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Industry 4.0 maturity models: review and classification as a support for Industry 4.0 implementation

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Abstract T Industry 4.0 is considered an important current trend and many companies are aware of its concept and the thrust that this technology can provide for the company's business model. However, many companies still do not know the starting point to implement this technology. In this sense, the analysis of maturity models in this topic can support industries in providing an Industry 4.0 roadmap implementation. This paper aims to identify and discuss Industry 4.0 maturity models available on literature, based on the dimensions of these models, as well the maturity level they can measure. This paper also identifies weaknesses and other issues of those approaches, and based on this result derive recommendations for a better, more suitable and comprehensive Industry 4.0 maturity model. To achieve the aims of the research, we have followed the systematic literature review methodology. This study reviewed 14 Industry 4.0 maturity model published in peer reviewed journals, conferences and consulting reports. The Industry 4.0 maturity model characteristics were grouped in some parameters such as: dimensions, classification levels, whether developed by scientific method or consulting. The results demonstrate that the research on the theme is in the beginning of development, the Industry 4.0 maturity model developed in partnership with universities and consultancies are more robust because their dimensions cover a greater range of aspects when compared to academic-based Industry 4.0 maturity model and there is no common method in the field in terms of scope, dimensions, measurements and indicators.

Keywords: Industry 4.0, Maturity Models, Literature Review.

1 Introduction

The fastest integration processes of information technology and high-tech communication, as well as the fastest integration processes in logistics and manufacture conducted fundamental changes in industry, that is, the Industry 4.0. These transformations, which are seen by several people as being an innovation, are new challenges not only for the industries but also for the sectors of research and development, and they transform radically the internal model of business in manufacturing companies.

The world industry is going through fast and fine advances. These are mainly related to the intense automation processes and use of information technology tools over the life cycle of the products. The inclusion of disruptive technology in the industrial domain, such as the Internet of Things (IoT); the Big Data; and the cloud computing, has a great potential to establish new paradigms in the competitive companies' area and business. Therefore, it was conceded that these paradigms modifications are called "the fourth industrial revolution" or "Industry 4.0".

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To get started in the digital transformation process the companies must have a clear view of today's situation and a strategic plan about what is to be reached (Rajnai and Kocsis, 2018). Hence, evaluate the current condition of the companies to start the implementation process of the Industry 4.0 and to know Industry 4.0 maturity models, is important to support the management of the corporations and provide them a guide on the digital changes of the companies.

The majority of the companies that are aware of the Industry 4.0, know that they need to make some adjustments in their processes, but they do not know how to carry out the methods of the Industry 4.0 on their businesses (Rajnai and Kocsis, 2018). The higher the maturity level, the lesser the risks are in the establishment of a new technology (Rübel et al., 2018). However, what is unknown yet is the knowledge level of the companies about their own digitalization (Leyh et al., 2016).

A roadmap or a common procedure to support the implementation of the Industry 4.0 was not yet established for the companies. Industry 4.0 maturity models are in research and development stage, are not commonly used, and not diffuse in the literature (Rajnai and Kocsis, 2018). Moreover, the lack of tools still represents a great obstacle to explore the full potential of the Industry 4.0 and particularly, the formal methods are crucial to consolidate the Industry 4.0, which has its singular challenges (Xu et al., 2018). Thus, this paper aims to identify and discuss Industry 4.0 maturity models available on literature, based on the dimensions of these models, as well the maturity level they can measure. This paper also identifies weaknesses and other issues of those approaches, and based on this result derive recommendations for a better, more suitable and comprehensive Industry 4.0 maturity model.

This paper is organized as follow: the next section presents a brief theoretical background of Industry 4.0. Section 3 presents the research method we followed. Section 4 discusses the Industry 4.0 maturity models. Finally, the last section draws conclusions and opportunities and challenges for future research.

2 Industry 4.0

The productive process has faced an evolutionary modification that was marked by transformations considering both changes in production processes and the breakdown of technological paradigms. Although there is still no universal agreement on what constitutes an industrial revolution (Maynard, 2015), from a technological evolution perspective, there are four commonly identified stages (Kagermann et al., 2013). The first industrial revolution follows introduction of water and steam-powered mechanical manufacturing facilities; the second industrial revolution was marked by the introduction of electrically-powered mass production based on the division of labour; a third industrial revolution is based on Information Technology (IT) and electronics to achieve further automation of manufacturing (Drath and Horch, 2014; Liao et al., 2017).

Recently, a new industrial revolution that will once again change the profile of industry has spread and is called as Industry 4.0 or fourth industrial revolution. The term "Industry 4.0" was first used at a Hannover in 2011, and drew the attention of academics, practitioners, government and politicians around the world (Siemieniuch et al., 2015; Sung, 2018).

Industry 4.0 originated from a high-tech strategy project of the German government, promoting the digitalization of the factory to ensure and increase the competitiveness of the industry, seeking to make the country the provider of key solutions. In general, Industry 4.0 is a set of technologies based on the concepts and interactions among cyber physical systems (Khaitan and McCalley, 2015), the IoT (Atzori, 2010) and Big Data, which will facilitate the vision and decision-making in the smart factory (Sung, 2018; Bernardi, 2016).

Thus, Industry 4.0 will bring about changes in the way in which the products are manufactured, causing impacts in several sectors. Besides that, Industry 4.0 has been considered as a strategy to increase product quality and become productive processes more efficient (Tortorella and Fettermann, 2018).

Some key technologies related to Industry 4.0 have been addressed through a literature review (Oesterreich and Teuteberg, 2016) and are presented in Table 1 based on three main groups.

Table 1 Key technologies and concepts of Industry 4.0.

Group	Technology
Smart Factory	Cyber Physical Systems (CPS), Embedded systems, Radio Frequency Identification (RFID), Internet of Things (IoT), Internet of Services (IoS), Automation, Modularization and/or pre-fabrication, Additive Manufacturing, Product Lifecycle, Management (PLM), Robotic, Human Computer Interaction (HCI).
Simulation and Modeling	Simulation tools and Simulation models, Augmented Reality (AR) or Virtual Reality (VR), Mixed Reality (MR).
Digitalization and Virtualization	Cloud Computing, Big Data, Mobile Computing, Social Media, Digitalization.

The groups with the greatest number of technologies are in this order: Smart Factory, Digitalization and Virtualization, Simulation and Modeling. These definitions and technologies are not the only ones, and as Industry 4.0 is spreading and evolving, new technologies and concepts can be added to the context. Some authors indicate technological factors that are indispensable for the structuring of Industry 4.0, such as: Smart Factories, IoT, Big Data, and Clouding Computing (Kagermann et al., 2013; Oesterreich and Teuteberg, 2016; Mouef et al., 2019).

3 Research Method

The authors have followed the systematic literature review (SLR) (Tranfield et al., 2003) with three stages: planning the review, conducting the review, and reporting and dissemination. This study employed a SLR methodology because of its transparency and repeatability to investigate the characteristics of the Industry 4.0 maturity models.

It is essential to conduct a SLR in any field, to understand the level of previous research that has been undertaken and to know about the weaknesses and areas that need more research in the field (Okoli and Schabraml, 2010). There is just one previous research when SLR has been published in Industry 4.0 maturity models (Gökalp et al., 2017). These authors have analysed the sufficiency of seven Industry 4.0 maturity models for providing insights about the organization's maturity for adoption of Industry 4.0.

Authors would argue that there is a clear need for SLR's to be carried out in the field of Industry 4.0 maturity models to bridge the gap in the previous literature, since the ability of companies to adapt and integrate into the new business model like Industry 4.0 is still under investigation. Table 2 presents the stages adopted for performing this SLR.

3.1 Planning the review

To achieve the aim of this research, we have used the following keywords: "Industry 4.0", "maturity model", "framework", "readiness", and "assessment model". The authors have decided to include non-scientific references developed by Consulting firms, like technical reports, because there are only a few scientific studies that investigate the Industry 4.0 maturity model (Gökalp et al., 2017) and we believe this kind of material could contribute to the findings of this research, since the field of Industry 4.0 maturity models is novel theme.

3.2 Conducting the review

This research was performed according to the research protocol presented in Table 2, which initially identified 423 articles in different journals within the research scope. After reading the abstract and considering general information for all these references, articles that were not directly related to the focus of this research were discarded. This evaluation selected 14 effectively relevant articles that were analyzed in detail. The content of these articles and its relationship to this paper is discussed in the next sections.

Table 2 Summary of research phases for Industry 4.0 maturity models literature review.

Stage	Research Phase	Research Phase of this Research
1. Planning the Review	1. Research Purpose: Define the purpose of literature review research.	To identify and discuss Industry 4.0 maturity models available on literature, based on the dimensions of these models, as well the maturity level they can measure.
	2. Research Protocol: This includes the scope of the study, the search strategy for identifying relevant studies and the inclusion and exclusion criteria.	Scope: Industry 4.0 maturity models; Strategy: keywords "Industry 4.0", "maturity model", "framework", "readiness", and "assessment model" were used; Inclusion and exclusion criteria: all qualified international scientific and nonscientific publications should be covered.
	3. Applying Criteria: Search criteria helps to ensure that only the most relevant articles are used for research purposes (or) the less important articles are excluded.	Inclusion criteria: No restriction for date; Portuguese, English or Spanish languages; Materials developed by consulting firms like reports and technical reports from non-scientific database references.
	4. Literature Searches: Online databases enabling access to full texts from relevant scientific publications.	Searches in the following electronic databases: Compendex (Engineering Village), EBSCO, Emerald, IEEE Xplore, Science Direct (Elsevier), Scopus, Web of Science and Wiley Online Library.
2. Conducting the Review	5. Selecting studies: Publication selection based on the characteristics defined in the research protocol.	Article selection is based on the application of established relevance criteria and characteristics presented in the research protocol (second row on Table 2).
	6. Quality Assessment: Publication's quality is evaluated by characteristics defined by the researcher.	Conference proceedings, consulting report, and articles from scientific journals.
	7. Data Extraction and 8. Synthesis: Data extracted from selected publications for the purpose of synthesizing them using appropriate techniques, such as quantitative or qualitative analysis, or both, for combining the extracted facts.	Data will be extracted considering some parameters related to Industry 4.0 maturity models. The following items will be used as criteria for data analysis: source, maturity model verification, dimensions, type of assessment result (quantitative/qualitative), and maturity level.
3. Reporting and Dissemination	9. Reporting: Report in detail the SLR, as well as the obtained results.	The third phase proposed will be explored in the next sections, where articles will be analyzed in detail.
	10. Dissemination: Publish the SLR, generating contribution in the field of knowledge.	Publication of a scientific article sharing the theoretical scientific contribution in Industry 4.0 maturity models to bridge the gap in the literature.

3.3 Report and dissemination

A discussion of the selected Industry 4.0 maturity models using the described criteria in this section is presented in the next section.

4 Results and Discussions

Table 3 presents some parameters of the Industry 4.0 maturity models studied. Dimensions and maturity levels used by the maturity models are also showed. Source parameter considers Academic based publication (those are developed by universities and research institutes); Consultant based (those are performed by consulting companies) and finally, Academic and Consultant based (those that are developed in partnership between universities, research institutes and consultancy companies).

The verification analysis aims to identify whether the authors have verified the Industry 4.0 maturity model. This parameter tries to show if the Industry 4.0 maturity model were implemented in practical investigation or execution approach. This practice of investigation or execution of Industry 4.0 maturity model is termed as verification of Industry 4.0 maturity model. The verification of any Industry 4.0 maturity model establishes its applicability and significance. On the other hand, if author has only proposed the conceptual model and not reported its implementation, they are labelled as not verified Industry 4.0 maturity model.

Dimensions are the areas that the model covers and can be applied within an organization. In other words, in practice, these are the areas in which the model can be applied to assess the maturity of Industry 4.0 in the organization.

Type is related to the assessment result that the maturity model presents, which can be: Qualitative (QL), Quantitative (QT) or Qualitative and Quantitative (QLQT) based. Qualitative result-based shows only qualitative maturity levels with statements and affirmations about the assessment result of Industry 4.0. Maturity models with Quantitative results based, however, present only numerical results, or a scale as an assessment result. On the other hand, Qualitative and Quantitative maturity models have both qualitative and quantitative maturity levels results and it is a more complete scale because it places the industry on the numerical scale through qualitative statements.

The last parameter of Table 3, that is, maturity level, is regarded to the nomenclature given to the maturity levels of the Industry 4.0 maturity models. In general, the first maturity levels follow an increasing scale, that is, the first nomenclatures of the maturity levels are directed for those companies in which they are in the initial phase of integration of Industry 4.0. The last levels are classifications given to the companies with the highest level of maturity of Industry 4.0 in its process.

Table 3 Parameters of Industry 4.0 maturity models.

Authors	Source[1]	Verified	Dimensions	Type[2]	Maturity level
Leyh et al. (2016)	A	No	Vertical Integration, Horizontal Integration, Digital Product Development, and Cross-sectional technology criteria.	QL	1: Basic digitization level; 2: Cross departmental digitization; 3: Horizontal and vertical digitization; 4: Full digitization; 5: Optimized full digitization.
Gökalp et al. (2017)	A	No	Asset Management, Data Governance, Application Management, Process Transformation, and Organizational Alignment.	QL	Level 0: Incomplete; Level 1: Performed; Level 2: Managed; Level 3: Established; Level 4: Predictable; Level 5: Optimizing.
PWC (2020)	C	No	Business Models, Product and Service Portfolio; Market and Customer Access; Value Chains and Processes; Information Technology (IT) Architecture; Compliance, Legal Risk, Security and Tax; Organization, and Culture.	QLQT	Qualitative and quantitative level for each dimension: Digital Novice; Vertical Integrator; Horizontal Collaborator; Digital Champion.
Schuh et al. (2017)	AC	No	Resources, Information systems, Organizational structure, and Culture.	QL	Computerization, Connectivity, Visibility, Transparency, Predictive, and Adaptability.

[1]A: Academic based; Consultant based; AC: Academic and Consultant based. [2]: QL: Qualitative; QT: Quantitative.

Table 3 Parameters of Industry 4.0 maturity models. (continued …)

Authors	Source[1]	Verified	Dimensions	Type[2]	Maturity level
Gill et al. (2016)	C	No	Culture, Technology, Organization, and Insights.	QL	Skeptics, Adopters, Collaborators, Differentiators.
Lichtblau (2015)	C	No	Strategy and Organization, Smart Factory, Smart Operations, Smart Products, Data Driven Services, and Employees.	QT	Outsiders, Beginner, Intermediate, Experienced, Expert, Top performer.
Schumacher et al. (2016)	A	Yes	Strategy, Leadership, Customers, Products, Operations, Culture, People, Governance, and Technology.	QT	Quantitative level for each dimension.
Agca et al. (2018)	AC	No	Product and Service, Manufacturing and Operations, Strategy and Organization, Supply Chain, Business Model, and Legal Considerations.	QL	Beginner, Intermediate, Experienced, and Expert
Pessl et al. (2017)	A	Yes	Acceptance and Application of new Technologies and Media, Professional Competence, Learning Competence, Corporate Strategy, Human Resources Development Strategy, Organization and Democratization, Flexible Working Models, Health and Safety, Information and Communication, Employer Branding, Change Management, Process Orientation, and Knowledge Management.	QL	Five levels, from 1 to 5.
Ganzarain and Errasti (2016)	A	No	Envision, Enable, and Enact.	QL	1. Initial; 2. Managed; 3. Defined; 4. Transform; 5. Detailed Business Model.
Leineweber et al. (2018)	A	No	Technology, Organization, and Employees.	QL	1. Shop floor level; 2. Production management level; 3. Corporate management level.
Akdil et al. (2018)	A	Yes	Smart products and services, Smart business processes, Strategy, and Organization	QL	Absence, Existence, Survival and Maturity.
Rockwell Automation (2014)	C	No	1: Assessment, 2: Secure and upgraded network and controls, 3: Defined and organized working data capital, 4: Analytics and 5: Collaboration.	QL	Do not specify.
Horvat et al. (2018)	A	No	1. Technology, 2. Management and strategy, 3. Employees and communication, 4. Organization of production and logistics, and 5. Interfirm cooperation.	QL	An evolutionary path that manufacturing companies take towards readiness for Industry 4.0 occurs in different four stages.

[1]A: Academic based; Consultant based; AC: Academic and Consultant based. [2]: QL: Qualitative; QT: Quantitative.

The analysis shows that 57.2% of the Industry 4.0 maturity models are from academicians. This can suggest that research in Industry 4.0 maturity models is still in development. There are four (28.6%) practitioner-based Industry 4.0 maturity models and two (14.2%) of the Industry 4.0 maturity models are classified as academic and consultant-based.

The Industry 4.0 maturity models developed in academic institutions are regarded as academic-based maturity models. The Industry 4.0 maturity models suggested by consultants and practitioners, based on their consulting experience, are entitled as consultant-based maturity models. Academic and Consultant based Industry 4.0 maturity models are the ones developed in partner with consultant companies and academic institutions, such as universities. Schuh et al. (2017) classified as Academic and Consultant based Industry 4.0 maturity model, is a partnership among Acatech and RWTH Aachen University, Technische Universität Darmstadt, University of Paderborn, Fraunhofer Institute for Material Flow and Logistics IML, and German Research Center for Artificial Intelligence, DFKI. Agca et al. (2018) Industry 4.0 maturity model is developed by The University of Warwick, in conjunction with industrial collaborators Crimson & Co and Pinsent Masons.

In all Industry 4.0 maturity model of this study, only 21.4% are verified and 78.6% Industry 4.0 maturity models are just proposed (implementation actions are not reported). It can be argued that a lower proportion of verified Industry 4.0 maturity models do not support its applicability and also does not promote to use these models. Thus, there is a need of more empirical research in Industry 4.0 maturity models subject. The practical verification of the Industry 4.0 maturity models could help researchers to identify the potential approach and related research designs used for Industry 4.0 maturity models verification.

The Industry 4.0 maturity model with more dimensions is Pessl et al. (2017) and the Industry 4.0 maturity model with less dimensions are Ganzarain and Errasti (2016) and Leineweber et al. (2018), with three dimensions only. There are some dimensions present in more than one Industry 4.0 maturity model. It occurs with following dimensions Business, Products, Services, Smart and Digital Products, Customer, Information, Legal Considerations, Organization, Culture, Strategy, People and Employees, Technology, and Operations. Otherwise, there are several dimensions addressed just by single Industry 4.0 maturity models, such as Asset Management, Employer Branding, Leadership, Supply Chain and some others.

The majority of Industry 4.0 maturity levels are composed of a qualitative scale. The higher the scale level, the more engaged is the company evaluated in the Industry 4.0 context. Quantitative maturity levels can be found in PWC (2020), Lichtblau (2015), and Schumacher et al. (2016).

The Industry 4.0 maturity model of PWC (2020) calculates the average of the answers (that can vary from 1 to 5) that is attributed to each dimension, presenting 4 levels of maturity. The maturity level for each dimension of Schumacher et al. (2016) is calculated using the following Equation:

$$M_D = \frac{\sum_{i=1}^{n} M_{DIi} * g_{DIi}}{\sum_{i=1}^{n} g_{DIi}} \quad (1.1)$$

Where: M: maturity; D: dimension; I: Item; g: Weighting factor; n: number of maturity item.

The major characteristic that differentiates maturity levels of the Industry 4.0 maturity models is that most of them present the maturity result on a scale of levels without identifying aspects of Industry 4.0 that are being assessed. Putting in another way, the majority maturity levels present only the degree of maturity. However, few of them present detailed level scale by area in which the company is placed in the Industry 4.0 considering what was assessed, as is the case of Leyh et al. (2016) and PWC (2020).

In addition to the parameters in Table 3, it is worth mentioning that some Industry 4.0 maturity models have specific application area. Schuh et al. (2017) cover functional areas: development, production, logistics, services, marketing and sales. Leyh et al. (2016) address Information and Technology (IT) in Industry 4.0. Pessl et al. (2017) is applicable for a set of five fields of actions (purchasing, production, intralogistics, sales and human). Rockwell Automation (2014) is focused on IT capability of companies.

4.1 Weaknesses and other issues of Industry 4.0 maturity models

The academic-based Industry 4.0 maturity models are very simple and subjective. Less than half of them have been validated within an empirical study. This maturity models are only initial ideas, which only report which aspects of Industry 4.0 will be evaluated and what level of maturity they will use to classify the companies (most of them qualitative), but they do not show how it is done this process. They do not show the calculations, or schemes that support the description of the Industry 4.0 maturity level that positions the organization at this or that level.

4.2 Recommendations for a better, more suitable and comprehensive Industry 4.0 maturity model

There is a need to develop an Industry 4.0 maturity model that meets the real needs of the organization in terms of using Industry 4.0 technologies. In this sense, the models to be developed should allow the company to define which sectors of Industry 4.0 can contribute, as well as the goals the organization wish to achieve in terms of the implementation of Industry 4.0 related to business strategy. Thus, if an organization is not interested in applying Industry 4.0 technologies in its transport and delivery process, because outsource, for example, it cannot be punished with low scores in the Logistics and Supply Chain dimension, if this issue is not one of its business strategies.

A factor also neglected in current industry 4.0 maturity models is sustainability. The relationship between Industry 4.0 and sustainability triggers a series of points, which must be explored, about the role of these new technologies and tools, to contribute to sustainable practices that use fewer natural resources and non-renewable energy. The industry has a great participation in this process. In addition, the environmental impacts of industrial products are not restricted to the factory gate. The entire product life cycle must be taken into account in this process, which involves the extraction of non-renewable raw materials, energy consumption, disposal and reverse logistics. Each stage has an important role and can be harmful to the planet if not treated properly.

5 Conclusions

The aim of this analysis is to identify and discuss Industry 4.0 maturity models based on the dimensions of these models, as well the maturity level they can measure. This study reviewed 14 Industry 4.0 maturity models published in peer reviewed journals, conferences and consulting reports. In this study some parameters were established for the reviewing Industry 4.0 maturity models, and they were classified into "Academic-based", "Consultant-based" and "Academic and Consultant-based" maturity models, "Verified" or "Not verified" maturity models; these 14 maturity models were also classified as quantitative or qualitative maturity level.

Major Industry 4.0 maturity models present qualitative maturity levels and do not reveal how they develop the maturity levels presented. This research demonstrated the development of Industry 4.0 maturity models is at an early stage of development and the "Academic-based" Industry 4.0 maturity models need to be improved, considering broader and more specific dimensions. Although the Academic and Consultant based Industry 4.0 maturity models are more robust because their dimensions cover a greater range of aspects when compared to Academic-based Industry 4.0 maturity models, none of them were verified through practical applications and empirical studies. This can be pointed out as a weakness of these Industry 4.0 maturity models.

This research also identified that there is no common method in the field in terms of scope, dimensions, measurements and indicators. So, it is difficult to compare companies to find out which company is best positioned in the maturity of sector 4.0.

Some topics for future work can be addressed: To deepen in the Industry 4.0 maturity model dimensions clusters and explore what they evaluate; To explore the results of the assessment of the Industry 4.0 maturity models studied. Develop a complete Industry 4.0 maturity model with comprehensive dimensions and solutions to solve the needs of Industry 4.0 and not only classify the companies in maturity levels in Industry 4.0 context.

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