for new platforms for on-the-job training and personnel qualification (Vrchota et al., 2019). Talent management is the set of practices related to the acquisition, development, and promotion of an organization's talents, such as training and development; succession management; career management; and compensation (Gamache et al., 2020).

4.2.9. Culture of innovation

Organizational culture is generally defined as a 'complex set of values, beliefs, assumptions, and symbols that define how a firm conducts its business' (Barney, 1986). Regarding I4.0, organizational culture is associated with people's assumptions about the transformation shared across all hierarchical environments in the company (Schumacher et al., 2016). It is 'a pattern of shared basic assumptions that was learned by a group as it solved its problems of external adaptation and internal integration, that has worked well enough to be considered valid . . . to new members as the correct way to perceive, think, and feel about those problems' (Merkus et al., 2020). In the I4.0, the main characteristics of the culture of innovation are: 'agility' and 'willingness to change':

- 'Agility': agile manufacturing is an organization's ability to create value and delight its client while promoting and adapting – in time – to changes in its environment. 'Agility' refers to easier attending to customer changes, adapting to different contexts, or new and disruptive challenges imposed by competitors (Zeller et al., 2018).
- 'Willingness to change': means that new endeavors must be faced bringing improvement opportunities for people in terms of work enrichment and personnel competencies (Mittal et al., 2018). If a company fosters a culture of change and establishes processes that value it, digital transformation efforts will be easily implemented.

The theoretical limits of the 3D-CUBE Model for organizational enablers (when the readiness vector is (x, 0, 0), where x = 1, 2, 3, 4, or 5) present a situation where a company focuses on organizational enablers but invests in few technologies and has not enough process maturity as required to accomplish I4.0 potentials.

4.2.10. Technological enablers

In the context of I4.0, the technological dimension is at the center of discussion (Schneider, 2018). The following sub-dimensions have been included:

(1) Production technology
(2) Information technology

(1) Production technology aims at supporting humans in their increasingly complex work context and is one of the most prominent research areas in I4.0 (Kadir et al., 2019). The ergonomic support can be digital or physical (Bücker et al., 2016) and can cover anthropomorphic skills, cognitive skills, and managerial skills (Iida & Buarque, 2016). A general discussion of employee safety is backgrounding in the ergonomic context of supporting technologies (Badri et al., 2021). Moreover, a discussion regarding the reliability of artificial intelligent objects in the production process, mainly for cognitive and managerial support must envelop this whole discussion. New technologies enable off-site manufacturing (Dilberoglu et al., 2017). The 'production technology' can be present in four areas: 'anthropomorphic support systems', 'cognitive support systems', 'managerial support systems', and 'driving network production'.

4.2.11. Anthropomorphic support systems

A robot is an anthropomorphic support system once it allows increasing the productivity of human labor from the physical point of view. Anthropomorphic support (Falzon, 2007) implies an ample utilization of robotics along the value chain: manufacturing processes, as primary use-cases for support when there are anthropomorphic limits for humans (painting, forging, pressing, or welding), as well as assembly processes. Some logistic processes, such as material handling and picking, are also suitable for technological support (Gualtieri et al., 2021). In a CNC machine, you can change tools automatically and turn the machining shaft of the part without operator interference. These human factors elements belong to the production technology because the operator is part of the productive system (Iida & Buarque, 2016).

4.2.12. Cognitive support systems

Cognitive ergonomics deals with mental processes related to interactions between people and other system elements, such as perception, memory, reasoning, and motor response. Relevant topics include mental load, decision-making, human-computer interaction, stress, and training (Iida & Buarque, 2016). So, cognitive support systems, such as mobile apps, tablet-based interfaces, industrial panels, or AR/VR devices (Lanyi & Withers, 2020) are also ergonomic solutions applied to I4.0 processes (Iida & Buarque, 2016). The company must design the interfaces to help line workers, intermediate managers, and other employees. Intensive knowledge-based operations such as technical sales, after-sales services, maintenance, and scheduling are important application areas for cognitive support (Rauch et al., 2020). Cognitive work analysis is suggested to design well-structured jobs (Guerin et al., 2019).

4.2.13. Managerial support systems

Managerial support systems deal with the management tasks of all organizations (Iida & Buarque, 2016; Rauch et al., 2020). The managerial body needs simpler and highly focused information to permit fast decision-making. Top and middle managers have specific user requirements for their daily activities, weekly appointments, and tracking goals and metrics for the design of decision support systems.

4.2.14. Driving network production

The last element, 'driving network production,' comprises technologies like additive manufacturing, which enable not only the main manufacturer to produce the full product or parts of it, but various actors in the value chain by the concept of shared manufacturing (Yu et al., 2020), even the final consumer (Dilberoglu et al., 2017).

(2) Information technology is differentiated into the following elements: 'data collection, analysis, interconnectivity, and transparency', 'information security', and 'decentralized decisions'.

4.2.15. Data collection, analysis, interconnectivity, and transparency

Data collection, analysis, interconnectivity, and transparency are operated in a business by acquiring, controlling, protecting, delivering, and improving the quality of the data and information assets. So, it can be broken down into three elements: collection, integrity (and quality), and data delivery.

Data collection means the data analysis, design, implementation, deployment, maintenance, and mechanisms for capturing and transferring data in an operating system (Merkus et al., 2020). Data quality means that the data provided to employees allows analysis and decision-making based on valid information. Data integrity represents activities that maintain the context, consistency, standardization, and sharing of accurate, up-to-date, and relevant information (Gamache et al., 2020).

Data analysis defines the transformation process from data into information. The degree of digitization and interdependence of production plants is increasing, directly resulting in an increasing amount of data. The literature describes data analysis along four levels: first, the descriptive analysis describes the evolvement from data to information. In the next step, cause-effect relationships are revealed by conducting a correlation analysis (diagnostic analysis). The predictive data analysis predicts future events by simulation methods. Last, prescriptive data analysis provides recommendations for action by optimization and simulation approaches. Within an I4.0 environment, a large and poly-structured amount of data is available and exceeds traditional analytic methods ('Big Data') which can be used for forecasting machine failures or optimizing the production planning process (Stich et al., 2017).

Interconnected company data implies 'to enable real cross-domain and inter-company collaboration, [to make] context-aware data from production, development, and usage [. . .], available in real-time, at a reasonable tier of granularity, and in a potentially global scale' (Pennekamp et al., 2019). When it comes to interconnection, a company should be integrated horizontally and vertically to allow for a continuous exchange of data and information (Kagermann et al., 2013). The horizontal integration must go across the entire value chain. Indeed, a company needs an adequate data management system to support integration and allow all users access to the same data set (Zeller et al., 2018). The information must always be linked to the product, work, process instructions, and customer information (Zeller et al., 2018).

Through the collection of data from connected objects and people in real-time, information transparency is achieved. Linking this data to digitalized models makes it possible to create a virtual copy of the physical world. Hence, all objects and people access relevant data (Bücker et al., 2016).

4.2.16. Information security

Information security, or 'cybersecurity', can affect internal storage, cloud services, and inter and intra-enterprise communications. Cybersecurity includes developing, planning, and implementing security procedures to prevent breaches, information leaks, and piracy (Gamache et al., 2020). An Information Security Management System (ISMS), according to the ISO/IEC 27001, is the system to ' … establish, implement, operate, monitor, review, maintain and improve information security'. ISO/IEC 27001 defines the requirements and process for implementing an ISMS. However, implementing this standard without a detailed plan can burden organizations (Proença & Borbinha, 2018). The increasing integration of information systems, human factors, and other contributors bear the risk of criminal attacks. The potential damage these attacks can cause increases in proportion to the degree of integration. IT security encompasses different strategies for identifying and implementing security measures. Compliance with standards such as IEC-62443 can help contain the risks (Stich et al., 2017).

4.2.17. Decentralized decisions

Decentralized decisions refer to the possibility of making informed decisions as autonomously as possible by both systems and humans since they can access relevant data (Ibarra et al., 2018). Analytics is one of the main pillars of I4.0. Nowadays, it is clear that manufacturing companies have to learn to manage and use a large amount of data, once advanced analytics can transform these data into useful information (De Carolis et al., 2017).

The theoretical limits of the 3D-CUBE Model for technological enablers (when the readiness vector is (0, y, 0), where y = 1, 2, 3, 4, or 5) probably depict the most common empirical situation when applying the Model in real cases. It characterizes a situation where a company solely focuses on implementing new technologies in some areas but does not yet leverage the full technology potential. For instance, in Brazil, companies seek to connect to I4.0 through technological facilities. They want to introduce technology to reduce costs, especially labor. It turns out that the focus on technology usually delivers underutilized solutions. The company has, for example, an ERP SAP system with all possible modules, but people are not trained, do not know how to use the system, or have difficulty understanding the unfolding of the work in other areas. The organizational enablers and the process maturity are low, so the technology is underutilized. Therefore, its technology aspirations are not supported by its organizational enablers or its process maturity, which is displayed in the 3D-CUBE Model.

4.2.18. Process maturity

A process is ' . . . a set of structured activities and measures aimed at resulting in a product specified for a particular customer or market' (Davenport, 1994). Three kinds of processes are present in companies: business processes, organizational processes, and managerial processes. Business processes connect customers to the company value chain, while organizational and managerial processes focus on decisions regarding the company's resources. Organizational and managerial processes are treated in 3D-CUBE as organizational enablers. To analyze maturity, we focus on the value under the concept of the product life cycle, Simetinger and Zhang (2020), including product development, process development, procurement, and manufacturing.

In the 3D-CUBE, the procedural views found in Zeller et al. (2018), Agca et al. (2017), and De Carolis et al. (2017) are considered for the process maturity evaluation in the value chain, similar to CMMI. Therefore, it includes two main processes:

(1) Product-service development
(2) Order fulfillment

(1) Product-service-based development addresses the effort to meet customer requirements based on customization, product-service systems, and shared manufacturing (Tukker & Tischner, 2006; Yu et al., 2020; Li et al., 2019), and implies a simultaneous development of products and services (Kaltenbach et al., 2018). The six levels follow similar reasoning as stated for the previously discussed sub-dimensions. This sub-dimension comprises the following elements: 'cross-company engineering, research, and development', 'customer-based new product development', and 'supply-chain development'.

4.2.19. Cross-company engineering, research, and development

'Cross-company engineering, research, and development' implies an innovation process integrated horizontally and vertically (Durakbasa et al., 2019). Interdepartmental integration in NPD projects comes from concurrent engineering discussions in the nineties (Patil et al., 2019). Today, a company must be innovation-driven, which means every department must be involved to provide ideas regarding new products or businesses (Schneider, 2018).

4.2.20. Customer-based NPD

Customer-based NPD is a customer-centered approach (Norman, 1988) that puts the client at the center of the NPD effort in digital servitization BMs (Kohtamäkia et al., 2019). In doing this, new products will take a form of a co-created design, partly with physical products but also as value-added services in IT platforms and VR/AR (Miranda et al., 2019). IT/cloud-based tools result from technological enablers in I4.0, which can directly connect customers to companies (Müller et al., 2018). Every company can use these connections to explore new business opportunities, even if they are not directly linked to its core business. Knowledge creation and management are essential issues here (Dragicevic et al., 2020), as well as the use of 'Big Data' (Lee, 2018) and cloud computing (Wu et al., 2020). Customer experience represents the efforts to provide more than one product to the customer in terms of design, associated service, and communication throughout the product lifecycle. It includes co-creation and open innovation, which represents using partners or crowds to develop new products and processes (Gamache et al., 2020).

4.2.21. Supply-chain development

Supply-chain development is centered on optimizing a value chain's efficiency to increase its profitability (Winkelhaus & Grosse, 2020). Procurement, as well as stocks in the supplier, have to be synchronized. Only then a 'one-piece flow' inside a manufacturing plant is achievable (Valamede & Akkari, 2020). According to Barbalho and Rozenfeld (2013), the supply-chain design is architected into the NPD process. It includes the development of the manufacturing, assembly, supply, and distribution structures. So, production design and supply-chain consist of the activities related to 'process engineering' and the design and development of the manufacturing structure necessary to introduce the product into the company's production line.

(2) The order fulfillment sub-dimension integrates the entire manufacturing process, from production to product delivery (Vollmann et al., 2005). Production is the main value-adding chain inside a manufacturing company and has been the primary focus of I4.0 MMs (Zeller et al., 2018). However, in the new technological context, logistics are also to be integrated (Winkelhaus & Grosse, 2020). Business logistics was born with a vision of integration. In this case, it means there would be greater possibilities of integration without needing so many specialized systems using step technologies or others. Furthermore, in an I4.0 approach, an international player must plan long, medium, short, and last-mile terms for product delivery (Rauch et al., 2020). It is subdivided into a 'customized-based production system', 'sales and operations integration', and a 'smart quality management system'.

4.2.22. Customized-based production system

A customized-based production system has been a long-term goal for process improvement activities. Customization means offering the customer an individual approach that meets specific needs (Gamache et al., 2020). New IT solutions, robotics, IoT, and smart architectures of cyber-physical systems enable production customization and small batches (Valamede & Akkari, 2020). Consequently, the whole production planning, resource planning, and the shop floor can be re-aligned to customized production. Using data and information technology enables the development of new BMs and creates new value for the customer.

4.2.23. Sales and operations integration

Sales and operations integration covers the traditional sales and operations planning of the main operations management literature (Vollmann et al., 2005), such as marketing and customer feedback. Still, it can be improved and highlighted by I4.0 technologies (Kotler & Keller, 2009; Vaz et al., 2019). First, the medium-term planning horizons can be shorter to reduce inventory and manufacturing costs. Secondly, new technologies can bring more agility to sales and operations decisions, gathering current data, enabling better communication, and supporting the decision-making processes. As in other integrative demanding areas, people must be aware of the integration's effectiveness (Hecklau et al., 2017). The degree of integration of an operations network, in general, can be measured by the number of connections between two companies.

4.2.24. Smart quality management system

Quality management considers that increased product quality is achieved through real-time monitoring and continuous optimization (characteristic of the smart factory). Enhanced predictive and detective approaches allow quality defects to be spotted sooner than later. In addition, the system can facilitate the identification of the root causes of defects, whether human, machine or environmental. Interviewees cited the benefits of lower scrap rates and reduced incidence of product defects and recall (Sjödin et al., 2018).

The theoretical limits of the 3D-CUBE Model for process maturity enablers (when the readiness vector is (0, 0, z), where z = 1, 2, 3, 4, or 5) is also a hypothetical case in which a company has more emphasis on process maturity than on organizational or technological enablers. It works effectively with partners along the supply-chain, its order fulfillment is integrated, its NPD involves customers and happens throughout a company's departments, and its sales and operations interfaces work harmonically. However, it does not have top management support for an I4.0 transformation, people are averse to change, and no investments are made in new technologies.

5. Methodology of readiness vector calculation

The 3D-CUBE was built in the form that a company readiness evaluation can be done by self-assessment or interview using the questionnaire available in Appendix B. It can help the analyst build propositions for the most suitable improvements because once a determined level is detected for a model element, the description of the next level will give guidelines for process improvement.

In 3D-CUBE Model, the company evaluation focuses firstly on each element. So, the elements are evaluated and receive a score from 0 to 5. Each sub-dimension will receive the same score from its respective element that has obtained the lowest score, i.e. the scores of all elements of a specific sub-dimension will be compared, and the lowest score found will be the sub-dimension score. The same logic applies from the subdimension to its respective dimension score.

So:
R = READINESS = [0, 5]
X = the lower value between (X_1, X_2)
Y = the lower value between (Y_1, Y_2)
Z = the lower value between (Z_1, Z_2)
Where: X_1, X_2, Y_1, Y_2, Z_1, Z_2 = [0, 5]

So, for each subdimension (X_1, X_2, Y_1, Y_2, Z_1, Z_2), the evaluation includes its elements:

X_1 = the lower value between (X_{11}, X_{12}, X_{13}, X_{14})
X_2 = the lower value between (X_{21}, X_{22}, X_{23}, X_{24})
Y_1 = the lower value between (Y_{11}, Y_{12}, Y_{13}, Y_{14})
Y_2 = the lower value between (Y_{21}, Y_{22}, Y_{23})
Z_1 = the lower value between (Z_{11}, Z_{12}, Z_{13})
Z_2 = the lower value between (Z_{21}, Z_{22}, Z_{23})
Where: X_{11}, X_{12}, X_{13}, X_{14}, X_{21}, X_{22}, X_{23}, X_{24}, Y_{11}, Y_{12}, Y_{13}, Y_{14}, Y_{21}, Y_{22}, Y_{23}, Z_{11}, Z_{12}, Z_{13}, Z_{21}, Z_{22}, Z_{23} = [0, 5]

As the 3D-CUBE has three dimensions, that is, three enablers, the company's final score will be a 3D vector, according to Table 2.

As mentioned, in 3D-CUBE, there was a '3D-CUBE Questionnaire' with 21 main questions to evaluate each element (Appendix B). Based on these answers, each element will receive a score. Therefore, the company will have a final vector score (X,Y,Z), which is its final result about the readiness for I4.0.

Once there is a difficult-to-understand tri-dimensional vector, our internet-based questionnaire will present a radar chart as a report (see, Figure 5), allowing a more in-depth analysis of possible improvements to be implemented. Lastly, the Model's elements can be evaluated and offer even deeper analysis and suitable improvement solutions. The radar charts are associated with the theoretical limits presented at the end of the description of each dimension.

In this example, there are four graphics: in the first one, the company only focus on technological enabler, not investing in the two others. It also happens for graphics 2 and 3, in which the company focuses on organizational enablers and process maturity, respectively. The last graph is a typical evaluation, where many companies fit in, considering investments in several areas with different readiness levels.

Table 2. Readiness vector matrix (source: Author).

LEVEL	READINESS VALUES MATRIX: R (X,Y,Z)						
0	(0,0,0)	(0,0,1)	(0,1,0)	(1,0,0)	(0,1,1)	(1,1,0)	(1,0,1)
1	(1,1,1)	(1,1,2)	(1,2,1)	(2,1,1)	(1,2,2)	(2,2,1)	(2,1,2)
2	(2,2,2)	(2,2,3)	(2,3,2)	(3,2,2)	(2,3,3)	(3,3,2)	(3,2,3)
3	(3,3,3)	(3,3,4)	(3,4,3)	(4,3,3)	(3,4,4)	(4,4,3)	(4,3,4)
4	(4,4,4)	(4,4,5)	(4,5,4)	(5,4,4)	(4,5,5)	(5,5,4)	(5,4,5)
5	(5,5,5)						

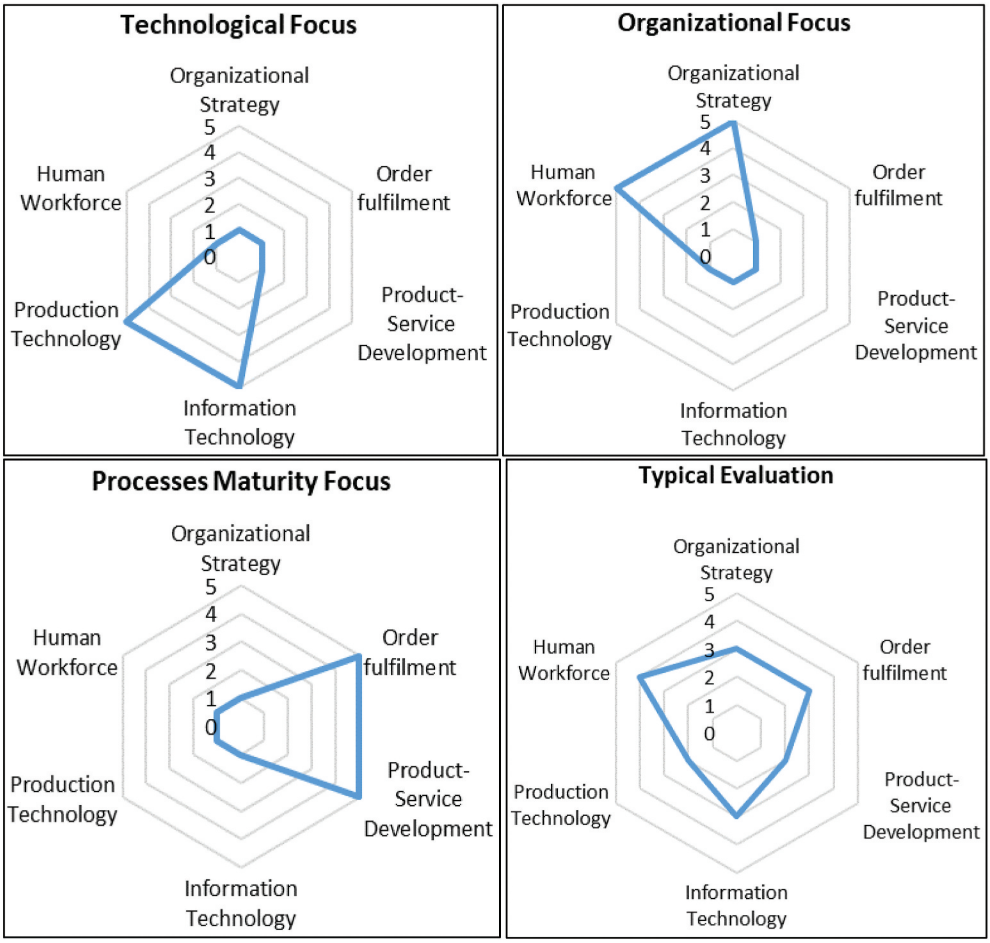

Figure 5. Analyzing the sub-dimensions of the 3D-CUBE model. source: authors.

6. Discussion and conclusion

This article proposes the 3D-CUBE, a Readiness Model for Industry 4.0 built by sound theoretical and empirical effort. The systematic literature review was performed with a specific 8-Steps Search Flow. It made it possible to select information from 486 relevant studies found in 10 databases, considering 63 existing MMs and all the scientific literature on this subject worldwide. The final purpose was to build a feasible MM to compare Brazilian and German companies in the I4.0 landscape.

The 3D-CUBE is elaborated, with 3 dimensions (X = Organizational Enabler, Y = Technological Enabler, and Z = Process Maturity Enabler), 6 sub-dimensions, and 21 elements, including a scale of 0 to 5 to assess the company readiness level.

The Model was applied in two situations. The first was a practical application in a manufacturing company that produces metal-based components for civil construction. In this case, a manager well-familiarized with Industry 4.0 concepts answered the whole questionnaire and was asked to give feedback regarding her perception of the concepts of maturity, readiness, and the whole Model. Moreover, a report was sent to the company. A follow-up is happening with new visits to its site and a discussion about the demanded improvements to reinforce the company's readiness for Industry 4.0. In general, this application brought about changes in the sub-dimensions of maturity analysis.

In the sequence, the second scrutiny was an expert validation. To do it, the whole Model was presented to a set of professors from Brazil and Germany, and they gave feedback and suggested better clarity on some issues. Propositions PROP 1 and PROP 2 were discussed and consensued by the set of researchers. The version presented in this paper is based on these contributions.

As a practical contribution, it can be suggested that the 3D-CUBE overcame the flaws of the analyzed models. It was built to be practically applied in companies. It presents an easy application form, provides a practical and complete methodology for data collection (survey), calculating a tri-dimensional readiness vector R = (X,Y,Z), that results in a value for future comparison, and allows analyzing the readiness level of companies, showing a radar chart for easy understanding of its improvement profiles. The questionnaire provides an easy way of seeing what can be done to increase the company's readiness for Industry 4.0.

As a theoretical contribution, based on the existing MM's shortcoming, 3D-CUBE contributes to this research stream with dimensions, subdimensions, elements, enablers, and granularity levels, defined and structured in an unprecedented way, besides considering, for the first time, maturity as an 'input' enabler for the company readiness evaluation, and not as an 'output' like in all existing other models (PROP 2). The Model conceptualizes maturity as an input dimension to evaluate readiness. This statement can be used as a hypothesis for a large set of research, from practitioners' perceptions to qualitative reflections from empirical data gathered in companies. What maturity means in practice? What does 'to be ready' mean? What do these concepts mean in real situations in Industry 4.0 and other kinds of improvement programs?

To go on in the validation and application of 3D-CUBE, we made propositions about the main model assumptions in search of contributing to understanding these relationships between maturity and readiness for I4.0 (PROP 1 and PROP 2). We also refer to it as the theoretical limits of the 3D-CUBE. The first two propositions already have an expert validation, but we would like to stress this understanding with numerous sets of experts from Brazil and Germany. Regarding the empirical validation, we expect to find numerous situations in which the technological dimension of the Model is dominant. It will probably be the case for most Brazilian companies, which need to build the appropriate organizational enablers in an economic crisis and find that technological enablers are paths to reducing labor hours. German companies might have a stronger balance among technological and organizational enablers. A strict focus on maturity would probably be the least common profile. An interview-based protocol will stress this issue in future works when this Model will also be longitudinally applied in some companies to test its application as an improvement tool. A 3D-CUBE Roadmap will be developed to guide strategies, based on the 3D-CUBE Questionnaire results, to improve their readiness through the digital transformation context.

The 3D-CUBE has some limitations. The Model was mainly built by deduction from the literature analysis and observation of the current business environment in Brazil and Germany. Although it was tried in a company and submitted to specialist feedback, it has few falsifiability tests and is strongly based on deductive thinking. Consequently, as the majority of current MMs for I4.0, most of its dimensions, sub-dimensions, and elements can be seen as a hypothesis. Specific research protocols can be built to stress the Model on real-based situations to test specific concepts. For example, a research protocol can explore the relations between product-service development and order fulfillment for a specific company. Are these processes enough to characterize process maturity? And, how deep is the influence of technology enablers on them? Is there an input-output relation between organizational and technological enablers and process maturity? Only empirical data can help us to answer some questions. Building a model as the 3D-CUBE in a so untimely historical moment brought to the research team many questions. Only specific protocols can help to clarify all the elements mixed in the Model. A focus group with industry experts is planned to evaluate the appropriateness of the granularity of the 3D-CUBE Model's dimensions, sub-dimensions, and elements.

The Model has another limit by focusing on manufacturing companies. Therefore, its applicability is limited to these companies, and the transferability to other industries is not yet addressed. Once I4.0 is outside the limits of the manufacturing industry and impacts from agriculture to services in general, accurate analysis and tailoring must be done before trying to implement 3D-CUBE in these sectors. That is a question to be addressed in future research.

Moreover, the questionnaire will be published in an internet-based form to get anonymous feedback once it is built to allow self-assessment. Future research can evaluate the applicability of 3D-CUBE in this open-access format. Possibilities of cross-checking among an internet-based filling, and presential-based application, can be interesting to understand possible differences in model dimensions, sub-dimensions, and elements. Furthermore, the Model was built thinking on our best knowledge of technology trends, but how can new frontiers such as nanotechnology or quantic computing impact the landscape of process improvements in the industry? Future research can wonder around these expectations, and 3D-CUBE is a sound framework to exploit them.

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Appendix A: Analysis of 63 MMs, Source: authors

N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
1	R. L. Nolan	EUA	1973	General Enterprises	Computer Resource MM	Computer Resource	(1) Priority setting(2) Budget(3) Computer operations(4) Programming control(5) Project management(6) Mgt. reporting system(7) Data base policies(8) Chg. out/non-chg. out systems (9) Audits(10) Quality control (11) Manual systems and procedures	1: Initiation 2: Contagion 3: Control 4: Integration	Maturity	Yes	Topic not applicable nowadays. This model was important for later models but had old templates and no web application. Similarly, some models use delayed data of the enterprises, so they are no longer up-to-date.
2	K. Lichtblau et al.	Germany	2015	Large and SME Enterprises (Mechanical, Plant Engineering and Manufacturing industries)	IMPULS	Smart Manufacturing	(1) Strategy & organization(2) Smart factory(3) Smart operations(4) Smart products (5) Data-driven services(6) Employees	0: Outsider 1: Beginner 2: Intermediate 3: Experienced 4: Expert 5: Top performer	Readiness	Yes	Lichtblau et al. (2015) state some questions of the online IMPULS form that do not follow a profile of the six levels as the maturity model proposes. It brings a question of why they appear in the form. Moreover, a juxtaposition of dimensions, for example, among smart factories and smart operations, could generate doubts for respondents regarding the clarity of each dimension and their questions to answer. It emphasizes the process view without tracking the common company functions such as engineering, marketing, manufacturing, and finance; however, most companies are structured in these functional units. Therefore, it can be difficult to identify the right person in a company who is familiar with the model's queried information. The model is only empirically grounded.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
											It uses a questionnaire, but it is not transparent and not validated, and it has just an online self-assessment based on a questionnaire. It doesn't describe an assessment method; it is for readiness only and doesn't consider all organizational aspects. The model is only empirically grounded. The model does not consider a few key technologies such as AI, AR, VR, smart glasses, and Blockchain Technology. The weights of each dimension are decided but not for the items, and they are decided only with the help of a survey conducted in the firms.
3	M. C. Paulk, B. Curtis, M. B. Chrissis, C. V. Weber	EUA	1993	General Enterprises	CMM (Capability Maturity Model)	General	(1) Commitment to perform (2) Ability to perform (3) Activities performed (4) Measurement and analysis (5) Verifying implementation	1: Initial 2: Repeatable 3: Defined 4: Managed 5: Optimizing	Capability	Yes	Traditional models, like CMM and its variations, were built only for well-established processes, such as software or product development. However, the outcomes of the new industrial revolution are still uncertain, especially when the processes involved are not known. So, the CMM is not a silver bullet and does not address all the important issues for successful projects in Industry 4.0. For example, it does not currently address expertise in particular application domains, advocate specific software technologies, or suggest how to select, hire, motivate, and retain competent people. However, these issues are crucial to a project's success.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
4	A. Schumacher et al.	Austria	2016	General Manufacturing Enterprises (not SME)	I 4.0 Schumacher MM	Smart Manufacturing	(1) Strategy(2) Leadership(3) Customers(4) Products(5) Operations(6) Culture(7) People (8) Governance(9) Technology	1: Complete lack of attributes 2: (no info) 3: (no info) 4: (no info) 5: State-of-the-art	Maturity	Yes	Schumacher et al. (2016) lack a process view connecting the whole supply chain. The model didn't address the lean aspects or identify improvement opportunities or a roadmap for further developments. Furthermore, an SME perspective is also missing from the model. It uses a validated questionnaire, but it is not a transparent methodology. It doesn't have a maturity definition or just general recommendations. The model extends existing maturity models and focuses on discrete manufacturing firms. It lacks details regarding maturity items and inadequate information regarding maturity levels.
5	M. B. Chrissis et al.	EUA	2003	General Enterprises	CMMI (Capability Maturity Model Integration)	General	(1) Systems Engineering(2) Software Engineering	0: Incomplete – Doesn´t have any process 1: Performed – No support infrastructure 2: Managed – Not performed across the organization 3: Defined – Doesn't have way to measure and improve 4: Quantitatively Managed – Can quantitatively maximize business 5: Optimized – Has all of these carachteristics	Capability	Yes	Chrissis et al. (2003) state some clauses that are difficult to map. It is difficult to use and needs professional judgment to interpret the results, and input dimensions are difficult to understand. Output levels differ from Continuous and Staged representation capability levels. Not feasible for a web-based application.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
6	De Bruin et al.	Australia	2005	General Enterprises	BPM – MM (Business Process Management Maturity Model)	General	(1) Factor(2) Maturity Stage(3) Scope Organizational Entity(4) Scope Time(5) Coverage(6) Proficiency	1: Initial State 2: Defined 3: Repeated 4: Managed 5: Optimized	Maturity	Yes	This model is incomplete at this stage and the impact of their findings and success in overcoming/minimizing inherent criticism is unknown. At this stage, there is no empirical evidence for the correlation between the factors of the BPMM model and BPM success. Further testing of the relationship between independent and dependent variables will be the core of future work.
7	C. Leyh et al.	Germany	2016	SME	SIMMI 4.0 (System Integration Maturity Model Industry 4.0)	IT and Software (digital integration technologies)	(1) Vertical integration(2) Horizontal Integration(3) Digital product development(4) Intersection of technologies (crosssectional technology criteria)	1: Basic Digitalisation 2: Crossed 3: Horizontal 4: Vertical 5: Total	Maturity	No	Leyh et al. (2016) are rather vague when describing how technology can be used for integration. Organizational enablers are treated as elements of maturity levels. Digital competencies and technologies outside the field of IT are not discussed. The model is simple to understand with a focus on the IT landscape in SMEs, but it doesn't have a questionnaire, assessment method described, or continuous assessment. It just has general recommendations. The scientific documentation of model development is missing, and it is not empirically developed, validated, and tested. The details about the maturity assessment and readiness level are missing. Derivated from RAMI 4.0 (The Reference Architectural Model Industry 4.0), the model is missing in crucial dimensions, like organizational awareness and cybersecurity.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
8	M. Kerrigan	Ireland	2013	General Enterprises	DI-CMM (Digital Investigations Capability MM)	Digital investigations	(1) Processes(2) People(3) Technology	1: Ad-hoc 2: Performed 3: Defined 4: Managed 5: Optimized	Capability	Yes	Kerrigan (2013) proposes the DI-CMM Model. It needs to be tested against more organizations to assess its usefulness fully as a benchmarking tool. While the DI-CMM has been developed with the needs of regulatory bodies and criminal investigations in mind, further refinement could make it applicable to various other sectors; for example, large corporations that maintain internal digital investigations capabilities.
9	R. Geissbauer et al.	USA	2016	Companies with morethan 500 employees, interaction company-customer	PwC SA (Price Waterhouse Coopers)	SCM scope	(1) Processes & Infrastructure(2) Vision, Strategy & Business Model (3) Customer Engagement(4) People, Culture, Governance & Organisation(5) Product and service portfolio(6) Market and customer access(7) Value chain (8) IT architecture(9) Compliance, risk, security, tax	1: Beginner 2: Vertical Integrator 3: Horizontal Collaboration 4: Digital Specialist	Readiness	Yes	Geissbauer et al. (2016) is a consulting-based model, not an applied scientific effort. The maturity dimensions are not elaborated on in detail. Considering it was proposed in 2016 when the effort to propose maturity models was starting, some maturity levels and dimensions lack synergy. It doesn't use a traditional questionnaire and a transparent methodology. It has just an online self-assessment. The scientific documentation of the model is missing.
10	Rockwell Automation Inc	USA	2014	General Enterprises	ROCKWELL	Smart Manufacturing	(1) Customer-focused innovation (2) Process improvements(3) Supply Chain management & collaboration(4) Human-resource management(5) Sustainability(6) Global engagement	1: Assessment 2: Secure & upgraded network and controls 3: Defined & organized working data capital 4: Analytics 5: Collaboration	Readiness	Yes	It uses a validated questionnaire but is not a transparent methodology with no explicit assessment approach. The model focuses only on the facets of the existing IT/OT network and inadequately addresses the organizational and operations-related dimensions. The model has insufficient details about its structure and maturity items and notably lacks scientific documentation.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
11	J. Ganzarain, N. Errasti	Spain	2016	SME	3SMM (3 Stage MM)	Smart Manufacturing	(1) envision(2) enable(3) enact	1: Initial 2: Managed 3: Defined 4: Transformation 5: Detailed Business Model	Maturity	No	Doesn't have questionnaire.
12	B. Gajsek et al.	Slovenia	2019	General Enterprises	FDMM4.0 (Forrester Digital Maturity Model 4.0)	General I4.0	(1) Culture(2) Organisation(3) Technology(4) Insights	1: Skeptics 2: Adopters 3: Collaborators 4: Differentiators	Capability	Yes	Gajsek et al. (2019) presents a digital maturity model that is useful for general diagnostics but insufficient for more detailed improvement planning.
13	G. Schuh et al.	Germany	2016	General Enterprises	ACATECH Industrie 4.0 Maturity Index	General	(1) Resources(2) Information Systems(3) Corporate Culture (4) Organisational Structure	1: Informatization/ Computerisation 2: Connectivity 3: Visibility 4: Transparency 5: Predictive Capacity 6: Adaptability	Maturity	No	Despite its well-integrated concepts, it lacks clarity in its evaluation, with few and incomplete examples provided. Moreover, the suggested improvements are area-specific. Consequently, the model only suggests capability improvements, not maturity improvements, which can strengthen differences in silo-areas. A lack of technology consideration for the proposed process analysis makes it difficult to comprehend the differences between the maturity analysis for Industry 4.0 and a generic improvement analysis for increasing something in the company´s performance. Even though the study is designed specifically for manufacturing companies, a section dedicated to Lean Production Systems (LPS) or existing production systems is missing. The model is also missing the perspectives concerning SMEs. It has a proposal of generic archetypes related to the different digital maturity stages but no explicit indications of activities for enabling maturity stage transition. It has just general recommendations and doesn't have a continuous assessment. Detailed information regarding the structure of the model is given, but the quantitative assessment process is missing.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
14	E.Gökalp et al.	Turkey	2017	General Enterprises	SPICE MM	Smart Manufacturing	(1) Asset Management(2) Data Governance(3) Application Management(4) Process Transformation(5) Organizational Alignment	0: Incomplete 1: Performed 2: Managed 3: Established 4: Predictable 5: Optimizing/ Innovating	Maturity	No	Gökalp et al. (2017) don't have a questionnaire and assessment method described. It is not a transparent methodology, and it has just general recommendations. The readiness evaluation process is not explained in detail, and the model lacks an account of scientific and empirical-based development. There is no testing and validation of the model in real-life applications.
15	A. De Carolis et al.	Italy	2017	General Enterprises	DREAMY (Digital REadiness Assessment MaturitY)	Smart Manufacturing	(1) Processes(2) Control(3) Monitoring(4) Organization(5) Technology	1: Initial 2: Managed 3: Defined 4: Integrated & Interoperated 5: Digitally Oriented	Maturity	Yes	De Carolis et al. (2017) did not explore the technological enablers of its interconnectivity dimension. It has a validated questionnaire, but it is not a transparent methodology. There are no explicit indications for maturity improvement. It doesn't have an assessment method described and presents just general recommendations.
16	C. Weber et al.	Germany	2017	General Enterprises	M2DDM (Maturity Model for DataDriven Manufacturing)	Smart Manu facturing, IT architecture, IoT	(1) Data storage and compute(2) Service oriented architecture(3) Information integration(4) Digital twins(5) Advanced analytics(6) Real-time capabilities	0: Nonexistent IT integration 1: Data and system integration 2: Integration of Cross-lifecycle data 3: Service orientation 4: Digital twins 5: Self-optimising factory	Capability	No	Doesn't have questionnaire.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
17	O. Agca et al.	United Kingdom	2017	General Enterprises	WMG (The University of Warwick)	General	(1) Strategy & Organization(2) Products & Services(3) Manufacturing & Operations(4) Supply Chain(5) Business Model (6) Legal Considerations	1: Beginner 2: Intermediate 3: Experienced 4: Expert	Maturity	Yes	Agca et al. (2017) present a model that lacks an alignment among maturity levels and technology applications. It doesn't have an assessment method described and has just general recommendations. The model structure is elaborated along with details about sub-dimensions. However, it has fewer details regarding maturity assessment and identification of maturity level. The model is not scientifically developed, and no empirical validation in a real-life environment is done.
18	E.Pessl et al.	Austria	2017	General Enterprises	Capability Human Roadmap 4.0 MM	Human	(1) Acceptance & Application of new Technologies and Media (2) Professional Competence(3) Learning Competence(4) Corporate Strategy(5) Human Resources Development Strategy(6) Organization & Democratization(7) Flexible Working Models(8) Health & Safety(9) Information & Communication(10) Employer Branding(11) Change Management(12) Process Orientation(13) Knowledge Management	1: I 4.0 is not considered 2: Company has begun to deal with I 4.0 3: Measures are implemented in some areas. 4: Measures are implemented by a majority 5: Measures are consistently implemented and evaluated	Maturity	Yes	Pessl et al. (2017) present a well-described but complex model where people from different divisions should ideally be included in the maturity assessment process. Moreover, the definition of the target requirements and the implementation of the final action plan become especially challenging if industry 4.0 has not yet been an embedded part of the overall strategy. It has a questionnaire not validated and is not a transparent methodology. It doesn't have an assessment method or continuous assessment and incorporates just general recommendations.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
19	SINGAPORE Economic Development Board (EDB)	Singapore	2017	General Enterprises	SINGAPORE READINESS INDEX	Manufacturing Enterprises	(1) Vertical Integration(2) Horizontal Integration(3) Leadership Competency(4) Strategy & Governance(5) Inter-Intra Company Collaboration(6) Integrated Product Life-cycle(7) Workforce Learning & Development	0: Undefined 1: Defined 2: Digital 3: Integrated 4: Automated 5: Intelligent	Readiness	Yes (tested by T. Lin, K. J. Wang, M. L. Sheng)	It is well-done research intended to analyze only manufacturing sites. However, first: the questionnaires were only distributed to Taiwanese enterprises within a specific industry, thus limiting the validity of the findings. Second, the subjects of this study are only manufacturers. Third, this study examines only manufacturing sites (not including executives and senior managers).
20	K. Y. Akdil et al.	Turkey	2018	General Enterprises (Retail Sector)	Akdil MM	SCM scope	(1) Smart products & services(2) Smart business processes(3) Strategy & Organization	0: Absence 1: Existence 2: Survival 3: Maturity	Maturity and Read iness	Yes	The diagnostic maturity form is unclear regarding the four levels for each question. It doesn't have a traditional questionnaire, just some complex architecture with an index to translate answers to a specific maturity level. The model fails to provide empirical validation of maturity items, and important levels of items and dimensions are not considered.
21	S. Mittal et al.	USA	2018	SME	SM3E (Smart Manufacturing Maturity Model for SMEs)	General	(1) Finance(2) People(3) Strategy (4) Process(5) Product	1: Novice 2: Beginner 3: Learner 4: Intermediate 5: Expert	Maturity	No	Mittal et al. (2018) present only one (digital) capability: "data-driven decision making".
22	L. Canetta et al.	Switzerland	2018	General Enterprises	Digitalization Canetta MM	Smart Manufacturing	(1) Strategy(2) Processes(3) Products & Services(4) Human Resources(5) Technologies	1: Absence 2: Beginner 3: Intermediate 4: Experienced	Maturity	No	In Canetta and Et. Al (2018), some steps were not available yet for analysis. It has a questionnaire, but it is not a transparent methodology.
23	S. Rübel et al.	Germany	2018	General Enterprises	Business Model Management MM	Business Model and SCM scope	(1) costumer segment(2) value proposition(3) channels(4) customer relationship(5) source of income(6) key resources(7) key activities(8) key partners(9) cost structure	1: Implicit 2: Defined 3: Validated/ Standardized 4: Analyzed 5: Optimized	Maturity	No	Rübel et al. (2018) don't have a questionnaire. Further development levels need to be reached to achieve satisfactory results.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
24	D. R. Sjödin et al.	Sweden	2018	General Enterprises	Sjödin MM	General	(1) Processes(2) People(3) Technologies	1: Connected Technologies 2: Structured Data Collection & Sharing 3: Real-time Process Analysis & Optimization 4: Intelligent & Predictive Manufacturing	Maturity	Yes	Sjödin et al. (2018) did not present the details of its dimensions, and the reported results suggest only a general analysis without the necessary granularity level to define process improvements.
25	F. Facchini et al.	Italy	2018	General Enterprises	Logistics 4.0 Facchini MM	Logistics/SCM scope	(1) management(2) flow of material(3) flow of information	1: Ignoring 2: Defining 3: Adopting 4: Managing 5: Integrated	Maturity	Yes	It is preliminary model. Just for logistics.
26	B. Asdecker, V. Felch, E. Sucky	Germany	2018	General Enterprises	DPMM 4.0 (Delivery Process MM)	Deliver Processes in Supply Chain (SCM)	(1) Plan(2) Source(3) Make(4) Deliver(5) Return(6) Enable	1: Basic digitization 2: Cross-department digitization 3: Horizontal & vertical digitization 4: Full digitization 5: Optimized full digitization	Maturity	Yes	Felch and Asdecker (2018) presented a MM validated through expert opinions and judgments. The model doesn't have a validated questionnaire, just a verified architecture. Moreover, the population and evaluation process were mostly based on experts from German industrial companies. Therefore, further research should consider a more international perspective.
27	J. Puchan et al.	Germany	2018	General Enterprises	I4-MMM/MUAS MM (Munich University of Applied Sciences)	General	(1) Key Factors(2) Employees(3) Organization(4) Product(5) Production	0: Basic Level1: Novice Level2: Advanced Level3: Expert Level4: Pioneer Level	Maturity	No	It is preliminary model.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
28	J. Tavčar et al.	Slovenia	2018	Automotive supply chain enterprises	Engineering Change Management MM	Lean criteria	(1) ECM process flow(2) Set-based CE(3) Chief engineer – technical leadership(4) Customer-defined value(5) Knowledge management(6) Continuous improvement culture	0: The criterion is not implemented at all. 1: There is a modest 2: The criteria are specified in written procedures, but are not practiced strictly in everyday work. 3: The criterion is practiced, but over 40% of employees do not recognize it as very helpful. 4: The criteria are defined and practiced at a good level, and are well accepted by 80% of employees. 5: The implementation of the criterion is at the top level, and can be used as a reference for others.	Maturity	Yes	In Tavčar et al. (2018), the ECM (Engineering Change Management) maturity assessment tool was tested and validated at eight automotive suppliers of different sizes, presenting state-of-the-art on this specific topic. So, there is a strong emphasis only on a reliable supply of automotive enterprises.
29	Y. Jin et al.	China	2018	SME	EMMMs (Energy Management Maturity Models)	Energy	(1) Energy Management System(2) Leadership(3) Planning(4) Support and Operation(5) Performance evaluation(6) Improvement	1: Initial 2: Managed 3: Systematic 4: Improved 5: Optimized	Maturity	Yes	In Jin et al. (2018), the main limitation of their model is that it presents difficulty to apply the SMEs in China, whose EM (Energy Management) practices were seldom summarized or even raised. Another limitation is that there are no standardized EM tools, although the first-stage standardization is moving forward. And this lack increases the difficulty of applying the maturity model.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
30	M. Colli et al.	Denmark	2018	General Enterprises (not SME)	360 Digital MM (based on PBL – Problem Based Learning)	Smart Manufacturing	(1) Governance(2) Technology(3) Connectivity(4) Value creation (5) Competence	1: None 2: Basic 3: Transparent 4: Aware 5: Autonomous 6: Integrated	Maturity	Yes	Colli et al. (2018) present no development of toolboxes to operationally address the improvement of each defined digital dimension and quantify the related potential. It has been tested only in large companies, not in SMEs. Further work has to be directed towards an efficiency improvement of the proposed assessment approach.
31	A. P. T. Pacchini et al.	Brazil	2019	General Industry Enterprises	SAE RM	General	(1) Cloud Computing(2) Cyber Physical System(3) Co-bots(4) Additive Manufacturing(5) Augmented Reality(6) Artificial Intelligence(7) IoT(8) Big Data	1: Embryonic 2: Initial 3: Primary 4: Intermediate 5: Advanced 6: Ready	Readiness	Yes	Pacchini et al. (2019) rely on only eight enabling technologies and a few prerequisites for each technology. The enabling technologies cannot have the same impact as far as I 4.0 implementation is concerned. In addition, the inter-relations among enabling technologies possibly affect the degree of readiness. The model is tested and validated only in a Brazilian auto-parts manufacturing organization.
32	L. Gaur et al.	India	2019	General Enterprises	IoT MM	IoT	(1) Strategy(2) IT(3) Data(4) Process (5) People(6) Assets(7) Products (8) Technology(9) Financial	0: No adoption 1: Work in Progress 2: Successful implementation & results	Maturity	No	It is preliminary model.
33	F. Pirola et al.	Italy	2019	SME	Pirola RM	Digital	(1) Strategy(2) People(3) Processes (4) Technology(5) Integration	1: $(1 < I \leqslant 1.8)$ not involved in I 4.0 2: $(1.8 < I \leqslant 2.6)$ intermediate 3: $(2.6 < I \leqslant 3.4)$ I 4.0 strategy & investing 4: $(3.4 < I \leqslant 4.2)$ already implementing 5: $(4.2 < I \leqslant 5)$ already implemented	Readiness	Yes	Pirola, Cimini, Pinto (2019b) do not extend capabilities assessments by defining specific roadmaps and action steps to drive the transition from the current maturity level to the desired one while considering SMEs' often limited resources.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
34	J. Vrchota et al.	Czech Republic	2019	General Enterprises	Human Vrchota RM	Human Resources/ Skills	(1) Technical(2) Personal	0: None1: Low 2: Medium 3: High	Readiness	No	Vrchota et al. (2019) analyze the employee competencies in Industry 4.0. However, national data of individual countries are always delayed by approximately 2 years, so it is always an analysis of data that is no longer up-to-date. Research does not include the economic situation of individual countries and market developments.
35	D. Trotta et al.	Italy	2019	SME	I 4.0 Trotta MM	General	(1) Strategy(2) Technology(3) Production(4) Products(5) People	1: not implemented/not present 2: (no info) 3: (no info) 4: (no info) 5: completely implemented/ present	Maturity	No	Trotta and Garengo (2019) present a preliminary model. Further research could improve the goodness of the proposed model, expanding the list of items emerging from the on-site feedback collection.
36	A. Toboła et al.	Poland	2019	General Enterprises	AI MM	Artificial Intelligence	(1) Management(2) Flow of material(3) Flow of information	1: AI Novice 2: AI Ready 3: AI Proficient 4: AI Advanced	Maturity	No	It is preliminary model.
37	F. Odważny et al.	Poland	2019	General Enterprises	ISO 9004:2000 MM	General	(1) Work environment(2) People(3) Communication(4) Mission, vision, values, culture(5) Natural resources(6) Infrastructure(7) Technology(8) Resource management(9) Organizational knowledge(10) Performance analysis(11) Selfassessment	1: Ignoring 2: Defining 3: Adapting 4: Managing 5: Integrating	Maturity	No	Odważny et al. (2019) propose a preliminary model with many lacks, such as a clear definition and specific value for each maturity level. This model will be ready for validation across companies with all values identified.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
38	R. C. Santos et al.	Portugal	2020	General Enterprises (automotive industries)	I 4.0 Santos MM	General	(1) Organizational strategy, structure & culture(2) Workforce(3) Smart factories(4) Smart processes(5) Smart products & services	0: low or none degree of implementation1: pilot actions 2: actions initiated, with some benefits 3: partial implementation 4: advanced implementation 5: reference in applying Industry 4.0	Maturity	Yes	Santos and Martinho (2020) developed a maturity model for Industry 4.0 to collaborate with companies to implement main related concepts and technologies and academics to understand the phenomenon better. The proposed model was adapted from three existing maturity models (Schuh et al., 2016), (Lichtblau et al., 2015) and (Schumacher et al., 2016), and a pilot test was performed on two Brazilian companies, both from the automotive industry. The main limitation of this research is the small number of professionals in the industry that participated in the validation phase of the model.
39	O. K. K. Bandara et al.	Sri Lanka	2019	General Enterprises	Banking MM	Bank processes	(1) Products & services(2) Technology & Resources(3) Strategy & organisation(4) Operations(5) Customers(6) Governance(7) Employees	1: Initial 2: Managed 3: Defined 4: Established 5: Digital Oriented	Maturity	Yes	The model of Bandara et al. (2019) can be further optimized by studying the importance of each dimension separately when calculating the overall maturity from a future research perspective.
40	G. Nick et al.	Hungary	2020	SME	CCMS (Company CoMpaSs)	Manufacturing	(1) Strategy & organization(2) Smart factory(3) Intelligent processes(4) Smart products(5) Services(6) Employees	Not considered	Readiness	No	It does not have information about output levels and hasn't been tested.
41	A. Azevedo et al.	Brazil	2019	General Enterprises	PIM 4.0 MM (Industrial Pole of Manaus)	Manufacturing	(1) Products and Services(2) Manufacturing(3) Business Model(4) Strategy(5) Supply Chain(6) Interoperability	Not considered	Maturity	Yes	Tested just in a pilot company. Doesn't have output levels.
42	R. Rojas et al.	Peru	2019	Security of Web Enterprises	Security of Web Attac MM	Security of web attac	Doesn't have, only has tests matrix	1: Incipient 2: Basic 3: Intermediate 4: Strategic 5: Optimized	Maturity	Yes	Just applicable for security of web. Doesn't have input dimensions.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
43	J. Basl	Czech Republic	2018	General Enterprises	Metamodel Basl	General	(1) ERP applications(2) Production planning(3) Workplace ergonomics(4) Security(5) Maintenance(6) Connectivity(7) Data & processes	Not considered	Readiness	No	Doesn't have output levels.
44	D. Li et al.	Sweden	2019	SME	Li CM	General I4.0	(1) Resources(2) Information systems(3) Organizational structure(4) Culture	1: 'World of Mouth'2: 'Pen and Paper'3: Computerization 4: Connectivity 5: Visibility 6: Transparency 7: Predictability 8: Adaptability	Capability	Yes	Li et al. (2019) have qualitatively assessed the Industry 4.0 capabilities of two case companies based on their employees' understanding of their working conditions. While previous research requires company managers to possess a certain amount of knowledge about Industry 4.0, this paper exhibits the possibility of exploring the subject based on individuals' situational awareness.
45	L. Joblot et al.	France	2019	General Enterprises	BIM2FR (Building Information Modeling Maturity Model For Renovation)	Renovation work	(1) Strategy(2) Foundations(3) Collaboration(4) Process(5) People(6) Technology(7) Standards(8) Enabling Tools(9) Resources	1: Pre-BIM 2: Modelling 3: Collaboration 4: Integration 5: Post-BIM	Maturity	Yes	Joblot et al. (2019) is just a preliminary model. In agreement with the work presented by De Bruin and Rosemann (2005), this BiM2FR will next be tested at a larger scale as a way to adjust the first version.
46	S. Elnagar et al.	USA	2019	General Enterprises	ARE-MMI4.0 (Agile Requirement Engineering Maturity Model for Industry 4.0)	Agile	(1) Technology(2) Governance(3) Products(4) Customers(5) Operations(6) Leadership(7) Strategy(8) Culture(9) People	1: Basic 2: Cross-departmental 3: Horizontal and vertical 4: Full digitization 5: Optimized	Maturity	No	Elnagar et al. (2019) presented the first version of ARE-MMI4.0, which is currently still at phase three, "populate", according to the general model (De Bruin & Rosemann, 2005). So, the next phases are the "evaluation" in developing the framework and the "action and observation" in integrating the maturity models, and the model still needs to be evaluated for user perception and technical excellence.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
47	D. Ifenthaler et al.	Germany	2020	General Enterprises	EOMM (Educational Organizations MM)	Educational Organizations	(1) Equipment and technology(2) Strategy and leadership (3) Organization(4) Employees(5) Culture(6) Digital learning and teaching	Not considered	Maturity	Yes	Ifenthaler and Egloffstein (2020) present practical concerns about organizational culture. Its model doesn't have output levels. An executive survey could provide valuable information on organizational conditions and cultural factors – 'digital leadership' (i.e. leadership that is in line with the affordances of digital transformation) is likely to play a crucial role. Doesn't have output levels.
48	R. G. G. Caiado et al.	Brazil	2020	General Enterprises	3M4.0 (Maturity Model for Manufacturing 4.0)	General	(1) Supply Chain Management(2) Technology(3) Sales & Operations Management(4) Knowledge, Skills & Attitude	1: Conceptual 2: Managed 3: Advanced 4: Self-optimized	Maturity	No	Caiado et al. (2020), through a systematic literature review, could demonstrate that no maturity model currently exists that meets the needs of manufacturing 4.0 in terms of socio-technical skills, production operations management, and supply-chain, considering the context of an emergent country. Therefore, as in (Leyh et al., 2016), 3M4.0 development is not yet complete.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
49	A. A. Wagire et al.	India	2020	General Enterprises	Digital Novice MM	Manufacturing	(1) People and culture (0.12)(2) Industry 4.0 awareness (0.06)(3) Organisational strategy (0.18) (4) Value chain and processes (0.17)(5) Smart manufacturing technology (0.13)(6) Product and services oriented technology (0.15)(7) Industry 4.0 base technology (0.18)	1.00 ≤ Mo < 2.00 Level 1: Outsider2.00 ≤ Mo < 3.00 Level 2: Digital Novice3.00 ≤ Mo < 4.00 Level 3: Experienced4.00 ≤ Mo ≤ 5.00 Level 4: Expert	Maturity	Yes	The maturity model of Wagire et al. (2020) is supported by prior literature, expert consultation and case study, and experts' judgment and opinion. Further efforts may be directed to measure the degree of readiness of the organization for Industry 4.0 as suggested by Pacchini et al. (2019), which is based on the assessment of prerequisites adopted by an organization for each maturity item mentioned in this study. Next, the important weight identification of each maturity item is based on opinions from a comparatively limited number of experts. Additionally, the existing model could introduce more maturity items related to legal and regulatory issues.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
50	V. M. Harokopio et al.	Greece	2020	Public Sevice	Organizational Interoperability MM	Organizational intero perability maturity	(A1) Procurement criteria(A2) Specification Process(A3) Design methodology(A4) Collaboration(B1) Compatibility (intergovernmental legislation) (B2) Certification(B3) Business Process Modelling(C1) Compatibility with EIF(C2) Compatibility with GDPR(D1) Procedural transparency(D2) User Feedback(D3) Service level Agreements(E1) Service Consumption(F1) Reuse and sharing(G1) Once-Only Principle(G2) Cross border service delivery(H1) Staff restructuring(H2) Training	1: Ad hoc 2: Opportunistic 3: Essential 4: Sustainable 5: Seamless	Maturity	No	The model of Harokopio et al. (2020) must be applied to test it and turn it into a standard for the objective sector.
51	M. A. O. Sanabria et al.	Colombia	2020	Public institutions	Open Government Data RM	Open government data	(1) Normativity(2) Organizational (3) Technology(4) Strategies	Not considered	Readiness	No	In Sanabria et al. (2020), the model must be applied to test it and turn it into a standard for the sector. It doesn't have output levels.
52	J. Merkus et al.	Netherlands	2020	General Enterprises	GCR MM (Generic Capabilities Reference)	Organizational intero perability maturity	(1) Strategy(2) Governance & Control(3) Organisation & Processes(4) Information Technology(5) Human Resources(6) Leadership(7) Communication (8) Culture(9) Value chain (10) Legislation(11) Environment	Not considered	Maturity	No	The model of Merkus et al. (2020) is limited to the selection made in its Literature Research (LR). Further research is necessary to validate the outcomes of this research, and the model doesn't have output levels.
53	L. D. Rafael et al.	Spain	2020	General Enterprises	Machine Tool MM	Machine Tool	(1) Strategy & organization(2) Smart factory(3) Smart operations(4) Smart products (5) Data-driven services	0: Outsider1: Beginner 2: Intermediate 3: Experienced 4: Expert 5: Top performers	Maturity	No	Rafael et al. (2020) present a model that must be applied to test it and turn it into a standard for the sector. A future improvement for the model could lie around using a more scientific and rigorous method for weighing the dimensions.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
54	S. Gamache et al.	Canada	2020	QuebecManufacturing SMEs	Gamache MM	General	(1) Leadership;(2) Culture and organization;(3) Technology management;(4) Data management;(5) Measurement system (decision-making process);(6) Customer experience.	0: Non-existant: absence of the business practice.1: Handwork: a worker works for this activity in a traditional way.2: Disciplined: the use of several non-integrated tools 3: Integrated: the use of an integrated, but not automated, management software package4: Predictable: is the maximum achievable and means that a respondent functions for the activity in an integrated, connected and real-time manner, ie uses up-to-date and real-time data to make effective decisions.	Maturity	Yes	Gamache et al. (2020) present a sound study, but it needs a more comprehensive assessment of the SMEs' tools to target those that offer the most benefits. A longitudinal study with the sample would also be interesting to validate the impact of the approach, the number of projects and the progress of the projects that have been put in place, and the gains made by the digital tools implemented.
55	N. Chonsawat et al.	Thailand	2020	SME	SMEs Readiness Indicators	General	(1) Organizational Resilience(2) Infrastructure System(3) Manufacturing System(4) Data Transformation(5) Digital Technology	1: Not Achieved 2: Partially Achieved 3: Achieved 4: Fully Achieved	Readiness	Yes	Chonsawat et al. (2020) have a limitation: this research has tested only a simple example. Future research will develop decision-making in selecting the priority of improvement implementation. Then, the researcher will develop indicators to cover more SME cases.
56	H. T. Maier et al.	Austria	2020	General Enterprises	LSM MM (Lean Smart Maintenance Maturity Model)	General	(1) Philosophy & Target System(2) Corporate Culture(3) Business Model & Service Strategy(4) Asset Strategy(5) Controlling & Budget(6) Organizational Structure(7) Process Organization(8) Knowledge Management(9) Data & Technology	0: Incomplete1: Initial 2: Managed 3: Defined 4: Quantitatively Managed 5: Optimizing	Maturity	Yes	In Maier et al. (2020), a more intensive investigation of the category 'Business & Service Strategy' is needed. Besides, only the data from Austrian companies were analyzed.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
57	M. I. Sanchez-Segura et al.	Spain	2020	SME	ALTUS MM	Software engineers and IT professionals	(1) Configuration(2) Training(3) Operational(4) Proactive(5) Transactive memory(6) SP3 valuation(7) Social	1: covers the capabilities that allow company employees to improve their knowledge individually 2: covers the capabilities that allow company employees to generate and improve collective knowledge 3: covers the capabilities that allow the company knowledge to be sustainable 4: covers the capabilities that allow the company knowledge to evolve	Maturity	Yes	Sanchez-Segura et al. (2020) discuss the tools that support the ALTUS model (excel sheet and interview templates). They will improve the tool to be used as a web application and to be applied in different sizes of companies to see the results.
58	R. B. Unny et al.	India	2020	General Enterprises	Blockchain in Supply Chain Management	Blockchain Technology	(1) Network(2) Information Systems(3) Computing Methodologies(4) Security and Privacy(5) Skills	1: Initial 2: Repeatable 3: Defined 4: Managed 5: Optimizing	Maturity	No	It is preliminary model.
59	P. J. Hsieh et al.	Taiwan	2020	General Enterprises	KNM 2.0 (Knowledge Navigator Model)	General	(1) Strategy(2) KM Promotion(3) Knowledge Sharing(4) Data and Knowledge Acquire(5) Knowledge Store(6) Knowledge and Intelligent Application(7) Knowledge Creation and Innovation(8) Knowledge Protection(9) Knowledge Learning	1: Knowledge Chaotic Stage 2: Knowledge Conscientious Stage 3: Knowledge Management Stage 4: KM Advanced Stage 5: KM Integration Stage	Maturity	Yes	In Hsieh et al. (2020), further research may focus on analyzing data collected from their model to reveal the difference in maturity status across the production/service industry and large/small-medium companies. In addition, the relationship among KM (Knowledge Management) culture, process, technology, and KM performance is worthy of being observed, as also the interplay between knowledge and intelligent application.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
60	R. G. G. Caiado et al.	Brazil	2021	General Enterprises	OSCM4.0 (Smart Operations and Supply Chain Management)	Operations and Supply Chain	(1) Customer(2) Logistics(3) Supplier(4) Integration(5) Planning & control of production(6) Quality(7) Maintenance	0: Non-existent 1: Conceptual 2: Managed 3: Advanced 4: Self-optimized	Maturity	Yes	Caiado et al. (2021) have a well-done and complete model with a fuzzy rule-based industry 4.0 maturity model. However, it focuses only on operations and supply chain management. For future works, this research suggests is to conduct a longitudinal survey and evaluating maturity at different times by applying a roadmap with periodic goals.
61	A. Amaral, P. Peças	Portugal	2021	SME	Framework SME 4.0	General	(1) People(2) Production Processes (3) Technology(4) Smart Products(5) Organization(6) Changes	0: Depends on the dimension (not informed) 1: Depends on the dimension (not informed) 2: Depends on the dimension (not informed) 3: Depends on the dimension (not informed) 4: Depends on the dimension (not informed) 5: Depends on the dimension (not informed)	Maturity	No	Outputs not transparent.
62	L. F. P. Ramos et al.	Brazil	2021	General Enterprises	I 4.0 Ramos RM	General	(1) Innovation(2) Culture(3) Strategy and Leadership(4) Smart Factory(5) Agile and Modular Management(6) Governance and processes(7) Digital Infrastructure(8) Smart Logistics(9) Smart Product and Services	Not considered	Readiness	Yes	In Ramos et al. (2021), the main contribution of this research is the need to align the theoretical concepts with those seen by specialists daily. Such a point allows a better understanding of what is intended to be delivered. All professionals stressed that the evaluation models aimed at I4.0 are essential to avoid too many trials and errors. Nonetheless, there is still a gap between a theoretical conception and a realistic view. Doesn't have output levels.

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N	Author	Country	Year	Enterprise Type	Model Name	Model Type	Input Dimensions	Output Levels	Main Output	Tested?	Critical Analysis
63	M. Zoubek, M. Simon	Czech Republic	2021	General Enterprises	Logistics 4.0 Zoubek MM	Logistics Internal Processes	(1) Manipulation(2) Storage(3) Supply(4) Packaging(5) Material identification.	Level 0: Processes are not explicitly defined. Information systems and simple software are not used.Level 1: Certified process management takes place here, which is controlled by the human factor. It uses simple software and basic information systems.Level 2: The use of automated elements in standardized processes is beginning. Data collection is partially digitized and data are processed by information systems only within the company.Level 3: Most processes are automated with partial human cooperation. Digitized technologies and information systems are used for data collection, which are also connected to external sources.Level 4: Processes are digitized and automated, with limited human intervention. It uses smart information systems that connect all areas, including external sources.Level 5: Processes are fully automated and human-controlled. The control of all systems is autonomous. Online communication thanks to sophisticated information systems that connect all company areas, including external sources.	Readiness	No	Especific just for logistics processes.

Appendix B: 3D-CUBE Questionnaire (source: authors)

Initial Information	
Email:	
Full Name:	
Cell Phone Number:	
Age:	
Level of Educational Qualification: () ELEMENTARY SCHOOL () HIGH SCHOOL () UNDERGRADUATE () MASTER () DOCTORATE () POST-DOCTORATE	
Name of your Company:	
Company Full Address:	
Years of Experience in the Company:	
Option	**How big is your Company?**
(1)	From 1 to 5 employees
(2)	From 6 to 10 employees
(3)	From 11 to 49 employees
(4)	From 50 to 249 employees
(5)	More than 250 employees
Option	**What is your Company's Economic Sector? (choose just one answer)**
Primary sector: extraction of raw materials	
(1)	Agribusiness
(2)	Animal husbandry
(3)	Forestry Base Materials
(4)	Mining
(5)	**Other:**
Secondary Sector: Industry	
(6)	Ceramics (Ex: Glass)
(7)	Chemical Materials
(8)	Composite Materials
(9)	Electrical, Electronic, and/or Smart Materials
(10)	Energy
(11)	Food and Beverages
(12)	Leather
(13)	Paper
(14)	Pharmaceutical Materials
(15)	Polymers (Ex: Plastic, Rubber)
(16)	Steel and/or Other Metals
(17)	Textiles
(18)	Tobacco
(19)	Wood
(20)	**Other:**
Tertiary Sector: sale of services and material goods	
(20)	Bank
(21)	Building
(22)	Education
(23)	Entertainment
(24)	Gastronomy
(25)	Health
(26)	Logistics
(27)	Trading
(28)	Transportation
(29)	Water Supply and Sanitation
(30)	**Other:**
Quaternary sector: goods and services related to Industry 4.0 (I4.0)	
(31)	3D Print
(32)	Artificial Intelligence
(33)	Augmented Reality

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Initial Information	
(34)	Big Data
(35)	Biotechnology
(36)	Bitcoin e Blockchain
(37)	Cloud Computing
(38)	Cyber security
(39)	Cyberphysical Systems (ex: Autonomous Robotics)
(40)	Digital Twin
(41)	Gamification
(42)	Internet of Things
(43)	Nanotechnology
(44)	Virtual Reality
(45)	**Other:**
Option	**Which of the options below better characterizes your current position in your Company?**
(1)	Technical level occupations - dealing with equipment or assembly lines
(2)	Technical level occupations - dealing with administrative support and sales
(3)	Analyst and/or higher-level occupations
(4)	Business Manager
(5)	Company Director or Chairman
	FIRST QUESTION
Score	**How do you describe the status of the I4.0 implementation process in your Company?**
(0)	NOT INITIATED: my Company does not comply with at least one of the three readiness dimensions (organizational, technological, or processes maturity). My Company has its internal processes but cannot use the concepts of I4.0, so it does not have the satisfactory organizational structure, technology, and/or process maturity that make it ready for this new reality.
(1)	INITIATED: my Company complies with the three readiness dimensions in an unstructured way. My Company shows interest and recognizes the importance of I4.0 but does not know how to make these changes.
(2)	MANAGED: my Company knows about I4.0 and plans to implement it. My Company allocates resources, people, and infrastructure, but with an individual solution adjusted separately for each department.
(3)	DEFINED: my Company defines goals, methods, and performance indicators for I4.0 implementation with an established, defined, and implemented process in which all departments are included.
(4)	OPTIMIZED: a process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. I4.0 improvements are re-evaluated regularly, and improvements are derived manually.
(5)	SELF-ADAPTED: my Company has a set of autonomous systems and adaptable organizational structures, technologies, and processes that allow self-optimization (without previous approval).
	ORGANIZATIONAL STRATEGY
Score	**How is the TOP-DOWN SUPPORT AND GOVERNANCE (executive and senior management) for I4.0 in your Company?**
(0)	My Company doesn't have it.
(1)	Top managers show interest and recognize the opportunities of I4.0 but do not know how to make the necessary changes in the Company. There is a well-communicated guideline for employees to propose improvements in top-down support and governance for I4.0. Top managers take sporadic and random initiatives to include I4.0 in the Company, but still in an unstructured way.
(2)	Top managers know about I4.0 and plan to implement it with investments in resources, people, and infrastructure. However, it's an individual solution adjusted separately for each department.
(3)	Top managers define goals, methods, and performance indicators for I4.0 implementing projects at the Company. A companywide process is established, defined, and implemented, which all departments adhere to.
(4)	A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. Top-down support and governance are re-evaluated regularly, and improvements are derived manually.
(5)	My Company has autonomous systems to self-adapt top-down support and governance to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization).
Score	**How is the ORGANIZATIONAL STRUCTURE management's continuous improvement to conform to I4.0 in your Company?**
(0)	My Company doesn't plan to make any changes yet.

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Initial Information

(1) My Company shows interest and recognizes that the organizational structure management needs to be updated continuously to adapt to I4.0, but it does not know how to make these changes. My Company takes sporadic and random initiatives to improve organizational structure, but still in an unstructured way.
(2) My Company knows about I4.0 and plans to implement organizational structure management continuous improvement. However, it's an individual solution adjusted separately for each department.
(3) My Company defines goals, methods, and performance indicators for organizational structure management continuous improvement. A companywide process is established, defined, and implemented, which all departments adhere to.
(4) A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. Organizational structure management is re-evaluated regularly, and improvements are derived manually.
(5) My Company has autonomous systems to self-adapt organizational structure management to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization).

Score How is the BUSINESS MODEL management to conform to I4.0 in your Company?

(0) My Company doesn't have it.
(1) My Company shows interest and recognizes that the business model management needs to be updated continuously to adapt to I4.0, but it does not know how to make these changes. There is a well-communicated guideline for business people to propose new business models (IT/CLOUD-BASED, SERVICE-BASED, SPIN-OFFS-BASED AND/OR PARTNERS-BASED) or some changes to existing models to conform to I4.0. The employee is congratulated when it happens. My Company takes sporadic and random initiatives to improve business model management, but still in an unstructured way.
(2) My Company knows about I4.0 and plans to implement business model management improvements. However, it's an individual solution adjusted separately for each department.
(3) My Company defines goals, methods, and performance indicators for business model management improvements. A companywide process is established, defined, and implemented, which all business departments adhere to.
(4) A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. Business model management is re-evaluated regularly, and improvements are derived manually. Business model management is beginning to include 4.0 technologies, but still with teams in training.
(5) My Company has autonomous systems to self-adapt business model management to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization). Business model management already uses 4.0 technologies fully, with all trained staff. The business models are autonomously evaluated and adapted partially without human interference on the self-adapted level, like exception messages in MRP II systems. The machine will identify data patterns and suggest adaptation strategies.

Score How is the REGULATORY COMPLIANCE AND CONTRACTUAL RELATIONS management to conform to I4.0 in your Company?

(0) My Company doesn't have it.
(1) My Company shows interest and recognizes that regulatory compliance and contractual relations need to be updated continuously to adapt to I4.0, but it does not know how to make these changes. My Company takes sporadic and random initiatives to improve regulatory compliance and contractual relations, but still in an unstructured way.
(2) My Company knows I4.0 and plans to implement regulatory compliance and contractual relations improvements. However, it's an individual solution adjusted separately for each department.
(3) My Company defines goals, methods, and performance indicators to improve regulatory compliance and contractual relations. A companywide process is established, defined, and implemented, which all departments adhere to.
(4) A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. Regulatory compliance and contractual relations are re-evaluated regularly, and improvements are derived manually.
(5) My Company has autonomous systems to self-adapt regulatory compliance and contractual relations to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization).

HUMAN WORKFORCE

Score How is the LEADERSHIP preparation for I4.0 in your Company?
(0) My Company doesn't have it.

(*Continued*)

(Continued).

Initial Information	
(1)	My Company shows interest and recognizes that the leadership preparation needs to be updated continuously to adapt to I4.0, but it does not know how to make these changes. There is a well-communicated guideline for employees to propose improvements in leadership preparation. My Company takes sporadic and random initiatives to improve leadership preparation, but still in an unstructured way.
(2)	My Company knows about I4.0 and plans to implement leadership preparation improvements. However, it's an individual solution adjusted separately for each department.
(3)	My Company defines goals, methods, and performance indicators for leadership preparation improvements. A companywide process is established, defined, and implemented, which all departments adhere to.
(4)	A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. Leadership preparation is re-evaluated regularly, and improvements are derived manually.
(5)	My Company has autonomous systems to self-adapt leadership preparation to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization).
Score	**How is the Vertical and Horizontal INTERNAL COMMUNICATION (Information Transparency) management in your Company?**
(0)	My Company doesn't have it.
(1)	My Company shows interest and recognizes that the internal communication management needs to be updated continuously to adapt to I4.0, but it does not know how to make these changes. There is a well-communicated guideline for employees to propose improvements in internal communication management. My Company takes sporadic and random initiatives to improve internal communication management, but still in an unstructured way. My Company has no technological solutions provided to enhance information transparency within the Company, like a digitally certified signature, for instance.
(2)	My Company knows about I4.0 and plans to implement internal communication management improvements. However, it's an individual solution adjusted separately for each department.
(3)	My Company defines goals, methods, and performance indicators for internal communication management improvements. A companywide process is established, defined, and implemented, which all departments adhere to.
(4)	A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. Internal communication management is re-evaluated regularly, and improvements are derived manually. Internal communication management is beginning to include 4.0 technologies, but still with teams in training.
(5)	My Company has autonomous systems to self-adapt internal communication management to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization). Internal communication management already uses 4.0 technologies fully, with all trained staff.
Score	**How is the employee TRAINING management in your Company?**
(0)	My Company doesn't have it.
(1)	My Company shows interest and recognizes that the employees' training management needs to be updated continuously to adapt to I4.0, but it does not know how to make these changes. My Company takes sporadic and random initiatives to improve employee training management, but still in an unstructured way.
(2)	My Company knows about I4.0 and plans to implement employee training management improvements. However, it's an individual solution adjusted separately for each department. Different departments have a qualification process to address the requirements within an I4.0 environment.
(3)	My Company defines goals, methods, and performance indicators for employee training management improvements. All training departments adhere to a companywide established, defined, and implemented process. A process to systematically empower employees is established in all departments and tracked with a qualification matrix.
(4)	A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. Employee training management is re-evaluated regularly, and improvements are derived manually. Employee training is beginning to include 4.0 technologies.
(5)	My Company has autonomous systems to self-adapt employee training management to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization). Employees training already uses 4.0 technologies fully.

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Initial Information	
Score	**How is the CULTURE OF INNOVATION (Willingness to Change and Agility) management in your Company?**
(0)	My Company doesn't have it.
(1)	My Company shows interest and recognizes that a culture of innovation needs to be updated continuously to adapt to I4.0, but it does not know how to make these changes. There is a well-communicated guideline for employees to propose a culture of innovation improvement methods to conform to I4.0. The employee is congratulated when it happens. My Company takes sporadic and random initiatives to improve the innovation culture, but still in an unstructured way.
(2)	My Company knows about I4.0 and plans to implement a culture of innovation improvements. However, it's an individual solution adjusted separately for each department.
(3)	My Company defines goals, methods, and performance indicators for the culture of innovation improvements. A companywide process is established, defined, and implemented, which all departments adhere to.
(4)	A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. The culture of innovation is re-evaluated regularly, and improvements are derived manually.
(5)	My Company has autonomous systems to self-adapt a culture of innovation to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization).
	PRODUCTION TECHNOLOGY
Score	**How are the ANTHROPOMORPHIC SUPPORT systems (as Robots) in your Company?**
(0)	My Company doesn't have it.
(1)	The Company addresses only a few areas of physical support for working, but in an incipient (without technology) and individual way. My Company takes sporadic and random initiatives to improve anthropomorphic support, but still in an unstructured way.
(2)	Different departments offer automated anthropomorphic support technologies and plan to improve anthropomorphic support systems. However, it's an individual solution adjusted separately for each department.
(3)	My Company defines goals, methods, and performance indicators for anthropomorphic support systems improvements. A companywide process is established, defined, and implemented, which all engineering departments adhere to and integrate these technologies into practice.
(4)	A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. Anthropomorphic support systems are re-evaluated regularly, and improvements are derived manually.
(5)	My Company has autonomous systems to self-adapt anthropomorphic support systems to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization).
Score	**How are your Company's COGNITIVE SUPPORT systems (as AI Systems)?**
(0)	My Company doesn't have it.
(1)	The Company addresses only a few areas of cognitive support for working, but in an incipient (without technology) and individual way. My Company takes sporadic and random initiatives to improve cognitive support, but still in an unstructured way.
(2)	Different departments offer automated cognitive support technologies and plan to improve cognitive support systems. However, it's an individual solution adjusted separately for each department.
(3)	My Company defines goals, methods, and performance indicators for cognitive support systems improvements. A companywide process is established, defined, and implemented, which all engineering departments adhere to and integrate these technologies in practice.
(4)	A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. Cognitive support systems are re-evaluated regularly, and improvements are derived manually.
(5)	My Company has autonomous systems to self-adapt cognitive support systems to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization).
Score	**How are the MANAGERIAL SUPPORT systems (as BIG DATA reports) in your Company?**
(0)	My Company doesn't have it.

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(Continued).

Initial Information	
(1)	The Company addresses only a few areas of managerial support for working, but in an incipient (without technology) and individual way. My Company takes sporadic and random initiatives to improve managerial support, but still in an unstructured way.
(2)	Different departments offer automated managerial support technologies and plan to improve managerial support systems. However, it's an individual solution adjusted separately for each department.
(3)	My Company defines goals, methods, and performance indicators for managerial support systems improvements. A companywide process is established, defined, and implemented, which all engineering departments adhere to and integrate these technologies in practice.
(4)	A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. Managerial support systems are re-evaluated regularly, and improvements are derived manually.
(5)	My Company has autonomous systems to self-adapt managerial support systems to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization).
Score	**How is the DRIVING NETWORK-BASED PRODUCTION (integrated production based on horizontal activities and employed by its value chain partners) management in your Company?**
(0)	My Company doesn't have it.
(1)	My Company shows interest and recognizes that the driving network-based production management needs to be updated to adapt to I4.0, but it does not know how to make these changes. My Company takes sporadic and random initiatives to improve driving network-based production management, but still in an unstructured way. My Company is focused on internal company manufacturing and traditional value networks for material flow. It has no technologies for collaborating with unusual manufacturing value chains systematically.
(2)	My Company knows about I4.0 and plans to improve driving network-based production management. Different business areas have technologies in place that allow this horizontal integration, but network partners are not systematically integrated to apply these technologies (which could be, for example, social networks: Facebook, Instagram, WhatsApp, Telegram, WeChat, and others, that can be used to connect the Company directly with the end consumer and not just as advertising).
(3)	My Company defines goals, methods, and performance indicators for driving network-based production management improvements. All manufacturing departments adhere to a companywide established, defined, and implemented process. For example, a manufacturer of plastic pots (that can be made on a 3D printer) could make available, in its social network, the updates of the products, besides having a contact team with the final customer who wants to perform customizations.
(4)	A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. Driving network-based production management is re-evaluated regularly, and improvements are derived manually. Driving network-based production is beginning to include 4.0 technologies, but still with teams in training.
(5)	My Company has autonomous systems to self-adapt and drive network-based production management to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization). Driving network-based production already uses 4.0 technologies fully, with all trained staff.
	INFORMATION TECHNOLOGY
Score	**How is your Company's DATA COLLECTION, ANALYSIS, INTERCONNECTIVITY, AND TRANSPARENCY?**
(0)	Data are not collected, analyzed, interconnected and/or transparent.
(1)	Data are collected and analyzed (manually or automatically), but my Company doesn't have a designated interconnectivity and transparency procedure employed. Objects and people within the Company are hardly connected, and silo-thinking is prevalent. My Company shows interest and recognizes that data interconnectivity and transparency need to be updated to adapt to I4.0, but it does not know how to make these changes. My Company takes sporadic and random initiatives to improve data interconnectivity and transparency, but still in an unstructured way.
(2)	My Company knows about I4.0 and plans to improve data interconnectivity and transparency. However, it's an individual solution adjusted separately for each department. Different people and/or objects deploy different structures and processes to exchange data.
(3)	My Company defines goals, methods, and performance indicators for data interconnectivity and transparency improvements. A companywide process to use the same relevant structures and processes for exchanging data is established, defined, and implemented, which all departments adhere to. Data are automatically collected, analyzed, and interconnected with transparency, with a single source of information and in real time by sensors, providing predictions and possible causes.

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Initial Information	
(4)	A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. Data interconnectivity and transparency are re-evaluated regularly, and improvements are derived manually. Data interconnectivity and transparency are beginning to include 4.0 technologies, but still with teams in training.
(5)	My Company has autonomous systems to self-adapt data interconnectivity and transparency to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization). Data interconnectivity and transparency already use 4.0 technologies fully, with all trained staff. My Company integrates horizontally and vertically to exchange data and information continuously. It has an adequate data management system to support integration and allow all users access to the same data set. The following features of I4.0 should be implemented: 1) horizontal integration through value networks, 2) end-to-end digital integration of engineering across the entire value chain, and 3) vertical integration and networked manufacturing systems. So, vertical and horizontal company integration with transparency continuously exchanges information between all the value chain IT systems, so that order information is always linked to the product, work, process instructions, and customer information.
Score	**How is the INFORMATION SECURITY management in your Company?**
(0)	My Company doesn't have it.
(1)	My Company shows interest and recognizes that information security management needs to be updated to adapt to I4.0, but it does not know how to make these changes. My Company takes sporadic and random initiatives to improve information security management, but still in an unstructured way.
(2)	My Company knows about I4.0 and plans to improve information security management. However, it's an individual solution adjusted separately for each department.
(3)	My Company defines goals, methods, and performance indicators for information security management improvements. A companywide process is established, defined, and implemented, which all IT departments adhere to.
(4)	A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. Information security management is re-evaluated regularly, and improvements are derived manually. Information security is beginning to include 4.0 technologies, but still with teams in training.
(5)	My Company has autonomous systems to self-adapt information security management to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization). Information security already uses 4.0 technologies fully, with all trained staff.
Score	**How is the DECENTRALIZED DECISIONS (with tools for data-driven decisions: IoT, big data, analytics, augmented and virtual reality, cloud computing, and/or artificial intelligence) management in your Company?**
(0)	My Company doesn't have it. Decisions of employees are not data-driven but based on experience. Some arrays, tables, or forms are used to facilitate the decision.
(1)	My Company shows interest and recognizes that decentralized decision management needs to be updated to adapt to I4.0, but it does not know how to make these changes. My Company takes sporadic and random initiatives to improve decentralized decision management, but still in an unstructured way.
(2)	My Company knows about I4.0 and plans to improve decentralized decision management. However, it's an individual solution adjusted separately for each department.
(3)	My Company defines goals, methods, and performance indicators for decentralized decision management improvements. A companywide process is established, defined, and implemented, which all departments adhere to.
(4)	A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. Decentralized decision management is re-evaluated regularly, and improvements are derived manually.
(5)	My Company has autonomous systems to self-adapt decentralized decision management to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization).
	PRODUCT-SERVICE DEVELOPMENT
Score	**How are CROSS-COMPANY ENGINEERING, RESEARCH, AND DEVELOPMENT in your Company?**
(0)	My Company doesn't have it.

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Initial Information	
(1)	My Company shows interest and recognizes that the cross-company engineering, research, and development need to be updated to adapt to I4.0, but it does not know how to make these changes. There is a well-communicated guideline for business people, engineering, or top-down management to propose cross-company engineering, research, and development throughout engineering. The employee is congratulated by NDP (New Product Development) managers when it happens. My Company takes sporadic and random initiatives to improve cross-company engineering, research, and development, but still in an unstructured way.
(2)	My Company knows about I4.0 and plans to improve cross-company engineering, research, and development. However, it's an individual solution adjusted separately for each department, which reports data in mobile systems and is non-necessarily integrated into other company systems.
(3)	My Company defines goals, methods, and performance indicators for cross-company engineering, research, and development. All engineering departments adhere to a companywide established, defined, and implemented process. A procedure for organizing project teams in multidepartmental groups is running. Employees on teams go beyond engineering, research, and development and involve manufacturing, marketing, sales, financial, accounting, and post-sales personnel.
(4)	A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. Cross-company engineering, research, and development are re-evaluated regularly, and improvements are derived manually. Interdepartmental committees are in place to analyze current and possible NPD efforts. Integrated PLM (product lifecycle management) solutions are in place. Several collaborative tools (big data, problem-solving, and analytics techniques) are used to track project progress to enable fast decision-making and ensure that the NPD process has been carried out on a multidepartmental basis, with integrated solutions.
(5)	My Company has autonomous systems to self-adapt cross-company engineering, research, and development to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization). All collaborative data gathering and data processing technologies are integrated into this self-adaptation.
Score	**How is the CUSTOMER-BASED NEW PRODUCT DEVELOPMENT (NPD) in your Company?**
(0)	My Company doesn't have it.
(1)	My Company shows interest and recognizes that the customer-based NPD needs to be updated to adapt to I4.0, but it does not know how to make these changes. There is a well-communicated guideline for an employee to propose customer-based NPD improvements. The employee is congratulated when they happen. My Company takes sporadic and random initiatives to improve customer-based NPD, but still in an unstructured way.
(2)	My Company knows about I4.0 and plans to improve customer-based NPD, with clear policies to drive NPD based on technological-enabled customer relations and inter-departmental approaches. However, it's an individual solution adjusted separately for each department. The process is based on marketing and sales personnel information, which report data in mobile systems is non-necessarily integrated.
(3)	My Company defines goals, methods, and performance indicators for customer-based NPD improvements. All engineering departments adhere to a companywide established, defined, and implemented process. Gathering customer needs is based on the life cycle of customer experience. People involved in customer interfaces are multidepartmental, meaning gathering customer data in mobile systems are integrated and validated in collaborative tools. All procedures and technologies imply customer requirements indicators.
(4)	A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. Customer-based NPD is re-evaluated regularly, and improvements are derived manually. Several tools are used to gather customer needs, assuring that a customer-based procedure has driven the NPD process. Strict partnerships are in place with current and potential customers, IoT sensors are gathering customer data, collaborative tools are in place, and big data and analytics techniques are used to discover unusual requirements.
(5)	My Company has autonomous systems to self-adapt customer-based NPD to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization). All collaborative data gathering and data processing technologies are integrated into this self-adaptation.
Score	**How is the SMART SUPPLY CHAIN integration in your Company?**
(0)	My Company doesn't have it.

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Initial Information	
(1)	My Company shows interest and recognizes that smart supply-chain integration needs to be updated to adapt to I4.0, but it does not know how to make these changes. Logistics are partially integrated. A large inventory is kept to ensure flexibility. My Company takes sporadic and random initiatives to improve smart supply chain integration, but still in an unstructured way.
(2)	My Company knows about I4.0 and plans to improve smart supply chain integration. However, it's an individual solution adjusted separately for each department. For some parts of the value chain, supply and on-demand order fulfillment solutions have been established.
(3)	My Company defines goals, methods, and performance indicators for smart supply chain integration improvements. A companywide process is established, defined, and implemented, which all departments adhere to. On-demand order, fulfillment, and supply solutions are applied throughout the Company. However, these solutions are not optimized in terms of flow and inventory.
(4)	A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. Smart supply-chain integration is re-evaluated regularly, and improvements are derived manually. On-demand order fulfillment and supply solutions are applied throughout the Company and optimized in terms of flow and inventory.
(5)	My Company has autonomous systems to self-adapt smart supply-chain integration to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization).
	ORDER FULFILLMENT
Score	**How is the CUSTOMIZED-BASED PRODUCTION system in your Company?**
(0)	My Company doesn't have it.
(1)	My Company shows interest and recognizes that the customized-based production system needs to be updated to adapt to I4.0, but it does not know how to make these changes. Only some manufacturing departments would allow a single lot without any technology. My Company takes sporadic and random initiatives to improve its customized-based production, but still in an unstructured way.
(2)	My Company knows about I4.0 and plans to improve the customized-based production systems. However, it's an individual solution adjusted separately for each department. Different parts of the production system (such as machining, assembly, storage, picking, and/or transportation) allow a single lot with some technology. However, customization requires extensive setup time and transition efforts. For these parts, manufacturing and supply chain solutions have been established.
(3)	My Company defines goals, methods, and performance indicators for customized-based production system improvements. All engineering departments adhere to a companywide established, defined, and implemented process. The production system is adjusted to "lot with size one" but without data-driven optimization.
(4)	A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. The customized-based production system is re-evaluated regularly, and improvements are derived manually.
(5)	My Company has autonomous systems to self-adapt the customized-based production system to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization).
Score	**How is the SALES AND OPERATIONS (commercial, marketing, technical assistance, customer feedback department) integration in your Company?**
(0)	My Company doesn't have it.
(1)	My Company shows interest and recognizes that sales and operations integration needs to be updated to adapt to I4.0, but has no knowledge of how to make these changes. My Company makes ad-hoc (temporary) integration between sales and operations. Sometimes they are integrated, and sometimes they have different goals and objectives. My Company takes sporadic and random initiatives to improve sales and operations integration, but still in an unstructured way.
(2)	My Company knows about I4.0 and plans to improve sales and operations integration. However, it's an individual solution adjusted separately for each department. My Company integrates sales and operations when new endeavors are starting, as well as all levels of production planning.
(3)	My Company defines goals, methods, and performance indicators for sales and operations integration improvements. A companywide process is established, defined, and implemented, followed by every operational department.
(4)	A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. Sales and operations integration is re-evaluated regularly, and improvements are derived manually.

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Initial Information	
(5)	My Company has autonomous systems to self-adapt sales and operations integration to market and I4.0 contextual changes. They redefine goals, methods, and performance indicators without previous approval (self-optimization), enabled by artificial intelligence systems that use multiple customer integration channels.
Score	**How is the SMART QUALITY MANAGEMENT system in your Company?**
(0)	My Company doesn't have it.
(1)	My Company shows interest and recognizes that the smart quality management system needs to be updated to adapt to I4.0, but has no knowledge of how to make these changes. My Company takes sporadic and random initiatives to improve smart quality management systems, but still in an unstructured way.
(2)	My Company knows about I4.0 and plans to improve its smart quality management system. However, it's an individual solution adjusted separately for each department.
(3)	My Company defines goals, methods, and performance indicators for smart quality management system improvements. A companywide process is established, defined, and implemented, which all departments adhere to.
(4)	A process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. The smart quality management system is re-evaluated regularly, and improvements are derived manually. The quality management system is beginning to include 4.0 technologies, but still with teams in training.
(5)	My Company has autonomous systems for the self-adapt smart quality management system to market and I4.0 contextual changes, redefining goals, methods, and performance indicators without previous approval (self-optimization). The quality management system already uses 4.0 technologies fully, with all trained staff.
	FINAL QUESTION
Score	**How do you describe the status of the I4.0 implementation process in your Company?**
(0)	NOT INITIATED: my Company does not comply with at least one of the three readiness dimensions (organizational, technological, or process maturity). My Company has its internal processes but cannot use the concepts of I4.0, so it does not have a good organizational structure, technology, and/or process maturity that make it ready for this new reality.
(1)	INITIATED: my Company complies with the three readiness dimensions in an unstructured way. My Company shows interest and recognizes the importance of I4.0 but does not know how to make these changes.
(2)	MANAGED: my Company knows about I4.0 and plans to implement it. My Company allocates resources, people, and infrastructure, but with an individual solution adjusted separately for each department.
(3)	DEFINED: my Company defines goals, methods, and performance indicators for I4.0 implementation with an established, defined, and implemented process in which all departments are included.
(4)	OPTIMIZED: a process of data-driven optimization (of goals, methods, and performance indicators) runs with manager approval. I4.0 improvements are re-evaluated regularly, and improvements are derived manually.
(5)	SELF-ADAPTED: my Company has a set of autonomous systems and adaptable organizational structures, technologies, and processes that allow self-optimization (without previous approval).
Option	**How would you evaluate this questionnaire?**
(1)	Difficult to fill in and ineffective
(2)	Difficult to fill in and effective
(3)	Easy to fill in and ineffective
(4)	Easy to fill in and effective
	OPEN QUESTION
	What can your Company do to accelerate the development of the processes, skills, and attitudes needed for I4.0?
	Other Comments: