

# An Industry 4.0 maturity model proposal

Industry 4.0  
maturity model  
proposal

Reginaldo Carreiro Santos

*Instituto Politécnico de Coimbra Instituto Superior de Engenharia de Coimbra,  
Coimbra, Portugal and  
Pontifícia Universidade Católica do Paraná, Curitiba, Brazil, and*

José Luís Martinho

*Instituto Politécnico de Coimbra Instituto Superior de Engenharia de Coimbra,  
Coimbra, Portugal*

Received 1 September 2018  
Revised 18 December 2018  
10 June 2019  
19 September 2019  
Accepted 18 October 2019

## Abstract

**Purpose** – In recent years, the development and application of innovative and disruptive technologies in manufacturing environments is shaping the fourth industrial revolution, also known as Industry 4.0. The purpose of this paper is to describe a tool to assess the maturity level in implementing Industry 4.0 concepts and technologies in manufacturing companies.

**Design/methodology/approach** – Using a framework to develop maturity models found in literature, three main steps were taken: the model design from the literature review on industry 4.0 and the comparative analysis of existing models; interviews with engineers and managers of relevant industries; and pilot tests in two relevant industrial companies.

**Findings** – The proposed maturity model has 41 variables considering five dimensions (organizational strategy, structure and culture; workforce; smart factories; smart processes; smart products and services). The studied companies showed different levels of Industry 4.0 implementation. According to respondents, the model is useful in making an initial diagnosis and establishes a roadmap to proceed the implementation.

**Practical implications** – Empirical evidence supports the relevance of the proposed model and its practical usefulness. It can be used to measure the current state (initial diagnostic and monitoring assessments), and to plan the future desired state (goal), identifying which transformational capabilities should be developed.

**Originality/value** – The literature review did not return an enough complete maturity model to guide a self-administered assessment. Therefore, the proposed model is a valuable tool for companies and researchers to understand the I4.0 phenomenon, plan and monitor the transformation actions.

**Keywords** Manufacturing technology, Digital transformation, Industry 4.0, Capabilities, Maturity model

**Paper type** Research paper

## 1. Introduction

Emerging and disruptive technologies applied to manufacturing systems have the potential to bring significant changes to value chains of diverse segments and generate expectations of an exponential evolution in the production and distribution of goods and services.

Throughout the history of industrialization, new products, materials, energy sources, production methods, management concepts and applied technologies have emerged and enabled disruptive changes that were considered industrial revolutions. The first three industrial revolutions, since the use of steam machines in the eighteenth century until the recent internet and robotics applications, were responsible for huge transformations in societies, in the industrial competition, in geopolitics and in urban growth.

Following the major changes described above, innovative technologies emerged, in what is conventionally called fourth industrial revolution, also known in the literature as “Industry 4.0,” “industrial internet of things,” “advanced manufacturing,” “intelligent manufacturing,” “smart factories,” “factories of the future.” It comprises the evolutions of microelectronics, robotics, internet applications, the expansion of data processing and storage, cloud computing, information and communication technologies (ICT), cyber-physical systems (CPS), the internet of things and services (IoTS), artificial intelligence (AI), autonomous equipment, additive manufacturing (3D printing) and other technologies. Emerging concepts as mass



---

customization, business servitization, digitalization of equipment, products and processes, the adaptability of systems, are responsible for a profound change in business environment. ElMaraghy and ElMaraghy (2016) affirm that isolated, they seem to have no evident relation, and can contribute to incremental gains of productivity and flexibility for organizations. But when combined in an industrial application context, the integration of these new concepts and technologies tends to deeply modify companies, supply chains competitiveness and the society in general.

In this context, companies need suitable tools and approaches to deal with and take advantage of those innovative and sometimes disruptive technologies. This study aims to propose a maturity model to assess industrial capabilities related to the Industry 4.0 concepts and technologies. It is expected to help professionals and academic researchers, to evaluate the maturity level of industrial companies as an initial diagnostic, as intermediate assessments throughout technology implementation projects, or as a goal to be reached at the end of a horizon plan.

This paper is structured as follows: to support the maturity model proposal, in Section 2 a theoretical background based on literature review of Industry 4.0 concepts and an analysis of existent maturity models is presented. Section 3 describes the methodology utilized for the development of the proposed maturity model. A detailed explanation of the proposed maturity assessment model and the results obtained in the pilot test are presented and discussed in Section 4. Finally, in Section 5, conclusions and possible future research is discussed.

## 2. Literature review

### 2.1 Industry 4.0 concepts and enabling technologies

A worldwide movement is happening in some of the most developed economies, toward increasing in productivity, flexibility and agility in manufacturing systems, due to the incorporation of the last advances of ICT and operation technologies. The adoption of these technologies and their relative importance for the industrial competitiveness will grow in the following years, and completely new solutions and services will emerge, generating new business opportunities (Posada *et al.*, 2015).

Emerging concepts such as mass customization, business servitization, digitalization of equipment, products and processes, systems adaptability, sharing and circular economy can stimulate organizations to rethink their business models and enhance their competitiveness. The introduction of IoTS in manufacturing environments is driving the fourth industrial revolution and will establish communication networks incorporating machines, warehousing systems and production resources. Through CPS, equipment and systems will share information, generating actions and controlling themselves autonomously (Kagermann *et al.*, 2013).

Porter and Heppelmann (2015) analyze how the network of connected products can significantly modify all functions of manufacturing companies. The central point of this revolution of products and processes, and transformation of value chains, are data, supported by technologies of acquisition, storage, processing, presentation and response of the performed analysis (descriptive, prescriptive, of diagnostic and predictive).

The product design and concepts should be revised and adapted for a modern model, with an interdisciplinary product development approach. Industries have been facing challenges of product individualization, with the need to increase efficiency in resource utilization and to minimize the time in launching new products. These challenges are often related to digitalization, the usage of ICT and the connectivity of products and productive resources, which are potentiated by the internet of things (Rennung *et al.*, 2016). The increasing needs for individualized products have been changing the configuration of mass production, from the creation of standardized products to

the configuration of mass customization, where customers find what they really want and need (Scheuermann *et al.*, 2015).

When dealing with the phenomenon of Industry 4.0, there are many concepts and technologies (enabling technologies) related to this global trend, like the CPS, the IoTS, machine-to-machine communication (M2M), industrial automation, autonomous and intelligent equipment, Big Data analytics, products and processes digitalization, visual computing technologies (such as virtual and augmented reality, 3D images processing and human-machine interaction interfaces), cloud computing, additive manufacturing, AI (Kagermann *et al.*, 2013; Rüßmann *et al.*, 2015; Porter and Heppelmann, 2015; Ghobakhloo, 2018). The union of these technologies brings new possibilities to organizations, and together with new business models and the raise in commercial changes between countries, tend to generate a significant increase in industrial production. With more potent microprocessors and the spread of AI, products and machines become intelligent in the sense of having not only advanced capabilities of computing, communication and controlling, but also autonomy and socialization (Wang *et al.*, 2016).

Lee *et al.* (2015) define CPS as transformative technologies to manage interconnected systems between physical assets and computational capacities, consisting of two main functional components: an integration layer with advanced connectivity that ensures real-time data acquisition from the physical world and information feedback from the cyber space; and an intelligence layer with capabilities of data management, analytics and computational to construct the cyber space. In the integration layer, data will be acquired by a huge diversity of sensors, machines, production lines, manufacturing management and control systems, and outside the factories environment, for example, by customers and supply chain components. In the intelligence layer, manufacturing systems will use data acquired in the integration layer to make decisions through intelligent technologies, enabling the analysis of great data volume and diversity (Big Data). Moreover, the intelligent manufacturing systems could be embedded with capabilities of self-awareness, self-optimization, self-configuration, which will enable the decentralization of machine decisions. The applications at these layers tend to be the implementation of advanced manufacturing (Qin *et al.*, 2016). These characteristics can change the current factories in a Factory 4.0 with significant economic potentials.

CPS are constituted by mechatronic components, with sensors to data acquisition and actuators, which influence the physical processes (Stock and Seliger, 2016). They are intelligently connected with each other and continually interact through data exchange in the virtual networks in real time. Gunes *et al.* (2014) resume the CPS as complex and multi-disciplinary systems, that integrate embedded computational technologies (cyber part) in the physical components, and this integration includes observation, communication and controlling of the physical systems from a multi-disciplinary perspective. The applications of CPS are the main fundamentals of the Industry 4.0 implementation and can be summarized in two concepts: interoperability and consciousness, that include many others secondary concepts. The main idea of the interoperability is the integration, which is the key point of the internet of things and the CPS. The integration can be divided in three components: horizontal across the value chain, vertical through the organization, and across the lifecycle of the engineering processes, and consists in digitalization, communication, standardization, flexibility, real time responses and customization. The consciousness is also a requirement of Industry 4.0, as it requires intelligent manufacturing systems, that reveals the knowledge, makes decisions and performs the actions intelligently and independently. It is comprised of predictive maintenance, autonomous decision making, intelligence capabilities, self-awareness, self-optimization and self-configuration (Kagermann *et al.*, 2013).

The application of the IoTS in manufacturing environments enable the existence of intelligent operations, contemplating the information exchange in real time between

---

production systems and operators. Thus, it is possible to improve quality and productivity, providing hardiness, autonomy, self-organization, self-maintenance, transparency, predictability, efficiency, interoperability, traceability, which are some of the benefits of Industry 4.0 (Monostori, 2014).

For a better comprehension of possible and expected transformations for the Industry 4.0 development, is important to understand the observable characteristics of technologies, the design principles. They are the base for product and service development and can support the knowledge of technological benefits for industrial applications. The attributes related to the Industry 4.0 technologies are intrinsically linked to CPS and IoT and can be summarized in digitalization, connectivity, interoperability, adaptability, scalability, efficiency, predictive capability, reconfigurability (Gunes *et al.*, 2014; Hermann *et al.*, 2016).

For Schuh *et al.* (2017), the development of Industry 4.0 will be different in each company. It is necessary thus, that companies begin the analysis of the current situation (initial or intermediate diagnostics) and of its strategic goals, considering horizons of medium and long-terms, and defining what technologies and systems are effectively implemented. The faster a company adapts and anticipates an event that can impact the business, the bigger are the benefits of this adaption.

## 2.2 Maturity models

A maturity model can be defined as a conceptual structure, composed of parts that define the maturity or the development status, of a determined interest area of study. Some of them identify and describe the processes that an organization should develop in order to reach a future desired scenario. Maturity models reflect aspects of the reality to classify capabilities of certain interest domains which can be used for internal analysis, competitor analysis and comparisons with the references in the domain (benchmark). These models typically contemplate dimensions and levels (Donovan *et al.*, 2016).

Maturity models are used as instruments to recognize and measure the maturity level of a company in a certain domain, or a process related to a future goal. They are based on premises that people, organizations, functional areas and processes, evolve through a development process toward a more advanced maturity, by means of a determined number of levels. A certain level in a model is the starting point from where an evolution to a higher level of maturity can be planned and implemented. The objective of maturity models is to quantify the performed activities and make them measurable and mature over time.

The content of each dimension can be derived of qualitative research methods, including bibliographic reviews, case studies analysis, focal groups and other methodologies of idea generation and decision making, as the Delphi method (Donovan *et al.*, 2016). The levels are ordinal labels that mean stages of maturity, while the dimensions represent specific capabilities of an interest domain. A maturity level consists in the consolidation of general and specific practices related to an entirety of predefined processes that increase the general performance of an organization, or a specific goal (De Souza and Gomes, 2015).

In some cases, instead of developing their own maturity models, organizations utilize models designed by specialized institutions in determined knowledge domains, as project management, software design and development, or standardization, such as COBIT, ITIL, PMI, CMMI, ISO. Finished models have some advantages, like being ready to be used and being validated and tested by other people and institutions. They also have disadvantages, often having scopes that only partially attend the needs, being generalists and inflexible, in the sense of having been used in the form as they were constructed (Goksen *et al.*, 2015).

The transformation toward Industry 4.0 involves a significant increase of digital competencies in manufacturing and causes changes throughout an organization. Considering the high complexity of this transformation, it is expected that it takes several years to be planned and implemented in order to enable positive impacts on

---

profitability through efficiency gains and must occur in incremental stages. It might not exactly be synchronized in all business processes, industrial installations, production lines, or even in all production cells in a same plant. Each company must decide which stage of development represents a good balance between costs and benefits of the change, according to the circumstances that involve the business, with a vision of a desired future state at the end of the transformation process (Schuh *et al.*, 2017).

### 2.3 Analysis of existent Industry 4.0 maturity models

The literature review revealed three types of maturity model proposals for industry 4.0: those from the main consulting companies, those proposed by industries associations, and the ones published in scientific periodicals. The maturity models proposed by the consulting companies were excluded from this study, because they have different scopes and commercial purposes. From industries associations two maturity models were taken for analysis (Schuh *et al.*, 2017; Lichtblau *et al.*, 2015). Finally, from the search on scientific databases, only one article compatible with the objective of this research was found (Schumacher *et al.*, 2016). For convenience, the models were labeled as follow:

- Model 1: Acatech – Industry 4.0 maturity index from Schuh *et al.* (2017).
- Model 2: model of maturity evaluation of manufacturing companies to Industry 4.0 from Schumacher *et al.* (2016).
- Model 3: IMPULS-VDMA – Industry 4.0 readiness of maturity from Lichtblau *et al.* (2015).

All the analyzed models are based on the main concepts and enabling technologies of Industry 4.0, such as those exemplified in the previous sections, and consider that these technologies applied to the industrial environment, are capable to implement significant changes to the competitiveness of companies and open new business opportunities. In general, the analyzed models cover the main structural areas of companies, contemplating products, installations, operations and management processes, workforce, organizational culture, technological resources, as was observed in the literature review.

The analyzed models assess maturity in different areas called dimensions and each dimension is described by several transformation capabilities. Industry 4.0 maturity is assessed by evaluating the degree of implementation of each transformation capability and consequently in each dimension. For a better understanding of the models, a comparative analysis was made, based on its dimensions and transformation capacities. The model 1 (Schuh *et al.*, 2017) and model 3 (Lichtblau *et al.*, 2015) are compound by 4 dimensions and 5 dimensions, respectively. Model 2 (Schumacher *et al.*, 2016) is compound by 9 dimensions, what brings a better stratification of subcomponents. In the consulted article of model 2 there are 62 evaluation items (subcomponents) mentioned by the authors but were not completely available. Therefore, the comparison could only be done with the 32 available, missing information and analysis. Table I shows the dimensions used by the analyzed models.

From the analysis of Table I, it can be asserted that the dimensions used by the different models are related not only to technological aspects, but also to organizational ones. The roadmap to industry 4.0 implementation in manufacturing companies should include issues related to leadership, culture, human resources and the company's own products and services, in addition to those related to operations and technology. The aspects they diverge are related to their content, existing differences in the quantity and description of maturity levels, in the components and subcomponents analyzed, in the objectivity and in the measurement criteria of the maturity levels. As the models use different levels of aggregation of transformation capabilities, it is necessary to look at these ones, instead of

the dimensions. Therefore, a possible and suitable comparison is the stratification of the dimensions and its respective transformation capabilities in three aspects of analysis: organizational and management; technical; contextual (external to companies). Tables II–IV illustrate the comparison of the transformational capabilities proposed by each model.

*2.3.1 Organizational and management issues.* Model 1 (Schuh *et al.*, 2017) presents two dimensions (organizational culture and organizational structure) related to organizational behavioral and management issues, that consist of an approach that considers the organization and management of the workforce, and the willingness of the high administration to organize a functional structure, with an objective of focusing on the requirements for an agile and responsive management to context changes. The dimension “Organizational structure” has a strong emphasis on task organization, employee autonomy, motivation, targets definition, flexibility and diversity of team skills, collaboration through the value chain, and customer orientation. In the dimension “Organizational culture,” the behavioral characteristics desired for the employees are valorized, as leadership, open communication between the teams and the adaptation to the technological changes.

Model 2 (Schumacher *et al.*, 2016) has four dimensions (culture, leadership, strategy, people) related to behavioral and management issues. The dimension “Culture” emphasizes the openness to innovation, the collaboration between companies and the valorization of ICT. In the dimension “Leadership,” a central coordination for Industry 4.0 is expected. The dimension “Strategy” comprises issues like the compatibilization of Industry 4.0 with the corporate strategy, the management of the resources to the actions execution, and the adaptation of the business model to Industry 4.0 requirements. The dimension “People” approach the competencies and openness of the employees for the new technologies, and their autonomy to make decisions.

Model 3 (Lichtblau *et al.*, 2015) presents two dimensions (strategy and organization, and workforce) related to behavioral and management issues. The dimension “Strategy and organization” evaluate issues connected to the strategy and the responsibility of the high administration in conducting transformational actions, the strategic management focused on Industry 4.0, the allocation of investments and the openness to innovation and the management of innovation. The dimension “Workforce” evaluates the abilities of employees and divides them in two subcomponents, the existent abilities and the acquisition of new ones, through the qualification of employees. Table II summarizes the comparison of the organizational and management issues.

*2.3.2 Technical issues.* The dimensions related to technical issues present in the three analyzed models contain subcomponents connected to technological features of the physical resources to collect, process and distribute information to the company and to other interested parties, and thus create value.

	Model 1 (Schuh <i>et al.</i> , 2017)	Model 2 (Schumacher <i>et al.</i> , 2016)	Model 3 (Lichtblau <i>et al.</i> , 2015)
	Organizational structure	Leadership Strategy	Strategy and organization
	Organizational culture	Culture People	Employees
	Resources	Technology	Smart factory
	Information systems	Operations	Smart operations
	–	Products	Smart products
	–	Customers	Data-driven services
	–	Governance	–

**Table I.**  
Dimensions  
comparison of  
analyzed maturity  
models

Model 1 (Schuh <i>et al.</i> , 2017)	Model 2 (Schumacher <i>et al.</i> , 2016)	Model 3 (Lichtblau <i>et al.</i> , 2015)	Industry 4.0 maturity model proposal
Organizational structure Flexible communities Decision rights management Motivational goal systems Agile management Focus on customer benefits Cooperation within the network	Strategy Utilization of an Industry 4.0 roadmap Availability of resources for Industry 4.0 Communication and documentation of Industry 4.0 activities Suitability of existing business models for Industry 4.0 Existence of strategy for digital transformation Compatibility of Industry 4.0 with company strategies Leadership Willingness of leaders Management competences and methods Existence of central coordination for I4.0 Culture Knowledge sharing Open-innovation and cross-company collaboration Value of ICT in company People ICT competences of employees Openness of employees to new technology Autonomy of employees	Strategy and organization Implementation status of Industry 4.0 strategy Operationalization and review of strategy Through a system of indicators Investment activity relating to Industry 4.0 Use of technology and innovation management Employees Employees skills Company's efforts to acquire new skill sets	
Organizational Culture Recognize the value of mistakes Openness to innovation Data-based learning and decision-making Continuous professional development Shaping change Democratic leadership style Open communication Confidence in processes and information systems			<b>Table II.</b> Organizational and management transformation capabilities comparison of the analyzed maturity models

Model 1 (Schuh *et al.*, 2017) has two dimensions related to technical issues (information systems, and resources). The dimension “Resources” comprises resources for the digitalization of processes, the automated data acquisition, the structured communication, the decentralization and automation of processes, and the contextualization of technological fittings to specific tasks. The dimension “Information Systems” focuses on the central importance of the information and operation systems in the context of Industry 4.0, enabling their vertical integration in the company, their horizontal integration through the value chain, and the standardization of communication interfaces, with the delivery of contextualized information to each team or individual.

Model 2 (Schumacher *et al.*, 2016) has three dimensions related to technical issues (operations, technology and products). The dimension “Operations” contemplates the decentralization and digitalization of processes, and the interdisciplinary and interdepartmental collaboration. The dimension “Technology” is connected to the utilization of applied technologies to enhance the efficiency of communication and operations, including machine-to-machine communication. The dimension “Products” brings an approach of the integration of products with other resources and systems through their digitalization and deals with the flexibility of product reconfiguration, aiming its individualization.

Model 3 (Lichtblau *et al.*, 2015) contemplates four dimensions (smart operations, smart factories, data driven services and smart products) related to technical issues. It comprises the main aspects of a composition of intelligent structures and resources to the

	Model 1 (Schuh <i>et al.</i> , 2017)	Model 2 (Schumacher <i>et al.</i> , 2016)	Model 3 (Lichtblau <i>et al.</i> , 2015)
<b>Table III.</b> Technical transformation capabilities comparison of the analyzed maturity models	Resources	Technology	Smart factory
	Provide digital competencies	Existence of modern ICT	Digital modeling
	Automated data acquisition through sensors and actuators	Utilization of mobile devices	Equipment infrastructure
	Decentralized preprocessing of sensor data	Utilization of machine-to-machine communication	Data usage
	Efficient communication		IT systems
	Task based interface design		
	Information systems	Operations	Smart operations
	Data analysis	Decentralization of processes	Information sharing
	Contextualized data delivery	Modeling and simulation	Cloud usage
	Application-specific user interface	Interdisciplinary	IT security
Resilient IT infrastructure	Interdepartmental collaboration	Autonomous process	
Horizontal and vertical integration			
Data governance			
Standard data interface			
IT security			
–	Products	Smart products	
	Individualization of products	ICT add-on functionalities of products	
	Digitalization of products	Extent to which data from the usage phase is analyzed	
	Product integration into other systems		
	The autonomy of products		
	Flexibility of product characteristics		
		Data-driven services	
		Availability of data-driven services	
		Share of revenues derived from data-driven services	
		Share of data used	

**Table IV.**  
Contextual transformation capabilities comparison of the analyzed maturity models

	Model 1 (Schuh <i>et al.</i> , 2017)	Model 2 (Schumacher <i>et al.</i> , 2016)	Model 3 (Lichtblau <i>et al.</i> , 2015)
–		Governance	–
		Labor regulations for I40	
		Suitability of technological standards	
		Protection of intellectual property	
–		Customers	–
		Utilization of customer data	
		Digitalization of sales/services	
		Customer's digital media competence	

future vision. The dimension “Smart operations” emphasizes the agility, security and autonomy of processes, beyond the sharing of information and the usage of cloud computing. The dimension “Smart factories” evaluate the digitalization of production installations and equipment, and the usage of data from integrated information and communication systems. The dimension “Data driven services” evaluates the offer of services based on collected data of clients and the conditions of products usage, and their contribution to the company’s revenue. The dimension “Smart products” evaluates the



existence of embedded systems on products and the utilization of collected data in the usage phase of the products by the clients. Table III summarizes the comparison between technical issues of the analyzed models.

*2.3.3 Contextual issues.* Only model 2 (Schumacher *et al.*, 2016) contains a dimension related to contextual issues that are external to companies. It includes aspects related to labor and intellectual property laws, technologies standardization, the definition of emerging technology standards, as well as aspects of digital management of customer data and sales, and the use of these data. Table IV exemplifies these transformation capabilities.

The three maturity models are based on the key enabling issues and technologies of Industry 4.0, such as those exemplified in previous sections. All models consider that the implementation of these technologies in the manufacturing environment can promote competitive advantages and new business opportunities, generating huge changes throughout the value chain. It can also be verified in all models that one of the main attributes of the fourth industrial revolution will be the integration, made possible by the technologies mentioned above, with special attention to ICT.

Model 1 (Schuh *et al.*, 2017) has special emphasis on information technology but does not assess, for example, the smart products dimension. Model 2 has been partially published in a journal article and the literature review did not reveal any article showing the implementation of such model. Due to the lack of information, this model cannot be adopted. The most complete model is model 3 (Lichtblau *et al.*, 2015). However, the other models and the literature review revealed some aspects not present in model 3. Model 1 has a strong focus on data acquisition and processing with AI, not present in model 3. Model 2 refers to the machine-to-machine communication and the autonomous processes, an important feature of I4.0, as it has been seen in the previous sections. The literature review also showed the importance of the security issues and the emergence of the reconfigurable layouts. In terms of strategic management, only model 2 refers to the availability of resources and the needed support of top management and central coordination.

From the comparison of the analyzed models and the identification of improvement opportunities between them, it was decided that it would be opportune to develop a new and enhanced model, which would join the positive attributes of each one, filling in the existing gaps through a combination of the three models. It corroborates the principle that maturity models, including those of Industry 4.0, must follow a natural process of continuous improvement over time, to reflect the updates of concepts and technologies to what are intended to be evaluated. According to the above mentioned, model 3 was taken as reference model and some adjustments were done to incorporate other concepts and evaluation items to foster the assessment of Industry 4.0 maturity.

### 3. Methodology

The methodology adopted for the development of the maturity model in this study was based on the process of maturity model development of De Bruin *et al.* (2005), which is applicable to diverse knowledge domains, not restricted therefore, to the Industry 4.0 domain. This methodology was utilized by several authors in different domains, like, for example, Donovan *et al.* (2016), for the Industrial Analytics Maturity Model, Mamoghli and Cassivi (2018) for the business processes support through human and IT factors, and Asdecker and Felch (2018) for the delivery process in supply chains.

De Bruin *et al.* (2005) propose in their methodology a sequence of six iterative stages, because the results of a determined stage can require that an earlier stage be visited for enhancement. Figure 1 synthesizes the stages of the development process that are succinctly described below for a better comprehension of the methodology.

Stage 1 – definitions of the model scope – the combination of definitions of the scope that configures the external frontiers for the application and usage of the model. The main definitions in this phase are the focus of the model, comprehending if it attends a specific or a general domain, and the target audience, for example academic researchers, executives, governmental institutions or even a combination of them.

In this research, the knowledge domain is specific, the Industry 4.0 domain, and the defined target audience are academic researchers, companies involved in digital transformation and professionals that want to know about industry 4.0 capabilities and maturity levels.

Stage 2 – definitions of the model design – consist in the comprehension of the target audience needs and how these needs will be attended. Briefly try to respond the following questions:

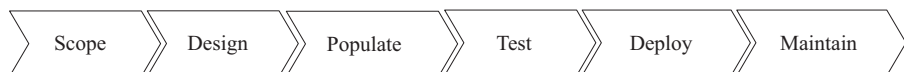
- Why does the audience of this model want to apply it?
- How does the model can be applied in diverse organizational structures?
- Who needs to be involved in applying the model?
- What can be obtained by applying the model?

In the present work, the proposed model was designed for a self-evaluation by the users. They do not need a third party to do it, unless they want. This paper presents the model in its complete content, comprising the dimensions and respective transformation capabilities, the maturity levels and the questions to guide the actors involved in the assessment. Therefore, no other tool is needed to fulfill the assessment.

Stage 3 – model composition and validation – in the third stage the model is compound and validated, contemplating the activities of concept and population of its content, identifying what needs to be measured in the maturity evaluation and how it can be measured. In emerging knowledge domains, the literature review for the definition of components and subcomponents might not be enough, once the explicit knowledge cannot cover the most relevant aspects, due to specificities and constant changes in the state of art of the domain. Therefore, the literature review serves only as a starting point to the model composition, making it necessary to complement this stage with other knowledge acquisition methods.

A literature review was done in order to deepen the knowledge of industry 4.0 concepts and technologies, as well as analyzing the existing industry 4.0 maturity models available at the main publications. Searches were done in the databases Web of Science, Scopus and Science Direct with the search terms “industry 4.0”; “advanced manufacturing”; “smart factories”; “maturity models” and a combination of them. Some references of the consulted papers were also analyzed. Three explicit maturity models related to Industry 4.0 were compared. From the literature review and the analysis of existent Industry 4.0 maturity models, a first version of a model was proposed. Care was taken to avoid concepts overlaps and ambiguities, so the components and subcomponents of the model were intended to be mutually exclusive and collectively exhaustive. For this purpose, an empirical research method was adopted, and interviews were conducted with professionals from two Brazilian companies in the automotive sector, which contributed to the improvement and validation of the model form and content, resulting in some changes of the first version.

**Figure 1.**  
Stages of the  
development process  
of maturity models



**Source:** Adapted from De Bruin *et al.* (2005)

The form validation was done evaluating the comprehension of the utilized terms and concepts, both in the components and subcomponents, as well as the questions to be answered by the audience, along with the practicality and usability of the model. The respondents were asked about the structure of the evaluation instrument (survey) presented in Appendix, its usability, the needed time to be filled in and if the questions were well formulated. It was important to evaluate how representative the model is in measuring the main aspects of the domain of interest.

Stage 4 – model pilot test – the test stage consists in having verified its adequacy of form and content. The form validation can be done evaluating the comprehension clarity of the utilized terms and concepts, both the components and subcomponents, as the questions to be answered by the audience, besides the practicality and usability of the model.

In order to choose the companies for the model validation and pilot test, the model application in companies of diverse industries or choosing a single reference industry leader in Industry 4.0 capabilities was considered. In both cases there are advantages and disadvantages, because applying it in different industries would enable a wider coverage, aligned with the objective of developing a multi-sectorial application tool. However, the inconvenience of not allowing comparisons between companies of the same industry and having opinions of professionals not yet knowledgeable to the concepts and technologies of Industry 4.0. The decision of applying the pilot model to a single industry was made, and the automotive industry was chosen, because accordingly to the researched literature, it leads the efforts in learning and applying the concepts and technologies related to Industry 4.0. Schuh *et al.* (2017) affirm that Industry 4.0 will be applied in many sectors, contemplating the automotive industry, siderurgy, ship construction, textile, electrical energy, electronics, machine and equipment industry and many others. Among these, the automotive industry is the one that earlier applies the concepts and technologies of Industry 4.0, because it has more favorable conditions, in hardware and in software, compared to other industries. Thereby it perceives more benefits in products development, production planning and in production integration.

The selected companies were the same two that collaborated in the model validation stage. For this purpose, the researchers met with the respondents, seven in total for both companies, who work in different areas, namely, production scheduling, information technology, strategic planning, industrial engineering, product engineering and quality management. The diversity of respondent's jobs made possible a multidisciplinary approach. A structured survey (Appendix), containing 41 questions, was previously sent and respondents were invited to answer the survey in the presence of the researchers, who clarified doubts, took notes and registered the perception of the respondents. From the responses, the maturity assessment from 0 to 5 of the transformation capabilities and the dimensions, were obtained. A methodology where the respondents utilized the model to assess the maturity in their respective companies in the same way they would do in a self-administered process, was planned.

Stage 5 – deployment – after the model validation and testing by its audience, it can be available for usage. Two important issues must be observed for the model to be accessible and widely accepted. For specific domains, the distribution to associations and sectorial committees can be more suitable. The identification of organizations that can benefit from its utilization and the ability of applying it to multiple organizations can also contribute to the standardization and global acceptance of the model. This stage was not an objective of this research.

Stage 6 – maintenance – the maintenance of the maturity model is impacted by the resources needed for its updating and utilization over time. These resources, such as data repository, are necessary to support a big volume of users of the model. The availability of resources is determined from the definition of the model scope. If the model become available online, several resources are required to continuously update its interface and follow the technological evolution, besides its content. This stage was not an objective of this research.

---

#### 4. Maturity model adaptation and improvement

The general objective of this section is to describe the maturity model developed to assess the implementation of concepts and technologies related to Industry 4.0 which can be applied in industrial and service companies, in order that they can identify the current stage of maturity, reveal the causes of non-attainment of the desired maturity, and monitor the development of actions that enhance their technical and managerial capabilities. De Bruin *et al.* (2005) assert that a descriptive maturity model can be understood as a model focused on evaluating the maturity in the current state (the “as is” state) and is not intended to indicate actions needed to improve the maturity nor relates to the performance of a company.

##### 4.1 Model composition

The proposed model is composed of four key elements: (i) the dimensions, (ii) the transformation capabilities, (iii) the maturity levels, (iv) the measurement instrument. The elements (i) and (ii) components and subcomponents, respectively, are named as “dimensions” and “transformation capabilities,” respectively, to accord with the denominations utilized in model 3, which was taken as reference to the composition of this proposed model.

**4.1.1 Dimensions.** The dimensions (components) are multi-disciplinary and can be understood as grouping factors of the transformation capabilities (subcomponents). They have the function of generating a synthetic comprehension of the main aspects related to the Industry 4.0 development, comprising human resources, technologies, products, processes, and the strategic orientation of the company. Based on the literature review and the comparative analysis of the existent models, five dimensions were proposed related to organizational and management issues and to technical issues. The contextual dimension, related to externalities, proposed by model 2 (Schumacher *et al.*, 2016), is not included because the proposed model is focused on the assessment of internal aspects that are manageable by companies, to contribute to the Industry 4.0 maturity level. The proposed dimensions have a description that justifies their utilization and foster the evolutionary process to enhance the model, with the possibility of inclusion, exclusion or changing of the dimensions over time. Table V presents the proposed dimensions and the respective descriptions.

**4.1.2 Transformation capabilities.** The transformation capabilities are the base of the process of adaption to Industry 4.0 and can be perceived as the areas of interest to be fostered by organizations, through the strategy and the actions to be executed for the achievement of the strategic goals of Industry 4.0. They are in fact the evaluation items that will receive a measurable maturity classification. They are the most relevant principles that guide the implementation of concepts and innovative technologies, in some cases disruptive. Table VI shows the proposed transformation capabilities grouped by dimension.

**4.1.3 Maturity levels and evaluation questions.** In this proposed model, each dimension (Table V) and each transformation capability (Table VI) are evaluated in six levels of maturity (from level 0 to level 5). The number of levels is the same as the reference model, which was previously described. The analyzed model 1 (Schuh *et al.*, 2017) and model 3 (Lichtblau *et al.*, 2015) have six levels of maturity and model 2 (Schumacher *et al.*, 2016) has five levels. There is not a standard or historical number of levels in maturity models, therefore the decision to maintain the same number of levels as those of the reference model was adopted. The adopted level 5 is the maximum level of maturity (state of art). It is implicit that the levels 0 to 4 are incremental evolutions until the achievement of the maximum level. The ideal situation would be for the company to evolve in a balanced way in the process of digital transformation, which reflects a good planning and execution of the response actions of the company.

Industry 4.0  
maturity model  
proposal

Dimensions	Description
Organizational strategy, structure and culture	The evolution toward Industry 4.0 needs a change of paradigms of the administration board through the promotion and dissemination of an innovative culture and continuous improvement, the disposability of required resources to implement new information and operation technologies, the adequacy of the organizational structure, and of the constant pursuit of customers satisfaction. The innovative culture is expected to be implemented from a top-down perspective
Workforce	The digital transformation and the intensive use of innovative technologies are not possible without proper qualification and constant updating of the technical and management skills and of the workforce. The teams need to be opened for innovative technologies, and to have flexibility and autonomy for fast changes in context
Smart factories	The factories of the future, compound by smart sensors and actuators, installations and equipment with embedded systems and connectivity, will enable the communication in real time between machines, products, people and infrastructures, forming a digital network environment
Smart processes	The connectivity and interoperability of information and operation systems, and of equipment and installations, will enable the existence of autonomous systems and processes. Embedded with advanced algorithms of artificial intelligence, will contribute to the continuous machines learning, allowing the self-optimization and self-configuration of processes of production, maintenance, logistics, and support processes
Smart products and services	Products with intelligent embedded systems will constitute the base for data acquisition in real time, allowing the constant communication with customers, with the factory and with the productive processes through the value chain. Complementary services, based on acquired data, and enabled by connectivity technologies, will be an important source of the company's revenue

**Table V.**  
Descriptions of the  
dimensions of the  
proposed model

The maturity levels described below must be interpreted according to the coverage and extension of the concepts and technologies related to each question:

- Level 0 – low or none degree of implementation.
- Level 1 – pilot actions being planned or being developed.
- Level 2 – implementation of actions initiated, with some benefits being observed.
- Level 3 – partial implementation of actions, that enhance the competitiveness of the company.
- Level 4 – advanced implementation of actions, with clear economic returns.
- Level 5 – reference in applying the concepts and implementing the technologies of Industry 4.0.

For each dimension, the highest level of maturity is the reference to be achieved, in terms of implementation maturity of Industry 4.0 concepts and technologies. With the objective of assessing the maturity level of each transformation capability, a survey instrument (Appendix) was developed. It comprises questions to guide respondents and inquirers to establish the maturity level of the transformation capabilities more accurately. The criteria used in this model to classify the maturity of a dimension and consequently for the overall company evaluation was the mean, with a rounding down rule.

#### 4.2 Model validation and pilot tests

Besides the literature review and the analysis of existent Industry 4.0 maturity models, an empirical method of qualitative interviews with relevant industrial companies was chosen, with the objective of obtaining contributions of specialists to the composition and validity of

Dimensions	Transformation capabilities
Organizational strategy, structure and culture	<ul style="list-style-type: none"> <li>Analysis of impacts of the Industry 4.0 to the company's competitiveness</li> <li>Strategic management to the Industry 4.0 implementation</li> <li>Investments in the technologies of Industry 4.0</li> <li>Innovation management and use of technologies</li> <li>Resources availability to implement the transformation actions</li> <li>Focus on benefits to the clients</li> <li>Collaboration with other companies of the value chain</li> <li>Existence of a central coordination for the Industry 4.0</li> </ul>
Workforce	<ul style="list-style-type: none"> <li>Existent and required skills</li> <li>Skills acquisition</li> <li>Equips flexibility and autonomy</li> <li>Creativity and labor enrichment</li> <li>Innovation openness and change responsivity</li> </ul>
Smart factories	<ul style="list-style-type: none"> <li>Digital modeling of installations and equipment</li> <li>Equipment infrastructure with embedded systems</li> <li>Integrated information, communication and operation systems</li> <li>Data acquisition through sensors and actuators</li> <li>Autonomous equipment and artificial intelligence</li> <li>Reconfigurable layouts</li> <li>Utilization of mobile devices</li> </ul>
Smart processes	<ul style="list-style-type: none"> <li>Utilization of cloud computing</li> <li>Security of assets and data protection</li> <li>Autonomous processes</li> <li>Digital modeling and simulation of processes</li> <li>Agile information share across organization</li> <li>Visual computing and contextualized tasks interfaces</li> <li>Data analytical capability and artificial intelligence</li> </ul>
Smart products and services	<ul style="list-style-type: none"> <li>Embedded software in products</li> <li>Data analysis through the product utilization phase</li> <li>Services offer based on acquired data of products</li> <li>Digital project and simulation of products</li> <li>Segmentation and individualization of products and services</li> <li>Capacity of agile reconfiguration of products</li> <li>Integration of products with other systems</li> </ul>

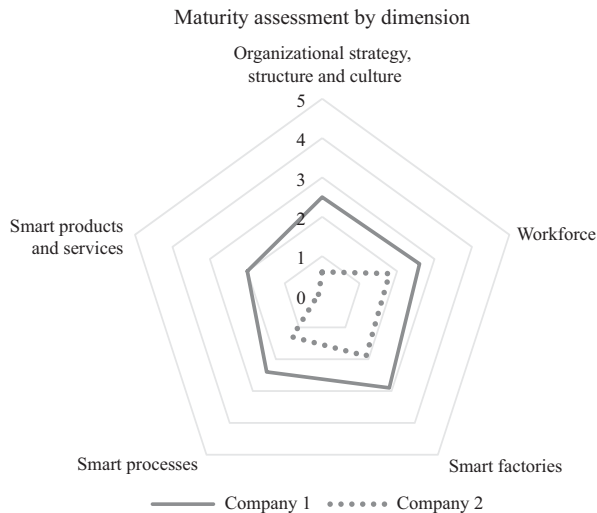
**Table VI.**  
Transformation capabilities of the proposed model

the adapted model. The model validation pursued to evaluate its coverage and representativeness, in order to confirm that it covers the most relevant dimensions and capabilities of the digital transformation process of an industrial company.

After the development of the model content, it was validated and tested with two Brazilian companies from the automotive industry. Both companies can be classified as world class manufacturers. Due to disclosure agreement, the names of the companies are not published. Company 1 is a tire manufacturer and Company 2 is an automobile assembler.

The realization of the pilot tests contributed to some minor adjustments in the survey instrument and showed that the usability of the model was considered suitable, the required time to complete it was about 45 min in a self-administered manner. The tests were well succeeded and allowed its dissemination, whilst it was not a research objective.

To verify the applicability of the model, a pilot test was done within the same companies of the validation phase. The maturity level in each dimension was obtained from the average of the respective transformation capabilities and the overall maturity of each company obtained from the average of the dimension levels. Company 1 revealed a higher maturity level than Company 2, as it reached an overall level of 2, 5 against 1, 3 of Company 2. Figure 2 compares the results obtained by both companies.



**Figure 2.**  
Maturity assessment  
of company 1 and  
company 2

Company 1, a multinational manufacturer of automotive tires, presented intermediate results, having obtained an overall rating of 2.5. The assessment of each dimension revealed a balanced maturity, between 2 and 3.

Company 2 is a multinational automobile assembler and the expectation was that the level of maturity would be intermediate, considering that the auto industry is often at the forefront of industrial technological innovations. However, the company's overall maturity rating stood at 1.3. The results of maturity of the dimensions were disparate, with some dimensions presenting a low or very low maturity, with exception to the "Smart processes" dimension and, to a certain extent, "Workforce" and "Smart factories." It seems that, although the company has some projects and the implementation of some technologies related to industry 4.0, it does not have an integrated strategy toward its full implementation.

In both companies, the less developed dimension was "Smart products and services," related to the generation of new smart products that incorporate the concepts of industry 4.0.

The analysis of weaknesses and strengths of Company 1 shows an ambiguity, since the lack of strategic direction for the operationalization of Industry 4.0 seems to be the weakest dimension. Innovative technologies, such as autonomous systems and processes, the application of AI in equipment and products, seems to be implementing and can be great opportunities for the company to evolve, allowing new levels of productivity, integration and a better relationship with customers, through connected products and generating new sources of revenue.

The results obtained from the evaluation of company 2 shows huge room for further improvement, specifically in the dimensions related to the performance of top management and the incorporation of embedded technologies in the products, which can bring tangible and intangible benefits to the business. The organizational structure was evaluated as rigid, where the work teams have a lack of autonomy and flexibility to participate in the creation of new solutions. However, it seems that teams have the skills required for the transformation process for Industry 4.0 and are open to change.

It was not an objective of this work to make recommendations of corrective and preventive actions in the companies that contributed to the model validation, because it is understood that these actions are derived from the strategy of each company and require a differentiated approach.

---

## 5. Conclusions

Industry 4.0 is still an emerging topic in literature and industrial applications. Thus, the number of scientific publications is still low compared to other mature topics in engineering. The concepts and technologies addressed are of great relevance for manufacturing industries, and in the medium and long-term, can significantly change the competition between companies and entire value chains. It is therefore imperative that companies be prepared for the great changes in business environments and have practical and robust tools for assessing maturity in the implementation of these concepts and technologies.

The literature review shows that the implementation of Industry 4.0 in manufacturing companies requires a holistic view, not only focused on hardware and software improvements in production environment, but also including a new strategic orientation, the development of new workforce competencies, the adaptation of business models, the development of new products and services with new functionalities and the implementation of enabling technologies. The proposed maturity model supports the request for a holistic approach, as it comprises the good practices above mentioned, as it is compound by technical capabilities related to products and services, factories and processes, and managerial capabilities related to organizational strategy and culture, and workforce qualification.

From the literature review it can be observed that there is a convergence of key enabling technologies of Industry 4.0, which were consolidated over the last decades, that support the emerging industrial applications. Among these are the CPS, internet of things, cloud computing, Big Data Analytics, service-oriented architecture, autonomous and smart systems, the additive manufacturing (3D printing), mobile devices and its applications. In parallel with technological evolution, several concepts related to the fourth industrial revolution have evolved. Among the main ones are the customized demand, business process digitalization, including processes of product development, fabrication, delivery, the connectivity between machine and other entrepreneurial systems and the consequent decision decentralization, performed by autonomous systems. Other important concepts are the increasing real time data analytical capacities, product digitalization supported by intelligent embedded systems and by connectivity technologies, and the agile layouts reconfigurability.

In the center of all these emerging concepts and technologies are data, each time more precise and acquired in real time, allowing more data-driven decisions instead of those based on experience or feeling.

Donovan *et al.* (2016) assert that there are many challenges associated to the development of industrial analytical capacities, including the management of technologies and heterogeneous platforms, composition of multi-disciplinary teams, trainings and others. Some challenges are amplified when there are no methods to measure the level of current capability and strategically identify the areas that need improvements. The focus of this work was on developing a complete and ready to use tool to quantify the maturity in applying the proposed transformation capabilities.

This paper aimed to develop a maturity model for Industry 4.0, to collaborate with companies for the implementation of main related concepts and technologies, and academics to better understand the phenomenon. The proposed model was adapted from three existent maturity models, and a pilot test was performed on two Brazilian companies, both from the automotive industry.

Although the validation was done with a few executives from both companies, the model seems to contain all the facets of industry 4.0 implementation and is ready to be used in a self-administration mode, and to proceed with the dissemination stage. This stage is important, in order to enable comparative analyses of maturity between companies and different industries.

The presented maturity model is designed to support companies evaluating their implementation strategies for Industry 4.0, as well as researchers wishing to better



understand the phenomenon. It is compound by dimensions, transformation capabilities, maturity levels descriptions and the survey instrument. These parts together constitute a complete tool for a maturity assessment. The main limitation of this research is the small number of professionals in the industry that participated in the validation phase of the model. In the future, it will be interesting to disseminate the model, physically or virtually, and enhance its statistical validation, essential for its utilization for research purposes.

## References

- Asdecker, B. and Felch, V. (2018), "Development of an industry 4.0 maturity model for the delivery process in supply chains", *Journal of Modelling in Management*, Vol. 13 No. 4, pp. 840-883, available at: <https://doi.org/10.1108/JM2-03-2018-0042>
- De Bruin, T., Freeze, R., Kaulkarni, U. and Rosemann, M. (2005), "Understanding the main phases of developing a maturity assessment model", *Australasian Conference on Information Systems (ACIS), January*, pp. 8-19, available at: <https://doi.org/10.1108/14637151211225225>
- De Souza, T.F. and Gomes, C.F.S. (2015), "Assessment of maturity in project management: a bibliometric study of main models", *Procedia Computer Science*, Vol. 55, pp. 92-101, available at: <https://doi.org/10.1016/j.procs.2015.07.012>
- Donovan, P.O., Sullivan, D.T.J.O. and Bruton, K. (2016), "IAMM: 'a maturity model for measuring industrial analytics capabilities in large-scale manufacturing facilities'", *International Journal of Prognostics and Health Management*, Vol. 7 No. 32, pp. 1-11.
- ElMaraghy, H. and ElMaraghy, W. (2016), "Smart adaptable assembly systems", *Procedia CIRP*, Vol. 44, pp. 4-13, available at: <https://doi.org/10.1016/j.procir.2016.04.107>
- Ghobakhloo, M. (2018), "The future of manufacturing industry: a strategic roadmap toward Industry 4.0", *Journal of Manufacturing Technology Management*, Vol. 29 No. 6, pp. 910-936, available at: <https://doi.org/10.1108/JMTM-02-2018-0057>
- Goksen, Y., Cevik, E. and Avunduk, H. (2015), "A case analysis on the focus on the maturity models and information technologies", *Procedia Economics and Finance*, Vol. 19, pp. 208-216, available at: [https://doi.org/10.1016/S2212-5671\(15\)00022-2](https://doi.org/10.1016/S2212-5671(15)00022-2)
- Gunes, V., Peter, S., Givargis, T. and Vahid, F. (2014), "A survey on concepts, applications, and challenges in cyber-physical systems", *KSI Transactions on Internet and Information Systems*, Vol. 8 No. 12, pp. 4242-4268, available at: <https://doi.org/10.3837/tiis.2014.12.001>
- Hermann, M., Pentek, T. and Otto, B. (2016), "Design principles for Industrie 4.0 Scenarios", *49th Hawaii International Conference on System Sciences (HICSS) IEEE, Vol. 2016, March*, pp. 3928-3937, available at: <https://doi.org/10.1109/HICSS.2016.488>
- Kagermann, H., Wahlster, W. and Helbig, J. (2013), "Recommendations for implementing the strategic initiative Industrie 4.0", Final report of the Industrie 4.0 Working Group, Acatech, Frankfurt/Main, available at: [https://en.acatech.de/wp-content/uploads/sites/6/2018/03/Final\\_report\\_Industrie\\_4.0\\_accessible.pdfQ5](https://en.acatech.de/wp-content/uploads/sites/6/2018/03/Final_report_Industrie_4.0_accessible.pdfQ5) (accessed January 11, 2017).
- Lee, J., Bagheri, B. and Kao, H.A. (2015), "A cyber-physical systems architecture for Industry 4.0-based manufacturing systems", *Manufacturing Letters*, Vol. 3, January, pp. 18-23, available at: <https://doi.org/10.1016/j.mfglet.2014.12.001>
- Lichtblau, K., Stich, V., Bertenrath, R., Blum, M., Bleider, M., Millack, A., Schmitt, K., Schmitz, E. and Schröter, M. (2015), *IMPULS – Industrie 4.0 Readiness*, VDMA's IMPULS-Foundation, Aachen.
- Mamoghli, S. and Cassivi, L. (2018), "Supporting business processes through human and IT factors: a maturity model", *Business Process Journal*, Vol. 24 No. 4, pp. 985-1006, available at: <https://doi.org/10.1108/BPMJ-11-2016-0232>
- Monostori, L. (2014), "Cyber-physical production systems: roots, expectations and R&D challenges", *Procedia CIRP*, Vol. 17, pp. 9-13, available at: <https://doi.org/10.1016/j.procir.2014.03.115>

- 
- Porter, M.E. and Heppelmann, J.E. (2015), "How smart, connected products are transforming companies", *Harvard Business Review*, Vol. 93 No. 10, pp. 96-114, available at: <https://hbr.org/2015/10/how-smart-connected-products-are-transforming-companies>
- Posada, J., Toro, C., Barandiaran, I., Oyarzun, D., Stricker, D., de Amicis, R., Pinto, E., Eisert, P., Döllner, J. and Vallarino, I. (2015), "Visual computing as a key enabling technology for Industrie 4.0 and industrial internet", *IEEE Computer Graphics and Applications*, Vol. 35 No. 2, pp. 26-40, available at: <https://doi.org/10.1109/MCG.2015.45>
- Qin, J., Liu, Y. and Grosvenor, R. (2016), "A categorical framework of manufacturing for Industry 4.0 and beyond", *Procedia CIRP*, Vol. 52, pp. 173-178, available at: <https://doi.org/10.1016/j.procir.2016.08.005>
- Renning, F., Luminosu, C.T. and Draghici, A. (2016), "Service provision in the framework of Industry 4.0", *Procedia – Social and Behavioral Sciences*, Vol. 221, June, pp. 372-377, available at: <https://doi.org/10.1016/j.sbspro.2016.05.127>
- Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P. and Harnisch, M. (2015), "Industry 4.0", available at: [www.bcgperspectives.com/Images/Industry\\_40\\_Future\\_of\\_Productivity\\_April\\_2015\\_tcm80-185183.pdf](http://www.bcgperspectives.com/Images/Industry_40_Future_of_Productivity_April_2015_tcm80-185183.pdf) (accessed August 21, 2017).
- Scheuermann, C., Verclas, S. and Bruegge, B. (2015), "Agile factory – an example of an Industry 4.0 manufacturing process", *Proceedings – 3rd IEEE International Conference on Cyber-Physical Systems, Networks, and Applications*, Vol. 2008, pp. 43-47, available at: <https://doi.org/10.1109/CPSNA.2015.17>
- Schuh, G., Anderl, R., Gausemeier, J., ten Hompel, M. and Wahlster, W. (2017), "Industrie 4.0 maturity index", *Managing the Digital Transformation of Companies (Acatech Study)*, Herbert Utl Verlag, Munich, available at: [https://en.acatech.de/wp-content/uploads/sites/6/2018/03/acatech\\_STUDIE\\_Maturity\\_Index\\_eng\\_WEB.pdf](https://en.acatech.de/wp-content/uploads/sites/6/2018/03/acatech_STUDIE_Maturity_Index_eng_WEB.pdf) (accessed June 26, 2017).
- Schumacher, A., Erol, S. and Sihm, W. (2016), "A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises", *Procedia CIRP*, Vol. 52, pp. 161-166, available at: <https://doi.org/10.1016/j.procir.2016.07.040>
- Stock, T. and Seliger, G. (2016), "Opportunities of sustainable manufacturing in Industry 4.0", *Procedia CIRP*, Vol. 40, pp. 536-541, available at: <https://doi.org/10.1016/j.procir.2016.01.129>
- Wang, S., Wan, J., Li, D. and Zhang, C. (2016), "Implementing smart factory of Industrie 4.0: an outlook", *International Journal of Distributed Sensor Networks*, Vol. 12 No. 1, Article No. 3159805, available at: <https://doi.org/10.1155/2016/3159805>

## Appendix. Evaluation instrument (survey)

Please, answer the question below according to the scope and implementation extension of the concepts and technologies related to each question, choosing one of the following answers:

Level 0 - Low or no degree of implementation

Level 1 - Pilot actions planned or in development

Level 2 - Implementation started, with some observed benefits

Level 3 - Intermediate implementation, which has improved the company's competitiveness

Level 4 - Advanced implementation, with clear economic returns

Level 5 - Reference in applying the concepts and implementing the technologies of Industry 4.0

### **1. Strategy, structure and organizational culture**

Does the company...

1.1. ... continuously analyze the impacts of Industry 4.0 of its competitiveness in medium and long terms?

1.2. ... incorporate the concepts and technologies of Industry 4.0 as main factors of competitive strategy?

1.3. ... have appropriate indicators to monitor the deployment of actions of Industry 4.0 with objectives and realistic targets?

1.4. ... plan and do investments to implement the technologies of Industry 4.0?

1.5. ... have an organizational structure oriented to innovation and incorporation of new technologies?

1.6. „, top management provide the needed resources to the realization of the transformation actions?

1.7. ... communicate an agile and digitized way with clients to acquire information?

1.8. ... focus on customers requirements to define their strategic and operational actions for the Industry 4.0 transformation?

1.9. ... share relevant information with other companies of the value chain in order to have an agile decision making process?

1.10. ... have a central coordination for the transformational actions of Industry 4.0?

### **2. Workforce**

Does the company...

2.1. ... have the required technical and managerial abilities to implement the transformational actions of Industry 4.0?

2.2. ... obtain the necessary qualifications to acquire technical and managerial abilities related with the concepts and technologies of Industry 4.0?

2.3. ... have an organizational structure and decision approval methods to promote flexibility and autonomy of equipments?

2.4. ... encourage the creativity and empowerment of employees considering the challenges and benefits of digital transformation?

2.5. ... observe and encourage the openness of employees to innovation and continuous learning, with a responsive actuation in context changes?

### **3. Smart factories**

Does the company...

3.1. ... have digital twins of the manufacturing facilities and equipment that virtually reproduce the physical world?

3.2. ... have bidirectional updating between the real facilities and equipment, and the digital twins?

3.3. ... have an infrastructure of equipment with embedded systems, that enable the data acquisition and processing, and the communication between each other and with other systems?

3.4. ... have information, communication and operation systems integrated and capable of meeting interoperability requirements?

3.5. ... collect data from sensors and actuators, without human intervention and in real time?

3.6. ... have manufacturing equipment equipped with artificial intelligence technologies that enable continuous improvement and autonomous decision making?

3.7. ... have agile reconfigurable layouts, to meet diversification and volume volatility in customized product demand?

3.8. ... use smart mobile devices to make operations more flexible and optimized?

### **4. Smart processes**

Does the company...

4.1. ... use cloud-computing systems for storing and processing data?

4.2. ... use technologies and procedures for the security of human and physical resources and data protection against theft and misuse?

4.3. ... have productive processes able to operate autonomously, aided by machine learning systems?

4.4. ... design its key business processes for agile information sharing, within the company and with other business partners?

4.5. ... have the main business processes digitized with an integrated information and communication systems?

4.6. ... can digitally model and simulate the performance of its main business processes?

4.7. ... use visual computing resources, such as supervisory systems, virtual and augmented reality systems, to aid operations?

4.8. ... use visual computing resources that deliver contextualized information and interfaces for tasks?

4.9. ... use data mining systems to help the key business processes, to process large volumes of data from multiple sources in real-time?

## 5. Smart products and services

Does the company...

- 5.1. ... have products with embedded and intelligent systems?
- 5.2. ... have products equipped with artificial intelligence systems for self-optimization of their characteristics and performance?
- 5.3. ... have products with embedded systems equipped with technologies that allow communication with the factory and the analysis of its conditions of use?
- 5.4. ... offer complementary services to products, developed from the data collect on customer preferences and conditions of use?
- 5.5. ... have a digitized product project, which can be sent to the company factory and other network value companies?
- 5.6. ... use digital simulation to test the conditions of use and performance of products?
- 5.7. ... develop products and services according to the demand customization?
- 5.8. ... resources and processes allow the agile reconfiguration of the products?
- 5.9. ... have products with embedded systems that are integrated with other management and operational systems?

### **Corresponding author**

Reginaldo Carreiro Santos can be contacted at: [reginaldocarreiro@yahoo.com.br](mailto:reginaldocarreiro@yahoo.com.br)

---

For instructions on how to order reprints of this article, please visit our website:

[www.emeraldgrouppublishing.com/licensing/reprints.htm](http://www.emeraldgrouppublishing.com/licensing/reprints.htm)

Or contact us for further details: [permissions@emeraldinsight.com](mailto:permissions@emeraldinsight.com)