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# AN INDUSTRY 4.0 MATURITY MODEL APPLIED TO THE AUTOMOTIVE SUPPLY CHAIN

# UM MODELO DE MATURIDADE DA INDÚSTRIA 4.0 APLICADO NA CADEIA DE SUPRIMENTOS NO SETOR AUTOMOTIVO

# UN MODELO DE MADUREZ DE LA INDUSTRIA 4.0 APLICADO A LA CADENA DE SUMINISTRO AUTOMOTRIZ

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## ABSTRACT

**Objective of the study:** to present and apply a maturity model to analyze industries in the 4.0 context, enabling to identify the main differences in the maturity level of the members of a supply chain.

**Methodology/approach:** from the literature review, a model was proposed to measure the maturity of Industry 4.0 concepts, to be tested using a questionnaire. This model was validated by experts and then applied to three automotive parts manufacturers in the Greater São Paulo (SP) region and to three relevant suppliers in their respective supply chains.

**Originality/Relevance**: this study addresses an existing research gap by providing an open model for analyzing the maturity of Industry 4.0 concepts in a supply chain in the Brazilian scenario.

**Main results:** the companies assessed showed low scores in most of the six dimensions in the model. The results from analysis of the responses to the questionnaire also demonstrated a low level of implementation of the Industry 4.0 methodology.

**Theoretical contributions**: a theoretical review of the relevant components of Industry 4.0 was carried out, as well as a synthesis of fifteen models available in the literature to analyze the degree of maturity of these concepts.

**Contributions to management:** to offer the entire academic and professional communities a structured, tested questionnaire with 66 questions for analysis of Industry 4.0 maturity level in a supply chain.


**Keywords:** Industry 4.0; Supply chain; Maturity level; Automotive industry.


## RESUMO

**Objetivo do estudo:** apresentar e aplicar um modelo de maturidade para analisar indústrias no contexto 4.0, possibilitando a identificação das principais diferenças existentes entre os níveis de maturidade dos membros de uma cadeia de suprimentos.

**Metodologia/abordagem:** a partir da revisão de literatura, foi proposto um modelo de maturidade dos conceitos da Indústria 4.0, testado por meio de um questionário. Esse modelo foi validado por especialistas, para em seguida ser aplicado em três empresas fabricantes de autopeças na região da Grande São Paulo (SP) e em três fornecedores relevantes em suas respectivas cadeias de fornecimento.

**Originalidade/Relevância:** preencher uma lacuna de pesquisa existente, ao fornecer um modelo aberto e disponível para analisar o grau de maturidade dos conceitos da Indústria 4.0 em uma cadeia de suprimentos, no cenário brasileiro.

**Principais resultados:** verificou-se que as empresas estudadas apresentaram notas baixas na maioria das seis dimensões do modelo. Os resultados obtidos pela análise das respostas ao questionário demonstram também um baixo nível de implementação da metodologia da Indústria 4.0.

**Contribuições teóricas:** foi realizada uma revisão teórica sobre os componentes relevantes para a Indústria 4.0, bem como uma síntese de quinze modelos que a literatura disponibiliza para a análise do grau de maturidade desses conceitos.

**Contribuições para a gestão:** tornar disponível para toda a comunidade acadêmica e profissional um questionário estruturado e testado, com 66 questões, para a análise do grau de maturidade da Indústria 4.0 para uma cadeia de suprimentos.

**Palavras-chave:** Indústria 4.0; Cadeia de suprimentos; Nível de maturidade; Setor automotivo.

**RESUMEN**

**Objetivo del estudio**: presentar y aplicar un modelo de madurez que analice la industria en el contexto 4.0, permitiendo identificar las principales diferencias entre los niveles de madurez de los participantes en una cadena de suministro.

**Metodología / enfoque**: a partir de la revisión de la literatura, se propuso un modelo de madurez de conceptos de industria 4.0 mediante la aplicación de un cuestionario. Este modelo fue validado por especialistas y aplicado a tres fabricantes de autopartes en la región del Gran São Paulo (SP) y a tres proveedores relevantes en sus redes.

**Originalidad / Relevancia**: Llenar un vacío de investigación existente, proporcionando un modelo abierto y disponible para analizar la madurez de los conceptos de Industria 4.0 de una cadena de suministro en el escenario brasileño.

**Principales resultados**: Se encontró que las empresas estudiadas tuvieron puntuaciones bajas en la mayoría de las seis dimensiones propuestas en el modelo. El resultado obtenido del análisis de las respuestas al cuestionario también demuestra un bajo nivel de implementación de la metodología Industria 4.0.

**Aportes teóricos**: se realiza una revisión teórica de los componentes relevantes para la industria 4.0, así como una síntesis con quince modelos que la literatura pone a disposición para el análisis del grado de madurez de estos conceptos.

**Contribuciones a la gestión**: poner a disposición de toda la comunidad académica y profesional un cuestionario estructurado con 66 preguntas testadas para el análisis del nivel de madurez de la industria 4.0 para una cadena de suministro.

**Keywords**: industria 4.0; cadena de suministro; nivel de madurez; Sector automotriz.

## 1 INTRODUCTION

Industry 4.0 and its related topics have generated great demand for studies and research in the academic, business, economic and even social environment, given the growing number of published articles and discussions on this context, since 2011, when the concept was created. Studies deal mainly with the search for continuous improvement of processes, based on increased productivity, cost reduction, greater profitability and on the social aspect, with concern related to changes in the labor market (Ortt, Stolwijk & Punter,2020; Hofmann & Rüsch, 2017; Thoben, Wiesner & Wuest, 2017).

In this context, it is important to develop a maturity model to analyze the current situation of industries that are seeking to adapt to the concepts and requirements of the Industry 4.0 concept. Thus, it is possible to have a starting point for these industries to develop technologically and digitally in order to identify their level of maturity, helping managers to understand the opportunities to strategically and technologically advance in their processes (Santos & Martinho, 2019; De Carolis , Macchi, Negri, & Terzi, 2017; Thoben, Wiesner & Wuest, 2017).

The introduction of Industry 4.0 in transformation processes can generate many impacts throughout the supply chain, because with collaboration from suppliers, manufacturers and end customers, it is possible to increase transparency and reliability in all stages of the production process, mainly with the introduction of digitization and process automation throughout the supply chain management structure (Stock & Boyer, 2009; Masteika & Cepinskis, 2015)

Recognizing these changes in the business environment, the demand for supply chain management concepts that reflect the challenges and opportunities emerging from the Digital Age ahead of us has increased. Thus, the best practice tools and processes that have been developed in recent decades can be reevaluated and refined for application in the supply chain. Maturity models, for example, are suitable tools for identifying and then creating the resources needed to produce a smart supply chain. The first manifestations of maturity models occurred in the 1970s and were rooted in software engineering, with the concept of maturity evolving into an important tool in business practice among organizations (Nolan, 1973; Van Looy et al., 2013). To understand the opportunities and possible threats of the introduction of these new technologies, it may be advisable to analyze the impact of Industry

4.0 in the supply chain in a broad way, identifying the level of maturity 4.0 that each chain member presents.

Most models are built with the hypothesis that organizational evolution follows a predictable pattern from stage to stage (Isoherranen, Karkkainen & Kess, 2015), with each stage representing a certain maturity level. These maturity stages can be applied to several domains, such as business units or specific processes, which can be considered dimensions of the model (Fraser et al., 2002). Knowing the maturity stage in the respective field of application is essential to identify potential opportunities and stimulate a process of continuous improvement. But can models be applied to a supply chain?

In this context, this article intends to explore this issue and its main objective is to present and apply a theoretically grounded maturity model to identify differences among members of a supply chain, associating it to the context of Industry 4.0.

To achieve the proposed objective, the study seeks theoretical references on the relevant components and maturity assessment models in industry 4.0, to then propose an alternative model that makes it possible to analyze this maturity through the application of a questionnaire specially developed for this purpose in a set of three supply chains, represented by the company-direct supplier dyads. The article is organized as follows: presentation of the theoretical framework, description of the adopted methodology, discussion of results, and finally, the authors' final considerations.

## 2. THEORETICAL FRAMEWORK

Seeking to elucidate the characteristics of the industry that meet the degree of agility and flexibility related to the context of Industry 4.0, the following is the view of Santos and Martinho (2020); Posada et al. (2015); Xu and Hua (2017); Roblek, Mesko and Krapez (2016); Marcon et al. (2017); Lu (2017); Li et al. (2017); Hofmann and Rusch (2017), identifying the relevance of these characteristics in the constitution of the components of Industry 4.0. All of these authors converge on the following points:

- Products manufactured and enabled through industrial IT systems;
- Flexible, agile manufacturing and automatically adapted to unplanned interruptions;
- Traceability, self-management and simultaneous communication (parts, machines and products);

• Improved human-machine interaction (smart factories);

• Wide use of IoT (Internet of Things) as a facilitating agent in manufacturing optimization;

• New business / service models, integrating changes in value chains;

• Correlated processes: network environment, manufacturing devices, assembly, storage, data transmission, wired or wireless networks (real time or not);

• Deep level of integration: connection between smart physical systems (a subject that will be addressed in the next sections), with cloud platforms;

• Availability of large amounts of data in real time: Big-Data Industrial running simultaneously with Big-Data Analysis in smart factories;

• Demand for small customized batches, real-time view of equipment status, manufacturing processes and product information (Big-Data).

Schwab (2016) points out that it is essential that organizations have the perception that changes caused by Industry 4.0 should actually be extended to the entire supply chain to which they belong, reaching stakeholders and possible future partners of their businesses.

Digital and innovative technologies improve products and services, adding value to the operation and the perception of customers. The generation of synergy in this scenario is leveraged by collaborative innovation, being converted into competitive advantage within organizations, and drives growth and socioeconomic development. Young companies, with few resources and innovative profile, seek collaboration and partnership with companies already well established in the market, and likewise, well-established companies seek partnerships and collaboration with young and innovative companies. The vision of a collaboration chain can then make companies more agile, flexible, dynamic and productive (Xu & Hua, 2017).

The fundamental premises of Industry 4.0 are basically linked to the continuous improvement of processes such as productivity, efficiency, safety, flexibility, quality of products and processes, cost reduction and return on invested capital. In this context, the components of industry 4.0, its main areas of activity and characteristics are identified, as can be seen in Table 1.

**Table 1**
Relevant components of Industry 4.0

| Components | Main characteristics | Authors |
|---|---|---|
| **1 – Cyber Physical System (CPS)** | CPS is defined by operating smart machines and equipment, data storage systems in a manufacturing system with autonomous, smart and real-time information exchange | Posada et al. (2015), Kang et al. (2016), Wang et al. (2016) |
| **2 – Additive Manufacturing (AM), Augmented Reality (AR) and Virtual Reality (VR)** | Additive Manufacturing is defined as a group of technologies with layer-by-layer approach for the creation of free-form objects, from bottom to top | Kang et al. (2016) and Wang et al. (2016) |
| **3 – Internet of Things (IoT)** | IoT (Internet of Things) is characterized by the wide use of sensors and software, by communication between machines and equipment with production lines and cells, guaranteeing the collection and exchange of data through smart sensors | Thoben, Wiener and Wuest, (2017), Kang et al. (2016), |
| **4 – IoT Impacts** | IoT is ensuring the integration between various technologies, mainly with regard to human activities with computer systems such as IoP (Internet of Persons) and IoS (Internet of Services) | Hofmann and Rusch (2017), Marcon et al. (2017); Conti, Passarella and Das (2017) |
| **5 – Big Data and Big Data Analysis** | Related to the development of software and data capture systems through IoT. A large amount of data is generated and must be interpreted and analyzed | Kang et al. (2016) |
| **6 - Information Security (IS)** | As it is the company's responsibility to maintain the integrity and reliability of its data and information, it is necessary to operate data security systems against possible cyber attacks | Freund, Fagundes and Macedo (2017) and Schluga et al. (2018) |
| **7 - Cloud Manufacturing (CM)** | This concept refers to the operational mode. Providers provide manufacturing resources, transforming them into services and grouping them into platforms in the clouds. The customer can access these platforms and request product requirements, such as design and performance tests, in addition to being able to manage all stages of the product life cycle | Kang et al. (2016) and Li and Xu (2017) |
| **8 - Energy savings (ES)** | Smart meters capable of monitoring and controlling the status of devices. They can communicate online with other meters / controllers, providing customers with more efficient control over their energy consumption. All of this in real time | Jirkovisk et al. (2016) and Faheem and Gungor (2018) |
| **9 – Smart infrastructure (SI)** | Smart infrastructure has a decentralized system, as it routes energy, data and information in real time. It also has the characteristic of being centralized, as it can manage and control energy consumption and the flow of information through robust diagnosis | Weyer et al. (2015); Li and Xu (2017); Roblek, Mesko and Krapez (2016) |
| **10 – Vertical Integration (VI), Horizontal Integration (HI) and End to End Integration (EEI)** | . Vertical Integration: with networked production systems package, with the help of CPS in the creation of flexible and reconfigured manufacturing systems, enabling integration between production, supply chain and big data. Horizontal Integration: with the integration of value-generating networks, intensifying the use of technology for data and information management. End-to-end digital integration: with focus on engineering, monitoring the phases of the product life cycle | Li and Xu (2017); Leyh et al. (2017); Wang et al. (2016); and Posada et al. (2015) |
| **11 – Product Lifecycle Management (PLM)** | PLM is a system that monitors, in an agile way, the product's life cycle, from its design to its end of life | Stark (2015); Weyer et al. (2015); Rajnai and Kocsis (2018); De Carolis et al. (2017) and Bangemann et al. (2016) |
| **12 - New professional profile** | The new professional profile required by industries of sector 4.0 will focus on the development of digital thinking, and the professional must have sense of critical analysis and fit into this new model. | Roblek, MeskoeKrapez (2016) and Merkel et al. (2017) |

Source: own elaboration (2020)

## 2.1 Maturity models of Industry 4.0

According to Simpson and Weiner (1989), in general, the term maturity is related to a "state of being perfect, complete or ready", implying a progress in the development of some system. Consequently, maturity processes, such as those that occur in biological, technological and organizational systems, tend to increase their capacities over time, considering the future conquest of some state or situation. Thus, maturity can be observed both qualitatively and quantitatively and in a discrete or continuous manner (Kohlegger; Maier & Thalmann, 2009).

For O'Donovan, Bruton and O'Sullivan (2016), a maturity model can be defined as a conceptual structure composed of parts that define the maturity or development status of a particular area of interest. These authors identify and describe the processes that an organization must develop to achieve a desired future scenario, reflecting aspects of reality to classify the capabilities of certain domains of interest that can be used for internal analyses, competitor analyses and comparisons with references in the domain (benchmark).

Such maturity models usually contemplate dimensions and levels in their structure and are based on the premises that people, organizations, functional areas and processes evolve through development stages towards more advanced maturity through a given number of levels. The purpose of maturity models is to quantify activities performed and make them mature over time (O'Donovan, Bruton & O'Sullivan, 2016).

The transformation to Industry 4.0 involves significant increase in digital manufacturing skills, lading to changes across the organization. Considering the high complexity of this transformation, it is expected that it will take several years to be planned and implemented in order to allow positive impacts on profitability through efficiency and productivity gains, which should occur in incremental stages. Each company must decide which stage of development represents good balance between costs and benefits resulting from the change, according to the circumstances surrounding the business, with a vision of a desired future state at the end of the transformation process (Schuhet al., 2020).

The literature in the area of operations management is lavish in providing maturity models for identifying the characteristics of industry 4.0. Table 2 presents the main models developed in relevant domains, also those related to components, the characteristics of the 4.0 context and its considered dimensions.

**Table 2**

Maturity models in the context of industry 4.0

| Model | Related components | Main characteristics | Dimensions | Authors |
|---|---|---|---|---|
| **1 – WM4.0 (Toolbox Workforce management 4.0)** | New professional profile | The elements of this model are divided into four levels: difficult skills, soft skills, usability / operability and work environment | Not disclosed | Galaske et al. (2018) |
| **2 – DREAMY (Digital Readiness Assessment Maturity Model 4.0)** | CPS, MA, AM, AR, VR, IoT, IoT Impacts, CM, VI, HI, EEI and PLM | Based on the CMMI model (Capability Maturity Model Integration), focuses on five specific areas considering activities that generate value: Design and Engineering, Production Management, Quality Management, Maintenance Management and Logistics Management | 1) Process Monitoring and Control<br>2) Technology<br>3) Organization | De Caolis et al. (2017) |
| **3 – Maturity Index Industry 4.0** | CPS, MA, AM, AR, VR, IoT, CM, VI, HI, EEI, PLM, New professional profile | Developed by the German Academy of Science and Engineering (ACATECH), focuses on the development of structure and organizational culture | 1) Resources<br>2) Information systems<br>3) Structure<br>4) Organizational Culture | Schuh et al. (2020) |
| **4 – MM (Maturity Model Industry 4.0)** | CPS, IoT, IoT Impacts | It is based on the SPICE dimensions (Software Process Improvement and Capability Determination) | 1) Assets management<br>2) Data governance<br>3) Applications management<br>4) Processes transformation<br>5) Organizational alignment | Gökalp, Sener and Eren(2017) |
| **5 – M2DDM (Maturity Model for Data-Driven Manufacturing)** | CPS, IoT, IoT Impacts | It covers six levels: non-existent IT integration of data and systems integration of data between life cycles, service orientation, digital twin and auto factory optimizer | Not disclosed | Weber et al. (2017) |
| **6 – The IoT Technological Maturity Model** | CPS, IoT, IoT Impacts | Composed of eight maturity levels: maturity 3.0, initial maturity level 4.0, connected, improved, innovation, integrated, extensive and maturity 4.0 | Not disclosed | Jæger and Halse (2017) |
| **7 – SMMI4.0 (System Integration Maturity Model Industry 4.0)** | CPS, IoT, IoT Impacts | Proposes a model in which the company identifies its technological level (IT resources) | 1) Vertical integration<br>2) Horizontal integration<br>3) Development of digital products<br>4) Cross-sectional technology criteria | Leyh et al. (2016) |
| **8 – Industry 4.0 Maturity Model** | CPS, MA, AM, AR, VR, IoT, CM, VI, HI, EEI, PLM, New professional profile | Evaluates the maturity of an organization in a broad way | 1) Leadership<br>2) Strategy<br>3) Culture<br>4) People<br>5) Technology<br>6) Operations<br>7) Products<br>8) Costumers<br>9) Governance | Schumacher, Erol and Sihn (2016) |
| **9 – The Digital Maturity Model 4.0** | CPS, MA, AM, AR, VR, IoT, IoTImpacts, CM, VI, HI, EEI, PLM | It seeks to help companies develop in the digitalization scenario | 1) Culture<br>2) Organization<br>3) Technology<br>4) Insights | Gill and VanBoskirk (2016) |

| Model | Related components | Main characteristics | Dimensions | Authors |
|---|---|---|---|---|
| **10 – MVMM (Manufacturing Value Modeling Methodology)** | CPS, MA, AM, AR, VR, IoT, IoT Impacts, CM, VI, HI, EEI, PLM and New professional profile | Developed in partnership with Siemens. This model has five stages: value map, maturity model, gap analysis, processes and validation and, finally, definition of areas for improvement | Not disclosed | Tonelli et al. (2016) |
| **11 – IMPULS (Industry 4.0 – Readiness)** | CPS, MA, AM, AR, VR, IoT, IoTImpacts, CM, VI, HI, EEI, PLM and New professional profile New professional profile | Evaluates the maturity of an organization by behavioral and technical management aspects | 1) Strategy and organization<br>2) Employees<br>3) Smart factory<br>4) Smart operations Smart products<br>5) Data-oriented services dados | Lichtblau et al. (2015) |
| **12 – IT Architecture Capabilities, IoT in SCM Domain** | CPS, IoT, IoT Impacts. | It focuses on how the IoT concept is adopted in the supply chain domain | Not disclosed. | Katsma et al. (2011) |
| **13 – Architecture and Maturity Level for CPS (Cyber-Physical Systems)** | CPS, IoT, IoT Impacts. | Evaluates the maturity of an organization. | Not disclosed | Westermann et al. (2016) |
| **14 – Model MMI4 (Maturity Model for Industry 4.0)** | CPS, MA, AM, AR, VR, IoT, IoTImpacts, CM, VI, HI, EEI, PLM and New professional profile | Focused on the existing characteristics and components of the literature review and on the evaluation of existing and relevant models. It uses a questionnaire and evaluates data obtained by using Fuzzy Logic | 1) Technology<br>2) Process<br>3) Organizational strategy | Basseto (2019) |
| **15 –Proposed Industry 4.0 Maturity Model** | CPS, MA, AM, AR, VR, IoT, IoTImpacts, CM, VI, HI, EEI, PLM and New professional profile | Focused on the existing characteristics and components of the literature review and evaluation of existing and relevant models. The model is useful for making an initial diagnosis and establishes a roadmap for further implementation | 1) Strategy, structure and Organizational culture<br>2) Workforce<br>3) Smart factories<br>4) Smart processes<br>5) Smart products and services | Santos and Martinho (2019) |

Source: own elaboration (2020)

In general, the models described assess the maturity level of organizations in different areas, called dimensions. Each dimension is described by several transformation resources. The maturity of Industry 4.0 is defined by assessing the degree of implementation of each transformation capacity and, consequently, of each dimension, and all models analyzed in this article are based on the main concepts and technologies that facilitate Industry 4.0 (see Table 1).

However, there is a discussion about the fact that none of the models can be fully applied using only published information, as some of them do not even provide a complete description of the maturity stages, such as the model by Schumacher, Erol and Sihn (2016). Other models provide at least partial information and briefly describe the characteristics of each stage and the maturity dimension (Westermann et al., 2016; Klotzer & Pflaum, 2017).

Perhaps the factor that partially explains this phenomenon is the authors' interest in using the models developed in paid consulting projects, where the intentional concealment of some information about the application of maturity models makes sense under the financial logic.

In general, the literature review shows scarcity of maturity models in sector 4.0 with comprehensive and available documentation. Thus, it is part of the general objective of this article to complement previously described publications, and in a timely manner, to develop a new and improved model, which combines the positive attributes of each model presented, allowing decision makers to document the status quo of their organizations and develop a holistic view of their business, providing proper guidance for achieving excellence in their processes and opening up the possibility of comparing capacities between business units and other organizations as an important adding value process (Rutner & Langley, 2000).

To end the discussion of the theoretical framework of this article, once the basic components of industry 4.0 and some existing maturity models were presented, one cannot lose sight of its fundamental objective: to present and apply a maturity model in a Brazilian context. For this, the proposed model must be related to supply chain management, filling the existing gaps, and follow the principle that maturity models, including those of Industry 4.0, suggest a natural process of continuous improvement over time to reflect concept and technology updates to the content being rated.

## 3. METHODOLOGY

For the initial survey of the theoretical framework of this work, a systematic literature review was carried out. The selection of journals was carried out in the Web of Knowledge database. The choice to use this database was due to the vast number of journals that generally overlap with other known databases (Periodics from CAPES, EBSCO, etc.), and to the use of the indicator called JCR (Journal Citation Report), which demonstrates the degree of relevance of a journal for the academic community based on the number of citations of it.

The search was carried out using the keywords: Industry 4.0+Mature Level. Filters for the number of citations and temporality were implemented, and the articles were selected in order to bring their content closer to the topic under study.

In this selection, 32 articles were chosen and read in detail. Then, it was necessary to organize the data from different articles on a common basis. For this, the researchers produced tables 1 and 2 already presented, summarizing the key components of Industry 4.0 and the 15 maturity models presented in the literature, summarizing their main components and characteristics, as well as their fundamental concepts.

For the proposition of the maturity molecule adopted to go into the field, the recommendations of De Bruin, Kulkarni and Rosemann (2005) were followed. According to these authors, there are four stages when the research includes the development of a new model, as shown in Table 3:

**Table 3**
Description of the research development stages

| Research stage | Stage description |
|---|---|
| **Stage 1** | Development of the maturity model |
| **Stage 2** | Proposition of the research model |
| **Stage 3** | Application of the research tool and data collection |
| **Stage 4** | Data analysis criteria |

Source: own elaboration (2020)

Stage 1 - Development of the maturity model

To propose the maturity model, a wide bibliographic review of studies carried out on the subject of Industry 4.0 was performed. The methodology adopted in this study was based on the process of developing the maturity model of De Bruin, Kulkarni and Rosemann (2005), being applicable to several domains of knowledge, therefore not being restricted to the Industry 4.0 domain.

Stage 2 - Proposal of the research instrument

In this stage of the work, the proposal of the research instrument and the structural composition of the model are developed. In this sense, information is collected from industries, seeking to assess their maturity level in the context of Industry 4.0.

We chose to use a questionnaire as instrument for collecting data and information, as it has advantages when compared to other available instruments, such as interviews, institutional records and structured observations. Such advantages consist of freedom in response time by respondents, possibility of replication, greater accuracy in responses and application practicality.

Thus, based on these premises, the literature review and the validation of questions by Industry 4.0 specialists, the questionnaire was elaborated, which enabled the assessment of the industry's status quo related to its maturity level in the context of Industry 4.0. Based on maturity items, assessment was performed using this questionnaire, consisting of closed questions, requiring for each of them response based on a Likert scale, duly adapted, ranging from 0, to characterize critical status, up to 5, indicating ideal status. The complete questionnaire developed and applied is presented in the appendix of this article.

For data collection, the option was for a convenience sampling, that is, a non-probabilistic and non-random sampling technique used to create samples according to ease of access was adopted. Thus, the researchers chose the respondents only because of their proximity and prior knowledge, not considering whether they really represented a representative sample of the entire population.

It is necessary to emphasize that the questionnaire should only be responded when respondents have basic understanding on the subject, in this case, the concepts of Industry 4.0. Responses obtained act as a data entry for the radar graph, which will represent the maturity level of companies in their supply chains.

The questionnaire in this article consisted of 66 closed questions. Questions, in turn, were properly divided into the six dimensions established for use in this work, namely: strategy, structure and organizational culture; workforce; smart factories; smart processes; smart products and services; and technology. This questionnaire is presented in full in the appendix to this article.

Stage 3 - Application of the research tool / data collection

This stage has as main objective to present the application of the proposed model and the results obtained from that application.

For the sake of convenience and access to data, companies chosen to participate in this study are located in the Metropolitan region of São Paulo (SP). Through previous telephone conversations with employees in May 2020, information that all companies are already inserted in the context of Industry 4.0 was obtained. These conversations were possible because the authors of this study (with more than two decades of professional experience in the area) already knew companies and initial respondents.

The questionnaire was applied in May 2020 at three companies considered to be major within the auto parts supply chain. As already mentioned, these companies sent the questionnaires to one of their suppliers.

All participating companies are part of the automotive segment (Table 4), being auto parts manufacturers, although the selected suppliers also manufacture products to other market segments.

To guarantee anonymity, the researched dyads were classified into three pairs: A, B and C, which were named as Tier 1A and Tier 2A; Tier 1B and Tier 2B; Tier 1C and Tier 2C. Based on information obtained from their respective official websites, a brief description of each company is presented below:

• Company The 1A is of German origin, with global presence, and manufactures engine components. Its chosen supplier, company Tier 2A, is also of German origin, with global presence, and manufactures rolled steel;

• Company Tier 1B is of Swedish origin, with global presence, and manufactures components for suspension and seals. Its chosen supplier, company Tier 2B, is of national origin, but with global presence, and manufactures special steel;

• Company Tier 1C is of American origin, with global presence, and manufactures clusters and displays. Its chosen supplier, company Tier 2C, is of national origin, only local presence, and manufactures injected plastic components.

**Table 4**
Relevant information about companies that responded the questionnaire

| Company | Operating segment | Product | Origin (foundation) | Compan y size | Number of employees | Position of respondents |
|---|---|---|---|---|---|---|
| **Tier 1A** | Auto Parts | Engines | German (1920) | Large | 78,000 | Quality Manager<br>Engineering / Laboratory |
| **Tier 2A** | Industrial | Rolled steel | German (1829 | Medium | 2,400 | Production Manager |
| **Tier 1B** | Auto Parts | Suspension and seals | Swedish (1907) | Large | More than 10,000 | Production Leaders / Lean Logistics Manager |
| **Tier 2B** | Industrial | Special steel | National (1901) | Large | More than 10,000 | Purchasing / Logistics Manager |
| **Tier 1C** | Auto Parts | Clusters and displays | American (2000) | Large | 11,000 | Engineering / Logistics Manager<br>Technology Manager and KAM |
| **Tier 2C** | Industrial | Plastic components | National (1993) | Small | 850 | Engineering Manager |

Source: own elaboration (2020)

Stage 4 - Data analysis criteria

To analyze questionnaire responses, the Likert scale with score ranging from 0 to 5 was used. Score 0 was equivalent to critical status; 1 to the initial status; 2 to the alert status; 3 to the acceptable status; 4 to the optimal status; and 5 to the ideal status.

These proposed statuses are similar to those used in the CMMI methodology presented in the DREAMY model by DeCarolis et al. (2017), in which each score is related to the evolution status of the industry in the context of maturity in Industry 4.0 according to the six dimensions proposed in this article.

## 4. ANALYSIS AND DISCUSSION OF RESULTS

In this topic, the results obtained with the return of completed questionnaires will be presented. Thus, it will be possible to start analyses related to the maturity level of members of a supply chain.

### 4.1 Adopting a model to be applied in the field: the six dimensions of industry 4.0

Based on studies on maturity models described, a maturity model 4.0 designed to identify the degree of homogeneity among members of a supply chain is presented (Table 5). Based on the synthesis of existing models, the proposed model is composed of six dimensions: strategy, organizational structure and culture, workforce, smart factories, smart processes, smart products and services, as well as technology.

**Table 5**
Description and characteristics of dimensions of the proposed model

| Dimension | Descriptive | Dimension characteristic in companies 4.0 |
|---|---|---|
| **Strategy, structure and organizational culture** | The evolution towards industry 4.0 needs a change in the board of directors' paradigms through the promotion and dissemination of innovative culture and continuous improvement, availability of necessary resources to implement information and operation technologies, adaptation of the organizational structure and constant search for customer satisfaction. The innovative culture is expected to be implemented from the top down. | ▪ Practices of new business models, integrating changes in value chains;<br>▪ Emphasis of organization on tasks, employee autonomy, motivation, goal setting, flexibility and diversity of team skills;<br>▪ Collaboration in the value chain and customer orientation;<br>▪ Appreciation of the behavioral characteristics desired by employees, such as leadership, open communication between teams and adaptation to technological changes. |
| **Workforce** | Digital transformation and intensive use of innovative technologies is not possible without adequate qualification and constant updating of technical, management and workforce skills. Teams need to be open to innovative technologies, have flexibility and autonomy for rapid changes in context. | ▪ Introduction of new and better professional qualifications;<br>▪ Development of appropriate learning platforms;<br>▪ Training of employees in a virtual environment;<br>▪ Generation of digital thinking. |
| **Smart factories** | The factories of the future, composed of sensors and smart actuators, facilities and equipment with embedded systems and connectivity, will enable communication in | ▪ Improved man-machine interaction;<br>▪ Use of robots;<br>▪ New forms of integration and operation within factories. |

| | | |
|---|---|---|
| | real time between machines, products, people and infrastructure, forming a digital network environment | |
| **Smart processes** | Connectivity and interoperability of information and operation systems, as well as equipment and facilities, will allow for the existence of autonomous systems and processes incorporated into advanced artificial intelligence algorithms, contributing to the continuous learning of machines. This will enable the self-optimization and self-configuration of production, maintenance, logistics and support processes. | ▪ Flexible and agile manufacturing practice;<br>▪ . Automatic adaptation to unplanned events, such as unexpected interruptions in production lines and rescheduling. |
| **Smart products and services** | Products with embedded systems will be the basis for acquiring data in real time, allowing constant communication with customers, factory and production processes of the value chain. Complementary services based on data acquired and activated by connectivity technologies will be an important source of revenue for the company | ▪ Products and servers developed and enabled by information technology systems;<br>▪ Meeting customized customer demands. |
| **Technology** | With the need for smart factories and processes, it will be necessary to develop new disruptive and interconnected technologies, such as CPS, IoT, Big Data, Big Data Analytics and CM | ▪ Use of self-managed traceability systems;<br>▪ Simultaneous communication between machine parts, products and processes;<br>▪ Use of technology as a facilitator in manufacturing optimization;<br>▪ Generation of broad communication between factories and / or members of the supply chain. |

Source: own elaboration (2020)

## 4.2 Dimensions of the proposed maturity model

To present data, we chose the representation of a "radar" type chart. In this article, the radar graph is understood as a diagram that consists of a sequence of equi-angular radiuses, with each radius representing one of the dimensions proposed in the model. The length of each radius is proportional to the scale from 0 (critical status) to 5 (ideal status). A line is drawn connecting the values of each radius, forming a hexagon. The assumed value of each dimension is calculated by the arithmetic mean of questions obtained in the dimensions of the proposed model.

The six dimensions that make up the radar chart are:

• Dimension 1: Organizational Strategy, Structure and Culture (16 questions)

• Dimension 2: Workforce (5 questions)

• Dimension 3: Smart Factories (8 questions)

• Dimension 4: Smart Processes (14 questions)

• Dimension 5: Smart Products and Services (16 questions)

• Dimension 6: Technology (7 questions)

Figure 1 seeks to summarize data obtained by applying questionnaires for each dyad (company-supplier).

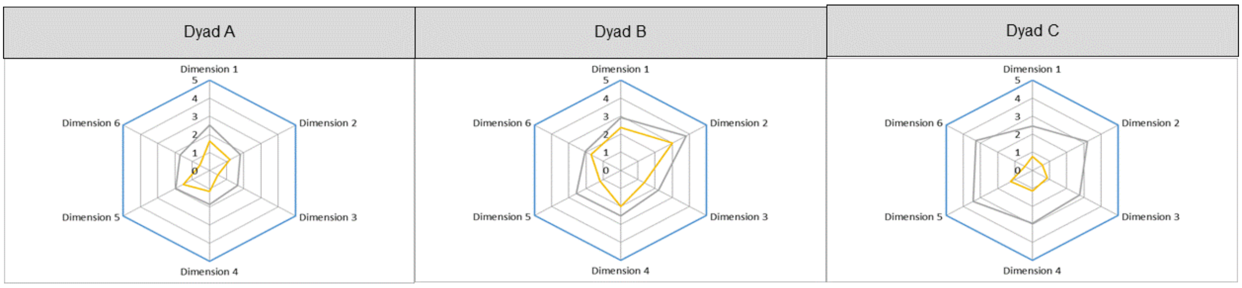


**Figure 1:** Summary of results obtained in the company-supplier dyads
Source: own elaboration (2020)

The first analysis of Figure 1 shows that in the three company-supplier dyads surveyed, the maturity level of suppliers (Tier 2) was lower than that of surveyed companies (Tier 1). This finding can be observed in graphs where the polygons of suppliers (in orange) are inserted within the polygons of companies (in gray). Different patterns regarding the homogeneity of dyads, low and similar scores in dyad A, similar and intermediate in dyad B and very different in dyad C were observed, indicating great differences between company C and its supplier in their maturity indexes in industry 4.0.

To facilitate the understanding of these issues, Table 6 helps identifying differences among members of a supply chain. In order to facilitate the reading of data, the dimension with the highest score is highlighted in green and the dimension with the lowest score is highlighted in pink.

**Table 6**
Evaluation of results obtained with Tier 1 and Tier 2 groups in the supply chains

| Dimension | Average obtained by companies | | | Average obtained by respective suppliers | | |
|---|---|---|---|---|---|---|
| | **TIER 1A** | **TIER 1B** | **TIER 1C** | **TIER 2A** | **TIER 2B** | **TIER 2C** |
| 1 | 2.50 | 2.92 | 2.44 | 1.63 | 2.38 | 0.75 |
| 2 | 1.80 | 3.80 | 3.20 | 1.20 | 3.00 | 0.60 |
| 3 | 1.63 | 2.21 | 2.75 | 0.50 | 1.40 | 0.88 |
| 4 | 1.86 | 2.52 | 2.93 | 1.14 | 2.00 | 1.14 |
| 5 | 1.96 | 2.56 | 3.44 | 1.50 | 1.19 | 1.25 |
| 6 | 1.71 | 2.05 | 3.29 | 0.57 | 1.71 | 0.43 |
| **Average** | **1.91** | **2.68** | **3.01** | **1.09** | **1.95** | **0.84** |

Source: own elaboration (2020)

Among companies participating in this work, Tier 1C was the one that presented the best score among the main companies, with practically all evaluation scores above 2.50, and with average of 3.01.

Its best evaluation scored 3.44 in dimension 5 - smart products and services. This fact is possibly related to the profile of the company that, according to information contained in its page on the Linkedin website, manufactures innovative electronic products designed for the cockpit and connected car solutions for the main vehicle manufacturers in the world, also presenting the following specialties: engineering, test operations, design and production, audio and infotainment (information and entertainment), information and controls, and domain controllers.

On the other hand, the worst evaluation of Tier 1C scored 2.44 in dimension 1, strategy, structure and organizational culture. This result demonstrates the possibility of the company not having a clear and objective policy in the disclosure of its corporate strategies, which may be unknown to employees who responded the questionnaire, whose responses were based only on what they know about their work routine. In addition, it demonstrates that the company is not prepared in terms of strategy, structure and organizational culture to support the implementation of Industry 4.0 concepts.

On the other hand, its main local supplier, company Tier 2C, presented the lowest evaluation scores, when compared to other suppliers, with scores below 1.3. Its highest score was 1.25 in dimension 5, and the lowest score was 0.43 in dimension 6, technology, with 0.84 being the average of evaluation scores. This result can be justified by the fact that it is a small national company, managed by its own owner, and which provides injected plastic components not only for the auto parts segment, which can characterize lack of focus and commitment regarding the implementation of the Industry 4.0 concepts, since in other market niches, these concepts are not yet well known, nor are they required by customers.

In the case of companies Tier 1B and Tier 2B, a good set of results can be identified, with company Tier 1B presenting the second best evaluation average among the main companies, and its supplier, Tier 2B, presenting the best evaluation average among supplying companies, that is, 2.68 and 1.95, respectively. The highest evaluation score of company Tier 1B was 3.80 in dimension 2, workforce, while its lowest score, 2.05, was in dimension 6. These scores demonstrate that the organization is committed to the development and training of employees, mainly in the Industry 4.0 concepts. However, its employees understand that the organization must still increase its focus on technology acquisition.

The highest evaluation score of Tier 2B, the main supplier in the supply chain of company Tier 1B, was 3.0 in dimension 3, smart factories. It is possible to attribute this high score to the fact that company Tier 2B is a manufacturer of special steels, with continuous production processes, using large and powerful auto-furnaces, which requires strong digitization and automation scheme to control the parameters of their processes. This ends up generating the need for great focus on the maintenance and stability of these processes through concepts of continuous improvement, such as those of Industry 4.0.

On the other hand, the lowest evaluation score of company Tier 2B was 1.19 in dimension 5. This may be linked to the type of product manufactured by the company, special steels, using continuous processes, and the fact that, even being national, the company is characterized as a large-size company, also operating internationally and holding a monopoly in this market.

With regard to company Tier 1A, its average score was 1.91. Its highest score was 2.50 in dimension 1, and its lowest score was 1.63 in dimension 3. These results demonstrate that the organization has good focus on its strategies and the existence of good organizational structure and culture to support the implementation of the Industry 4.0 concepts. However, it is clear that although it has a developing strategy, the organization has not yet guaranteed the necessary investments to transform its operations into smart factories through the Industry 4.0 concepts.

Company Tier 2A, in turn, has average evaluation score of 1.09. Its highest score was 1.63 in dimension 1, and its lowest score was 0.50 in dimension 3. Like its peer in the supply chain (company Tier 1A), its highest evaluation score refers to the fact that the organization apparently demonstrates focus on its strategies and develops its organizational structure and culture, directing them towards the implementation of the Industry 4.0 concepts. Its lowest evaluation score; however, shows that there is no short and medium term planning for the release of investments necessary to support the implementation of such concepts.

### 4.3 Maturity levels of the studied chain

To analyze maturity levels, the percentage of responses obtained at each level of the scale proposed in the model was considered. Thus, considering the 66 questions that make up the collection instrument, if all were at level 5, an ideal maturity level would be considered. Similarly, if all questions were at level 0, the maturity level would be critical. Evidently, these two cases are extreme, and what was found was a set of intermediate results between these two extremes.

For example, Table 7 shows that company Tier 1A has greater representation at levels 1 (initial status) and 2 (alert status) with 45.5% and 28.8%, respectively. Level 3 (acceptable status) has 9.1% of representativeness in responses obtained and levels 4 (optimal status) and 5 (ideal status) present only 13.6% and 3%, respectively.

Company Tier 2A, in turn, obtained the highest representativeness at level 1, with 34.8% of responses, followed by level 0 (critical status) with 33%. It is also observed that level 2 presented 12.1% of responses. This analysis also showed that there is greater representativeness of responses related to level 3, with 16.7%. On the other hand, there is low representativeness at levels 4 and 5, with 3.0% and 0% of responses obtained, respectively.

**Table 7**
Consolidation of the questionnaire evaluations of companies Tier 1A and Tier 2A

| Likert Scale (in this study) | Evaluation stages (De Carolis et al., 2017) | Amount of evaluations | | % on the 66 questions | |
|---|---|---|---|---|---|
| | | **TIER 1A** | **TIER 2A** | **TIER 1A** | **TIER 2A** |
| Level 0 | Critical Status | 0 | 22 | 0.0% | 33.0% |
| Level 1 | Initial Status | 30 | 23 | 45.5% | 34.8% |
| Level 2 | Alert Status | 19 | 8 | 28.8% | 12.1% |
| Level 3 | Acceptable Status | 6 | 11 | 9.1% | 16.7% |
| Level 4 | Optimum Status | 9 | 2 | 13.6% | 3.0% |
| Level 5 | Ideal Status | 2 | 0 | 3.0% | 0.0% |

Source: own elaboration (2020)

Continuing the analysis, Table 8 shows differences between companies Tier 1B and Tier 2B, members of the same supply chain, regarding the questionnaire responses versus their maturity levels and their status of implementing the Industry 4.0 concepts for each model dimension.

**Table 8**
Consolidation of the questionnaire evaluations of companies Tier 1B and Tier 2B

| | | Amount of evaluations | | % on the 66 questions | |
|---|---|---|---|---|---|
| Likert Scale (in this study) | Evaluation stages (De Carolis et al., 2017) | TIER 1B | TIER 2B | TIER 1B | TIER 2B |
| Level 0 | Critical Status | 1 | 18 | 2.0% | 27.0% |
| Level 1 | Initial Status | 8 | 7 | 12.1% | 10.6% |
| Level 2 | Alert Status | 21 | 21 | 31.8% | 31.8% |
| Level 3 | Acceptable Status | 20 | 15 | 30.3% | 22.7% |
| Level 4 | Optimum Status | 16 | 5 | 24.2% | 7.6% |
| Level 5 | Ideal Status | 0 | 0 | 0.0% | 0.0% |

Source: own elaboration (2020)

Through the analysis of Table 8, it was observed that company Tier 1B has greater representativeness at levels 2 (alert status) and 3 (acceptable status), with 31.8% and 30.3% of the responses obtained, respectively. There is also level 4 (optimal status), with 24.2% of responses, and level 1 (initial status), with 12.1%. It is also observed that 0% of responses were directed to level 5 (ideal status), while 2.0% were directed to level 0 (critical status).

Company Tier 2B obtained the highest representativeness at levels 2 and 3, with 31.8% and 22.7% of the responses obtained, respectively. Levels 0 and 1 presented, respectively, 27.0% and 10.6% of responses, while levels 4 and 5 represented 7.6% and 0% of the responses, respectively.

Table 9 presents differences between companies Tier 1C and Tier 2C, members of the same supply chain, regarding the questionnaire responses versus their maturity levels and their status of implementation of the Industry 4.0 concepts for each model dimension.

It was observed that company Tier 1C has greater representativeness at level 3 (acceptable status), with 54.5% of responses obtained, followed by levels 2 (alert status) and 4 (optimal status) with 24.2% and 21.2%, respectively. Levels 0 (critical status), 1 (initial status) and 5 (ideal status) are also observed, all with 0%

**Table 9**
Consolidation of the questionnaire evaluations for companies Tier 1C and Tier 2C

| Likert Scale (in this study) | Evaluation stages (De Carolis et al., 2017) | Amount of evaluations | | % on the 66 questions | |
|---|---|---|---|---|---|
| | | **TIER 1C** | **TIER 2C** | **TIER 1C** | **TIER 2C** |
| Level 0 | Critical Status | 0 | 29 | 0.05 | 44.0% |
| Level 1 | Initial Status | 0 | 16 | 0.0% | 24.2% |
| Level 2 | Alert Status | 16 | 18 | 24.2% | 27.3% |
| Level 3 | Acceptable Status | 36 | 3 | 54.5% | 4.5% |
| Level 4 | Optimum Status | 14 | 0 | 21.2% | 0.0% |
| Level 5 | Ideal Status | 0 | 0 | 0.0% | 0.0% |

Source: own elaboration (2020)

## 5. CONCLUDING REMARKS

Industry 4.0 is still an evolving topic in literature and in industrial applications. The concepts and technologies covered in this context are of great relevance for manufacturing industries and, in the medium and long term, can significantly change the level of competition between companies and even in entire value chains. Therefore, companies should be prepared for major changes and transformations in business environments and should have practical and robust tools to assess maturity in the implementation of concepts and technologies related to the context of Industry 4.0.

The literature review shows that the implementation of Industry 4.0 in manufacturing companies requires a broad and in-depth view, not exclusively focused on system improvements, such as software and hardware in the manufacturing environment, also bringing a new strategic orientation to business, generating the development of workforce skills, adapting current business models, developing new products and services for the new volatile demands and their functionalities, and implementing transformative and disruptive technologies that facilitate the process of introducing Industry 4.0 in companies.

In this context, this article fills an existing research gap by providing a methodologically rigorous and theoretically grounded maturity model for manufacturing companies focused on Supply Chain processes that help identifying the degrees of homogeneity among supply chain members. Thus, the value of the model presented focuses on the combination of scientific rigor, practical relevance and its direct applicability.

Some challenges are amplified by the fact that there are no methods available to measure the current level of capacity of companies and to strategically identify the areas that need improvement. The focus of this article was to develop a tool to be used to quantify the maturity of companies, also enabling the measurement of the degree of homogeneity of supply chain members and the identification of possible causes of imbalances.

This article and its proposed model aimed to collaborate with the business community to understand and implement the main Industry 4.0 concepts and related technologies, thus contributing to the academic environment, by bringing a better understanding of this phenomenon. The proposed model was adapted from two existing maturity models; based on them, a questionnaire was developed and applied to three multinational companies with manufacturing operations in the Metropolitan region São Paulo (SP), all related to the automotive market, and at least one of their relevant suppliers belonging to their supply chains.

Although the questionnaire validation was performed only by professionals specialized in the concepts of continuous improvement of these companies, the model demonstrates to contain multiple facets for the implementation of the Industry 4.0 concepts and is ready to be used in the self-administration format and to proceed with the scientific dissemination stage. This stage is relevant, as it will enable comparative maturity analysis between companies from different market segments.

Finally, the maturity model proposed in this article is composed of technical resources specifically related to products and services, factories and processes, management resources related to organizational strategy and culture, workforce qualification and all this, through the use of enabling and transforming technologies. It meets the requirement for a broader and more in-depth approach, as it includes previously mentioned good practices. In addition, data obtained brought up relevant information that enabled participating companies to identify potential improvements within their respective supply chains.

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## APPENDIX - QUESTIONNAIRE APPLIED TO RESEARCH

| | STATUS | | | | | |
|---|---|---|---|---|---|---|
| **Dimension 1 - Strategy, Structure and Organizational Culture** | critical | initial | alert | acceptable | good | ideal |
| Does your company | 0 | 1 | 2 | 3 | 4 | 5 |
| 1.1 .... continuously analyze the impacts of industry 4.0 on its competitiveness in the medium and long term? | | | | | | |
| 1.2 .... incorporate the concepts and technologies of Industry 4.0 as the main factors of the competitive strategy? | | | | | | |
| 1.3 .... have appropriate indicators to monitor the implementation of Industry 4.0 actions with realistic objectives and targets? | | | | | | |
| 1.4 .... plan and make investments to implement the technologies of Industry 4.0? | | | | | | |
| 1.5 ...have organizational structure oriented towards innovation and incorporation of new technologies? | | | | | | |
| 1.6 ....provide the necessary resources to carry out transformation actions with its senior management? | | | | | | |
| 1.7 .... communicate quickly and digitally with customers to obtain information? | | | | | | |
| 1.8 .... focus on customer requirements to define its strategic and operational actions for the transformation of Industry 4.0? | | | | | | |
| 1.9 .... share relevant information with other companies in the value chain to have an agile decision-making process? | | | | | | |
| 1.10 ... have central coordination for the transformational actions of Industry 4.0? | | | | | | |
| 1.11 ... have training program for the training of its employees on Industry 4.0? | | | | | | |
| 1.12 ...search for government incentives aimed at developing new technologies? | | | | | | |
| 1.13 ... seek for partnerships with knowledge institutions? | | | | | | |
| 1.14 ... have Internet of Things (IoT) resources? | | | | | | |
| 1.15 ... have supply chain integrated with all sectors in real time? | | | | | | |
| 1.16 ... make use of sustainable manufacturing (green planning)? | | | | | | |
| **Dimension 2 – Workforce** | | | | | | |
| Does your company | critical | initial | alert | acceptable | good | ideal |
| 2.1 ... have the necessary technical and managerial skills to implement the transformational actions of Industry 4.0? | | | | | | |
| 2.2 .... obtain the necessary qualifications to acquire technical and managerial skills related to the concepts and technologies of Industry 4.0? | | | | | | |
| 2.3 ... have organizational structure and decision approval methods to promote flexibility and autonomy of equipment or teams? | | | | | | |
| 2.4 .... encourage employees' creativity and empowerment, considering the challenges and benefits of digital transformation? | | | | | | |
| 2.5 .... observe and encourage employees' continuous learning and innovation, with responsive performance in changing contexts? | | | | | | |
| **Dimension 3 - Smart Factories** | | | | | | |
| Does your company | critical | initial | alert | acceptable | good | ideal |
| 3.1 .... have digital twins in manufacturing facilities and equipment that practically reproduce the physical world? | | | | | | |
| 3.2 .... have bidirectional update between real facilities and equipment and digital twins? | | | | | | |
| 3.3 ... have equipment infrastructure with embedded systems, which enable acquiring and processing data and communication with each other and with other systems? | | | | | | |
| 3.4 ... have integrated information, communication and operation systems able to meet interoperable 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 allow continuous improvement and autonomous decision making? | | | | | | |
| 3.7 ... have agile and reconfigurable layouts to meet diversification and volume volatility in the customized product demand? | | | | | | |
| 3.8 .... use smart mobile devices to make operations more flexible and optimized? | | | | | | |
| **Dimension 4 - Intelligent Processes** | | | | | | |
| Does your company | critical | initial | alert | acceptable | good | ideal |
| 4.1 .... use cloud computing systems to store and process data? | | | | | | |
| 4.2 .... use technologies and procedures for the security of human and physical resources and data protection against misuse? | | | | | | |
| 4.3 .... have production processes capable of operating autonomously, aided by machine learning systems? | | | | | | |
| 4.4 .... design its main business processes for agile information sharing within the company and with other business partners? | | | | | | |
| 4.5 .... have its main business processes digitized with integrated information and communication systems? | | | | | | |
| 4.6 .... digitally model and simulate the performance of its main business processes? | | | | | | |
| 4.7 .... use visual computing resources, such as supervisory systems, virtual and argued reality systems to assist operations? | | | | | | |
| 4.8 .... use visual computing resources that provide contextual information and interfaces for tasks? | | | | | | |
| 4.9 .... use data separation and classification systems to help the main business processes, analyzing large data volumes coming from various sources and in real time? | | | | | | |
| 4.10 ... use industrial processes such as M2M - Machine to Machine, which perform integrated information exchanges in real time? | | | | | | |
| 4.11 ...have Smart Grids resources in industrial processes to optimize energy consumption? | | | | | | |
| 4.12 ... perform smart maintenance? | | | | | | |
| 4.13 ... have a system to manage the product life cycle? | | | | | | |
| 4.14 ... have production lines that are adaptable or re-configurable? | | | | | | |

| Dimension 5 - Smart Products and Services | | | | | | |
|---|---|---|---|---|---|---|
| Does your company | critical | initial | alert | accept able | good | ideal |
| 5.1 ... have products with embedded and smart systems? | | | | | | |
| 5.2 ....have products equipped with artificial intelligence systems to self-optimize their characteristics and performance? | | | | | | |
| 5.3 ....have products with embedded systems equipped with technologies that allow communication with the factory and analysis of their conditions of use? | | | | | | |
| 5.4 .... offer complementary services to products, developed from data collected on customer's preferences and conditions of use? | | | | | | |
| 5.5 ....have a digitized product design, which can be sent to the factory and to 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 demand customization? | | | | | | |
| 5.8 ....use resources and processes that allow the agile reconfiguration of products? | | | | | | |
| 5.9 ...have products with embedded systems integrated with other operating and management systems? | | | | | | |
| 5.10 ... have microchip for the traceability of raw materials? | | | | | | |
| 5.11 ... have microchip for the traceability of Products in Transformation? | | | | | | |
| 5.12 ... have microchip for the traceability of Finished Products? | | | | | | |
| 5.13 ...have resources to carry out tests and simulations for the development of new products? | | | | | | |
| 5.14 ...perform additive manufacturing (three-dimensional-3D) of complete or finished products in the production area? | | | | | | |
| 5.15 ... allow the customer to have access to follow stages of the production process? | | | | | | |
| 5.16 ...fulfill orders with varied and fractioned lots in the production area? | | | | | | |

| Dimension 6 – Technology | | | | | | |
|---|---|---|---|---|---|---|
| Does your company | critical | initial | alert | accept able | good | ideal |
| 6.1 .... use Smart Sensors for measuring industry parameters? | | | | | | |
| 6.2 .... use any Big Data / Big Data Analysis resource? | | | | | | |
| 6.3 .... use any cloud computing service (Cloud Manufacturing)? | | | | | | |
| 6.4 .... use any artificial intelligence resources? | | | | | | |
| 6.5 .... use any Information Security resource? | | | | | | |
| 6.6 .... have augmented reality (AR)? | | | | | | |
| 6.7 .... have virtual reality (VR)? | | | | | | |