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An Employee Competency Development Maturity Model for Industry 4.0 Adoption

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Abstract: Industry 4.0 (I4.0) is challenging for organizations, as workers lack digital competencies, and research on new roles is limited. Additionally, existing models for its adoption focus on technology incorporation, process improvement, and organizational transformation. Therefore, the opportunity exists for designing a new model that emphasizes developing employees' competencies. A systematic literature review was conducted regarding existing models for I4.0 adoption and the desired worker competencies. After examining the gap in the current models and the categorization of their main elements, a new maturity model (MM) for I4.0 adoption, based on the development of employees' competencies, is proposed. The MM helps practitioners and researchers assess an organization's I4.0 adoption level in order to improve future actions. A validation process for the MM was implemented through the Delphi method. Additionally, a roadmap to guide workforce development is presented, which considers the digital challenges face by employees in advancing a strategic I4.0 adoption. The proposed roadmap allows for depicting new deployment strategies aligned with digital trends and employees' commitments to sustaining the implementation efforts. This research recognizes talent, organizational culture, and communication plans as key elements for defining actions for developing the skills and competencies required for embracing the I4.0 enabling technologies.

Keywords: industry 4.0; adoption; worker 4.0; operator 4.0; skills and competencies; maturity model; development roadmap; talent 4.0; human perspective

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1. Introduction

Currently, organizations deal with challenges driven by dynamic markets, uncertainty, and worldwide competitiveness [1]. Likewise, market trends such as digitalization are changing customer behavior and the way in which organizations compete. In this regard, the initiative of Industry 4.0 (I4.0) has become a reference for enterprises looking for a new competitive advantage. This initiative provides a meaningful opportunity to implement digitalization in enterprises, as it seeks to integrate enabling technologies into organizations so that they can support workers in making decisions and solving problems in real time. Based on these assumptions, I4.0 has been consolidated as a term referring to the Fourth Industrial Revolution. It is a transformation initiative integrating production systems and digital technologies to provide intelligent decision-making processes to radically modify an organizations' value chains and business models [2]. By adopting this initiative, enterprises can achieve higher flexibility, productivity, quality, cost benefits, and customer satisfaction [3]. However, adopting I4.0 strategies is not an inconsequential journey for organizations, since ambiguity, unawareness, and high-cost investments trigger their decisions regarding whether or not to embrace it [4].

The adoption of I4.0 represents significant challenges and opportunities for organizations, especially for people working and interacting with industrial systems [5]. Due to the adoption of new advanced technologies and the human–technology interaction required, employees are challenged with complex change management in their workplaces

and are asked to accept and trust the implementation of these technologies [6]. In this regard, employees with many years of experience in their professional fields are confronted with crucial changes. They are familiar with their everyday tasks and have mastered their performance after years of practice. Nevertheless, these practices are drastically changing into digitally interconnected scenarios in which a lack of technical skills is identified in workers [7]. Therefore, the role of human beings is evolving, and with it, the skills and competencies needed in the industrial field. In this sense, job profiles have been modified, and the need for new specialized skills to manage digitalization appropriately is emerging [8]. Consequently, organizations need to conduct training programs to develop the desired competencies and to encourage workforce participation in gaining confidence and awareness of the relevance of adopting the I4.0 initiative in today's digital world [9].

Due to the current I4.0 scenarios, organizations are demanding new skilled employees with high digital competence. However, they have difficulty integrating their workers into innovative, technological, and automated processes, as well as using data analysis for decision making and problem solving [10]. Additionally, enterprises are coping by modifying their organizational culture, hiring new skilled workers, developing their current workforce's skills and competencies, and significantly investing in development programs [4]. Thus, management expectations for I4.0 adoption are essential, since a lack of research regarding this digital era's organizational and managerial aspects has been identified [11].

Moreover, according to Kumar, Bhamu, and Sangwan [3], there are challenges regarding cybersecurity, data management and quality, and standards and norms, based on literature research and interviews with experts. Thus, rapid industrial changes occur in manufacturing and social scenarios in regard to this initiative. In fact, not only are enterprises confronting disruptive transformations, but cities are also modifying their lifestyles through "smart" technologies, aiming to improve citizens' well-being and quality of life [12]. Therefore, despite its challenges, first-world countries have proposed strategies, initiatives, and action plans with the intention of embracing I4.0. These countries aim to facilitate I4.0 adoption in industries and cities. Similarly, they intend to seize new business opportunities, promote competitiveness between nations, and positively impact the quality of their citizens' lives [13]. Additionally, researchers, academies, and consulting firms have developed models for I4.0 adoption to help evaluate the current state. Nevertheless, existing models for the adoption of this initiative focus on technology incorporation, process improvement, and organizational transformation.

Based on the previous statements related to I4.0 adoption, this research focuses on the needs of current employees which must be addressed in order for them to be able to adopt the new I4.0 technologies in terms of knowledge and culture, mainly in the development of skills and competencies that allow workers to implement, coexist with, and be supported by technologies enabling decision making. Hence, the objective of this work is to develop a maturity model (MM) that guides organizations in adopting I4.0, based on employees' competencies development, and to provide a roadmap to achieve workforce progress. The model developed is called "ECDMM4.0", referring to an "Employee Competency Development Maturity Model for I4.0 Adoption". For the ECDMM4.0, it was necessary to recognize I4.0 implications and the main challenges workers face when implementing enabling technologies and performing digital tasks. It was also necessary to review existing models for I4.0 adoption, detect relevant elements for a model characterization, and identify dimensions that enrich the human factor in this era. Lastly, it was also vital to identify the state-of-the-art skills and competencies required in the new "worker 4.0" role. After developing the ECDMM4.0, a validation process was implemented using the Delphi method, for which experts from industry and academia provided their comments and suggestions to improve the model design.

The remainder of the paper is organized as follows. Section 2 details the evolution of human tasks through the Industrial Revolutions, conceptualizes the I4.0 initiative, outlines the "worker 4.0" profile, and highlights the challenging role of employees according to new digitalized working scenarios. In Section 3, the methodology followed to develop the

maturity model, including conducting a systematic literature review (SLR) regarding the main existing models for I4.0 adoption and the primary skills and competencies required for workers in I4.0, is explained. Section 4 provides a comparative analysis of current models for embracing I4.0 and determines the required skills and competencies for workers. In Section 5, an MM for I4.0 adoption, based on the development of employees' competencies, and a roadmap for workforce development are proposed. In this section, the validation of the model from experts' point of view, applying the Delphi method, is also presented. Finally, Section 6 provides the conclusions, emphasizing how the ECDMM4.0 can guide enterprises in this challenging process by starting from a workers' development perspective. A direction for future research is also suggested.

2. Literature Review

This section reviews two main approaches: Section 2.1, the pathway of the Industrial Revolutions and the I4.0 initiative, and Section 2.2, the role and development of employees in I4.0.

2.1. The Fourth Industrial Revolution Origin and Key Elements

Throughout industrial history, humans have experienced a significant evolution in how they perform tasks, progressing from mechanical production, where operators performed their activities manually using machine tools [14], to mass production in assembly lines, where numerically control machines assisted workers in completing tasks [15], followed by automated production, in which human activities were reduced significantly, since employees worked cooperatively with industrial robots [16]. Currently, industries are embracing digital production, in which people, processes, and products are digitally interconnected, and enabling technologies support workers in performing tasks and making decisions in real time. This digital production is included in the I4.0 initiative, also denoted as the Fourth Industrial Revolution, presented by the German Federal Government during the Hannover Fair event in 2011. It was proposed as part of Germany's high-tech strategy, referring to its technological potential in manufacturing processes and indicating the beginning of worldwide digitalization [17].

The I4.0 initiative aims to involve people in innovative and digital scenarios in industries or cities. People can use and interact with enabling technologies to contribute to the resolution of entrepreneurial and urban challenges [18]. Regarding the I4.0 context, this initiative is recognized as an interconnected digital strategy. It has been considered relevant to place the human at the center of the entire value chain, since workers are digitally linked to processes and products for real-time data analytics and decision making [19]. In this sense, I4.0 influences the creation of future factories where digital interconnection exists so that instant data can be obtained and analyzed using software and algorithms [20]. It is characterized by a digital and innovative transformation that allows the system to be more flexible, agile, effective, and efficient across the value chain [21]. Thus, this initiative requires providing workers with the best advanced technologies and digital tools to empower them, enhance their capabilities, and facilitate their activities [22].

Furthermore, I4.0 requires the use of enabling technologies which include the cyber-physical systems (CPS), Internet of things (IoT), big data, cloud computing, additive manufacturing, augmented and virtual realities, autonomous robotics, and artificial intelligence [23]. Each technology has a specific purpose. Therefore, organizations must recognize each department's existing areas of opportunity in order to employ the appropriate advanced technologies according to specific cases [24]. I4.0 enabling technologies will allow organizations to increase their efficiency and productivity and improve their product or service quality [25]. Concerning the adoption of I4.0 enabling technologies, the terms "smart factory" or "intelligent factory" have been applied in the literature to indicate a completely interconnected manufacturing system. This system generates, transfers, receives, and processes data for analysis, decision making, and, most importantly, problem solving

in real time. The system is proposed to operate without a human workforce, avoiding the performance of manual tasks [26].

2.2. Workers' Role and Development in I4.0

The I4.0 initiative proposes that human beings can put their skills, experiences, and senses into practice [27]. Different terms have been used to identify and characterize the human worker of this era. Romero et al. [28] introduced the "operator 4.0" concept as a "smart" and skilled person who works interactively and cooperatively with advanced technologies, creating human–automation symbiosis work systems. It is a paradigm to support, complement, and enhance the future workforce by encouraging industries to increase human knowledge and improve their abilities and skills instead of replacing workers [29]. In addition, the term "worker 4.0" was applied to identify a participating and proactive employee who performs tasks actively, making decisions supported by digitalization [30].

Although I4.0 proposes placing the operator at the center of every process [19], it mainly challenges employees to integrate themselves into digital systems [31]. Whether or not companies are uncertain about the results that I4.0 adoption will create, the rapid evolution of digital transformation results in another significant challenge for industries [32]. Moreover, the human resources department is challenged by this initiative, as recruitment processes differ from common procedures. Also, motivating and engaging workers to participate actively in an I4.0 scheme is complex [33].

Additionally, when adopting I4.0, a high cost is implicated. Organizations do not know which enabling technologies to select and where to implement them in their operations [34]. There is a lack of knowledge regarding the successful adoption of I4.0 in enterprises and the methods for persuading, encouraging, and involving people in this digital initiative. It is worth mentioning that one of the most significant challenges is that the implementation of I4.0 enabling technologies is directly related to performing new skills [35]. However, high implementation efforts (e.g., costs, time, etc.), as well as the lack of employee expertise and their fear of adopting the I4.0 initiative, are associated with challenges in its adoption [36].

Not only has the job market been affected by the introduction of the I4.0 initiative, but also required employee competencies [37]. Thus, based on the rise of digitalization, connectivity, and analytics, I4.0 requires people to develop new skills and adapt skills, those already learned [38]. For instance, the top skills needed in workers to support I4.0 adoption include leadership, aptitude, decision making, and multidisciplinary thinking [39]. Therefore, companies that do not have the desired skilled employees require training and development programs to develop and improve their workforce competencies. Regarding this situation, learning factories have been suggested to include employee training plans [40]. These training programs should focus on developing specific skills and competencies for I4.0 to successfully advance its application in the digital schemes [41].

Furthermore, some authors have proposed managerial concepts to guide the adoption of I4.0. For instance, "Smart Human Resources 4.0" was established to be adapted in companies to attract and develop new human talent in I4.0. This concept contributes to a more efficient and optimal operation scheme regarding human resources [42]. Moreover, "Human Resources Management 4.0 (HRM4.0)" was suggested to cover the impact of I4.0 on human resource management across supply chains [43]. Other authors suggested the "Leadership 4.0" concept, which recognizes people's skills and competencies from a leadership perspective. It envisages managers' exemplary participation so that through their support in adopting I4.0, other workers can become interested, motivated, and successfully involved [44]. Given the role of a leader in I4.0, once the manager's participation has been achieved, it will be possible to establish and execute specific roles for other employees, including "operator 4.0".

In particular, Gazzaneo, Padovano, and Umbrello [7] proposed the "Operator 4.0 Compass", which identified the I4.0 enabling technologies and matched them to the "operator 4.0" capabilities needed in this digital era. Furthermore, by recognizing workers developing

new tasks, Dornelles, Ayala, and Frank [45] identified that I4.0 enabling technologies can develop workers' capabilities, such as analytical, augmented, collaborative, healthy, smart, social, super-strength, and virtual skills.

3. Methodology

This work stems from the fundamental role of workers in adopting the I4.0 initiative. It seeks to present an MM for I4.0 embracing, based on the development workers' competencies. Therefore, it focuses on characterizing a pertinent model for this initiative's adoption and recognizing the skills and competencies workers need according to the enabling technologies to be implemented. Hence, the research questions for this study were defined as follows:

- RQ1. What is a proper characterization of a model for I4.0 adoption from an employees' competencies development perspective?
- RQ2. What are the skills and competencies desired for workers when adopting I4.0?

The conceptual framework selected to develop the model for I4.0 adoption was based on the multi-methodological research approach for the development of maturity models, implemented by Wagire et al. [46] and Schumacher et al. [47], who based their established development guidelines on the work of Becker et al. [48], in which they followed the design science methodology presented by Hevner et al. [49]. The research framework used to develop a model for I4.0 adoption, based on the development of employees' competencies and implemented in the present work, is summarized in Figure 1, which leads to a three-step methodology further detailed in Section 3.1, Conceptualization; Section 3.2, Development; and Section 3.3, Validation.

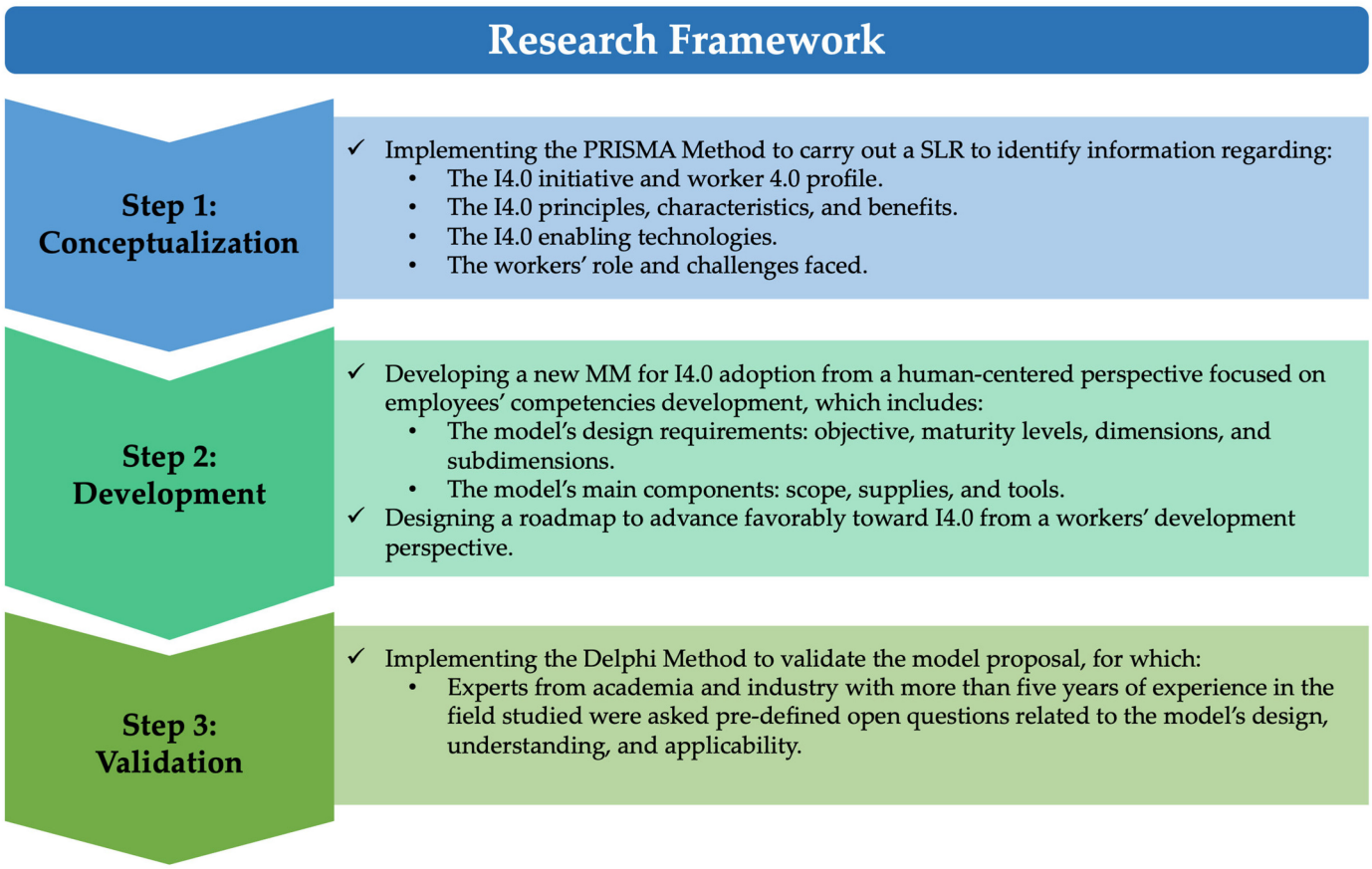

Figure 1. Research framework for the development of the model for I4.0 adoption.

3.1. Step 1: Conceptualization

The first step encompasses understanding the I4.0 initiative and the "worker 4.0" profile. The I4.0 principles, characteristics, enabling technologies, and benefits, as well as the employees' role and challenges faced due to the adoption of advanced technologies and the new digital tasks involved, were acknowledged. Moreover, this step involved conducting an SLR on the topic. For this, the PRISMA methodology was implemented.

The SLR was performed in December 2022 by searching publications containing key phrases in the article title, abstract, and/or keywords regarding two main areas which relate to the research questions. Since two research questions were established for this study, two SLR stages (A and B) were conducted separately. For Stage A, the search string used was [("Industry 4.0" OR "Fourth Industrial Revolution") AND ("maturity model" OR "readiness model" OR "assessment model" OR "diagnostic model" OR "capability model")]. For Stage B, the search string implemented was [("Industry 4.0" OR "Fourth Industrial Revolution") AND ("skill*" OR "competenc*") AND ("operator" OR "worker" OR "employee" OR "human factor")].

The databases Scopus and Web of Science were used for search purposes. They were selected due to their renowned and high-quality worldwide journal coverage [50]. Only journals publications written in English and published from 2011 to 2022 were considered to support the literature review. This period was chosen, as I4.0 originated in 2011 during the Hannover Fair event in Germany [17]. For both databases, records that appear more than once in several search phrases were detected. Additionally, duplicates were removed, since the research was conducted in two databases.

The inclusion and exclusion criteria were determined following the selection of the significant publications for the study. On the one hand, the specified inclusion criteria included: (i) peer-reviewed publications in journals, (ii) full-text available documents, and (iii) considering the title, abstract, and keywords, the manuscripts should present, for Stage A, a new model proposal for I4.0 adoption, depicting its main characteristics, and for Stage B, research regarding I4.0 and worker development, indicating the main skills and competencies needed by employees in this adoption journey. On the other hand, the defined exclusion criteria comprised: (iv) duplicated records in a database or between databases used, (v) non-peer-reviewed publications, (vi) non-available documents, (vii) manuscripts mentioning, for Stage A, existing models for I4.0 adoption, without presenting a new model proposal, and for Stage B, I4.0 and workers' roles and challenges, without specifying skills and competencies.

For Stage A (Figure 2), 600 publications were first identified, from which 91 were removed, since they were duplicated. When screening the titles, abstracts, and keywords of the 509 records, 385 were also excluded due to the following: (a) the publications were not published from 2011 to 2022, issued in journals, nor written in English; (b) the publications were not displayed online in their full text; and (c) the publications did not include one of the search terms fostering models related to I4.0 adoption in their title, abstract, or keywords. The remaining 124 full-text documents were analyzed, and 82 publications were excluded based on the following: (d) the publications did not propose a new model for I4.0 adoption nor specify its main characteristics. Hence, 42 records were finally chosen for this review because they present new models oriented toward I4.0 adoption and present the relevant characteristics of a model, including objective, scope, levels, level descriptors, and dimensions. Moreover, from the records that presented a literature review of existing models for I4.0 adoption, rather than developing a new example, new documents were selected from their references and other research sources, including governmental records, academy publications, or consulting firm reports. In this stage, 119 publications were identified, from which 59 were disregarded due to: (e) the publication was not published during in the period considered, published in journals or official websites, nor written in English. Hence, 60 records were eligible full-texts, from which four were excluded based on previously defined reasons (d), yielding a total of 56. From the searches via databases and other methods, 39 publications were relevant for the review of existing models for

I4.0 adoption. Of them, only five were key to developing the employee competency development maturity model. Moreover, for Stage B, the PRISMA method was also applied, from which 428 records were identified in the databases searched, identifying 68 duplicates. Thus, when reviewing their titles, abstracts, and keywords through a screening process, 255 were excluded, with 105 records retained.

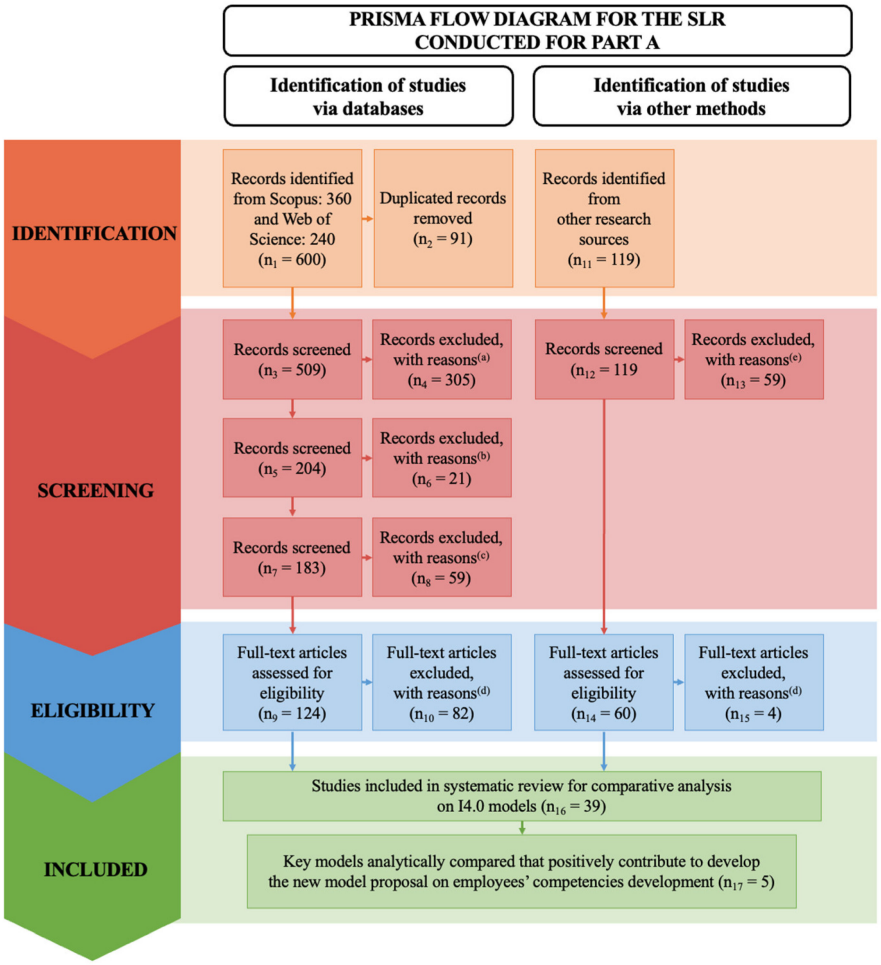

Figure 2. PRISMA flow diagram used for the SLR of Part A.

After developing the SLR, publications relevant to the literature review's research questions were selected and analyzed. A comparative analysis of the existing models for I4.0 adoption was developed. The relevant characteristics of a model were identified, including the objective, levels, levels descriptors, and dimensions. Also, the primary desired employee skills for digital interaction in their interconnected working environments were identified and classified accordingly into competencies.

3.2. Step 2: Development

In the second step, based on the research carried out, an MM was developed for I4.0 adoption, since this type of model is commonly implemented to measure an organization's maturity based on a target state [47]. The model was developed following the model's design requirements and the definition of its main characteristics. Additionally, a possible roadmap was generated to provide a guideline for the adoption process from the workforce development point of view.

First, the levels and their descriptors were established for the model design, followed by the recognition of relevant inputs. Then, the dimensions were indicated as the competencies identified in the literature review. The corresponding skills of the competencies were

encompassed as subdimensions. After this, the main components of the model—scope, supplies, and tools—were also depicted. Through the integration of all these elements, the MM was obtained. Later, the stages required to advance favorably toward I4.0, from a workers' development perspective, were stipulated for the roadmap design.

3.3. Step 3: Validation

Lastly, in the third step, a validation strategy was implemented following the technique proposed by the Delphi method. The RAND Corporation generated this technique in the 1950s. Its objective is to structure an effective communication process I n a group of experts to deal with a problem and obtain the most reliable opinion from experts [51,52]. In this method, a group of experts on the topic participates, providing their comments, observations, and independent judgments on a particular subject, according to the questionnaire provided [53,54].

The subject in question for this study is the MM for I4.0 adoption, from a human development perspective. After some iterations with controlled opinion feedback, a consensus from all experts is reached, and a report can be documented [51]. It is worth mentioning that this research validation technique has been applied in several different areas, such as indicating the pros and cons associated with policies, exposing the priorities of social goals, and developing the structure of a model, among others [55]. The last area mentioned concerns the research being developed, as it is intended to generate an MM for I4.0 adoption, based on the development of workers' competencies. In this sense, the validation of the MM is significant since the usefulness of a model must be validated so that its future applicability is not suspect [56].

Since the selection of experts is relevant for applying the Delphi method, for this study, an expert was identified as an academic or professional with more than five years of expertise in the fields of technology, innovation, I4.0, or other related areas. These include using the Internet, implementing robots in manufacturing areas, and managing computer programs, among others. This is because technology and innovation are the first priorities for digitalization in I4.0. For the MM validation, a group of experts was identified in the academic field of investigation and another in the organizations' professional domain. This was possible due to the authors' university connections with research professors and professionals through education and company consulting projects. The experts were asked pre-defined open questions about the model's design, understanding, and applicability, among other aspects. The duration of the interviews was around 60 min, being virtually implemented through an online video platform.

4. Results

This section provides answers to the research questions according to the results obtained from the SLR. For each research question, a Section is depicted as follows: Section 4.1, the existing models for I4.0 adoption, and Section 4.2, the desired worker skills and competencies.

4.1. Existing Models for I4.0 Adoption

The first research question was: "What is a proper characterization of a model for I4.0 adoption from an employees' competencies development perspective?" Therefore, models for I4.0 adoption created over the last ten years were reviewed and analyzed by research authors, globally recognized consulting firms, and research academies to guide organizations toward embracing I4.0. Among these models, the following types can be distinguished:

1. Maturity Model: It evaluates the current maturity of an organization according to maturity levels and a target state [47,57].
2. Readiness Model: It determines how ready an organization is to start a development process [47].

3. Assessment Model: It measures an organization's implementation level based on determined dimensions [58].
4. Diagnostic Model: It identifies the relevant elements of an organization and their subsequent association [59].
5. Capability Model: It recognizes an organization's ability to achieve a particular objective [60].

The models' characterization includes the following criteria:

- Objective: It defines the main purpose of the model, intending to evaluate the organizations' status in regard to I4.0 adoption.
- Levels/Stages: They denote the maturity of a dimension or driver, considering the advancement path on I4.0 adoption based on the evaluation criteria. The relevant characteristics of each level are provided and well-defined as level descriptors.
- Dimensions/Drivers: They determine the criteria to be evaluated for specific areas related to the field of interest; in this study, I4.0 and worker development.

Appendix A depicts a sample selection of 39 existing models for I4.0 adoption, indicating the model's name, reference, publication year, type, objective, levels/stages, and dimensions/drives.

The presented models included 27 MMs, 4 RMs, 6 AMs, 1 CM, and 1 GM (a new category defined for a general model). These 39 models help organizations recognize their current state regarding I4.0 adoption. However, some of them are mainly focused on a company's sector, and consequently, could not apply to other organizations. Furthermore, generally, these models focus on technological (>76%) or manufacturing aspects (>66%). Only 17 of the total number included the organizational perspective as a dimension (43.59%), and 17 considered employees (also workforce, or people) (43.59%). Additionally, five publications were identified as being related to competencies development. The first was an AM designed by Colli et al. [61] in 2019. It relates to a maturity assessment approach that proposes "competences" as a dimension. In this work, they refer to this dimension as a set of skills required for digital transformation, which includes digital competencies and training and learning cultures. Then, in 2020, Dzwigol et al. [62] presented an AM for manager competency, in which they assessed current managers' competencies using an algorithmic "fuzzy logic" model. In the same year, an RM was presented by Sony and Aithal [63] for engineering industries in India, depicting "employee adaptability with Industry 4.0 skills in Indian Engineering Industries" as a dimension. Moreover, Maisiri and van Dyk [64] developed an MM to evaluate industrial engineering professionals' competencies in preparation for graduation. One year later, in 2021, Steinlechner et al. [65] generated an MM to assess employee competencies, focusing uniquely on digital competencies in industrial enterprises.

Although relevant models for I4.0 adoption have been identified in the literature, and some of them focus on competencies development, they do not present a holistic view of worker development. This condition prevents the improvement of people skills and competencies in all areas (i.e., professional, personal, social) and the guidance of the workforce in a new digital scenario. Moreover, since the models could not be used to adopt I4.0 based on the development of talent aligned to the new digital era, a significant area of opportunity for improvement is distinguished. Mainly in providing an MM and a roadmap that go hand in hand to recognize the current state of an organization, allow it to propose its desired state, and guide it throughout its favorable progress in embracing I4.0 based on their employees' competencies development.

Based on the comparative analysis developed and the categorization of the desired skills for workers into competencies, the new model must be able to assess the maturity level in I4.0 adoption based on employees' competencies development. Therefore, the levels, dimensions, and subdimensions must be depicted properly, including clear and understandable definitions. This will allow organizations to evaluate their current status and determine future steps toward embracing I4.0.

4.2. Skills and Competencies Desired in "Workers 4.0"

The second research question asked: "What are the skills and competencies desired in "workers 4.0" when adopting I4.0? Considering the relevance of humans in I4.0, valuable skills and competencies are required in workers to achieve digitalization in organizations properly. For instance, Kipper et al. [66] carried out a systematic literature review identifying the set of skills desired in workers due to I4.0 needs. These skills include leadership, self-organization, pro-activity, creativity, problem-solving, interdisciplinary, teamwork, collaborative work, communication, adaptability, flexibility, among others. Likewise, Hernandez-de-Menendez et al. [67] acknowledged the skills previously mentioned and others needed in people and classified them into technical, methodological, social, and personal competencies. Also, Hecklau et al. [68] identified the skills for I4.0 through surveys to enterprises and classified the main competencies into social, methodological, personal, and domain. Moreover, it is worth indicating that before I4.0, Erpenbeck and Rosentiel, cited by Scharnhorst and Ebeling [69], recognized personal, technical-methodical, socio-communicative, and activity-related as the main competencies needed for human development. However, it is the embracing of new I4.0 enabling technologies that updates the competencies required to deal with digital tasks.

Based on the classifications reviewed in previous publications and the research gap we intend to close about the evaluation and development of employees' competencies in I4.0, the categorization chosen to provide an answer to the RQ2 includes four competencies determined as follows:

1. Personal competencies: Human beings carry out their activities under an organized reflexive criterion.
2. Socio-communicative competencies: Individuals demonstrate a disposition to communicate and cooperate when performing tasks.
3. Problem-solving competencies: People use their intellectual and technical knowledge to solve objective problems.
4. Activity-related competencies: Humans actively execute tasks and integrate emotions, skills, and experiences to implement plans effectively.

A set of desired skills was identified from the literature reviewed for each of these competencies. Soft and hard skills were identified and classified according to the four competencies. Based on the literature, several authors highlight the requirement of soft skills as they account for human behaviors that technological elements cannot perform. The soft skills recognized for personal competencies include creativity, cognitive flexibility, people management, emotional intelligence, and service orientation [33,70]. Various authors have defined that for these, a committed person with leadership is expected to take an active role [30,33,71].

Since in the I4.0 initiative, customers take on additional value under personally customized and dynamic demand schemes, the sense of negotiation and understanding with people, principally customers, is critical for a "worker 4.0" [70]. Collecting, visualizing, and analyzing data to make real-time decisions are fundamental activities in I4.0 [72]. Mainly because the information is shared across the company's departments and levels, being necessary for employees to develop new communication and teamwork skills determined for socio-communicative competencies [73].

For problem-solving competencies, "workers 4.0" distinguishes by collaborating with advanced technologies and being supported by them to make real-time decisions and solve problems [30,71,74]. In this regard, employees should quickly adapt to digital trends and innovations, use Big Data and Analytics, and interact with robots to forecast and identify important information [75].

Based on the previous, not only digital capabilities are required, but also personal and socio-communicative competencies are relevant. Participative talent is desired when considering the skills identified for the three competencies previously mentioned. A person capable of managing complexity, having the willingness to share knowledge, and working in teams. These skills correspond to activity-related competencies.

In addition to the skills identified and classified into competencies, when focusing on the soft skills found in the literature, it is worth indicating that previous works have studied the impacts of implementing enabling technologies such as IoT, VR, among others, to enhance learning and development programs. These advanced technologies have shown an increase in humans' abilities, behaviors, knowledge, and skills in solving problems [76,77].

5. Discussion

A comparative analysis of the different existing models in the literature for the I4.0 adoption was carried out throughout the investigation. Likewise, the main characteristics of a maturity model were identified to determine a new model proposal focused on covering the identified gap in the development of competencies in workers to face the digital challenges that I4.0 brings with it. Additionally, the maturity levels and dimensions for the model developed were defined.

Considering the comparative analysis of existing models' main characteristics and selection of maturity levels and dimensions, the proposed model named "Employee Competency Development Maturity Model for I4.0 Adoption" (ECDMM4.0) arises. In this section, discussions on what was developed in the research are presented as follows: Section 5.1, the ECDMM4.0 development; Section 5.2, the Worker 4.0 Development Roadmap proposal; and Section 5.3, the validation from experts through the Delphi Method.

5.1. The ECDMM4.0 Development

The transition process for I4.0 adoption is defined by digitalization and human development in digital ecosystems. In this regard, an MM focused on developing employees' competencies is necessary for organizations to embrace I4.0. For instance, it will provide a guideline through the initiative adoption journey. From the workers' perspective, developing strategic levels to guide organizations and success in this process is highly relevant. The model developed considers the previously conducted comparative analysis of existing models for I4.0 adoption, which identifies model levels and dimensions, hence establishing five maturity levels (MLs) that indicate the progress of workers in developing I4.0 competencies, from the very basic to the most specific skills needed. These include: (1) Beginner, (2) Managed, (3) Proactive, (4) Expert, and (5) Leader. The maturity level (ML) descriptors for the ECDMM4.0 are detailed as follows:

- ML1. Beginner: The organization must recognize an existing I4.0 initiative and create a benchmark to identify the practices of other countries and enterprises. It must also evaluate the organization's current status and carry out a gap analysis for I4.0 adoption, recognizing the need for "Talent 4.0" development. Thus, workers start establishing a conceptualization of I4.0 terms.
- ML2. Managed: It is relevant for the organization to determine a strategy to define training and development programs for its workforce. In this sense, the Worker 4.0 Development Roadmap (proposed in Section 5.2) can be followed to allow the organization to generate a strategic plan for embracing I4.0 from the workers' perspective. Focus groups are essential because the organization needs to identify how its employees feel about these programs and their expectations and uncertainties about I4.0.
- ML3. Proactive: The organization must implement training and development programs to develop workers' skills and competencies. It is suggested to follow up on strategic projects and use I4.0 enabling technologies, such as virtual and augmented realities, for carrying out the programs through simulations. In this regard, worker participation in working and collaborating in "smart" operations is enhanced.
- ML4. Expert: It is fundamental for the organization to start mastering its understanding of the I4.0 enabling technologies. They include the IoT, CPS, big data, artificial intelligence, and additive manufacturing, which are fundamental for I4.0 embracing, according to each organization's profile, are adopted. In this sense, the organization has a clear vision of the benefits of enabling technologies. It accepts this digital genera-

tion of disruptive tasks and identifies the added value that people provide to its value chain. Thus, employees become experienced in implementing and collaborating with these technologies and are empowered to make real-time decisions supported by I4.0 enabling technologies.

- ML5. Leader: The organization becomes "smart" when it digitally interconnects "smart" people, processes, and products (or services), accomplishing a leader profile regarding I4.0 worldwide adoption. Hence, human–technology interaction is possible, and real-time data analysis for making decisions, among other relevant digital activities, occurs. In light of this situation, a leading digital organization is distinguished by transcending and seeking to become a benchmark for others worldwide. It identifies, documents, and shares its best practices in an information repository to replicate the followed-up strategies. Moreover, at this level, a leading organization in I4.0 considers it fundamental to perform continuous development in a digital ecosystem and consolidates a "work culture 4.0".

In addition to the MLs recognition, three main inputs are identified for these levels: the I4.0 reference model, I4.0 MMs, and I4.0 frameworks. Additionally, the MM takes into consideration the classification previously proposed by other author regarding competencies desired in workers; thus, it depicts four dimensions corresponding to the four main selected competencies require by employees for I4.0 adoption (i.e., personal, socio-communicative, problem-solving, and activity-related). The four competencies are integrated into the ECDMM4.0 as dimensions supporting employees' development which are necessary to advance toward the MLs in I4.0 adoption. Thus, the skills are classified for each competency, and their advancements, encompassing the subdimensions, are detailed across the MLs, as shown in Appendix B.

Lastly, the ECDMM4.0 includes three components:

- Scope: The target (final achievement) the organization must consider to achieve the requirements indicated for each ML and meet all the skills stipulated in each competency for each level.
- Supplies: The inputs the organization requires to start each ML.
- Tools: The technologies, software, equipment, and other components the organization requires to perform the activities related to the ML.

Once all elements of the model are integrated (i.e., MLs, dimensions, support elements, inputs, timeline, and components), the ECDMM4.0 is reached, as illustrated in Figure 3, aiming to guide organizations to advance from a thorough understanding of the concept of I4.0 to a leading position in its adoption. The figure shows the advancement in the levels toward I4.0 adoption, for which it is necessary to consider the set of competencies, along with their corresponding specifications, and reach a specific scope for each maturity level. To achieve these, it is required to use the supplies and tools indicated in the figure. In addition, it is worth noting that the ECDMM4.0 specifies two areas. The model focuses on worker 4.0 development throughout the first three maturity levels. It is only in the fourth and fifth levels that the model focuses on talent and culture scalability to sustain I4.0 adoption, based on updating and enriching the organization, according to the latest digital and technological trends.

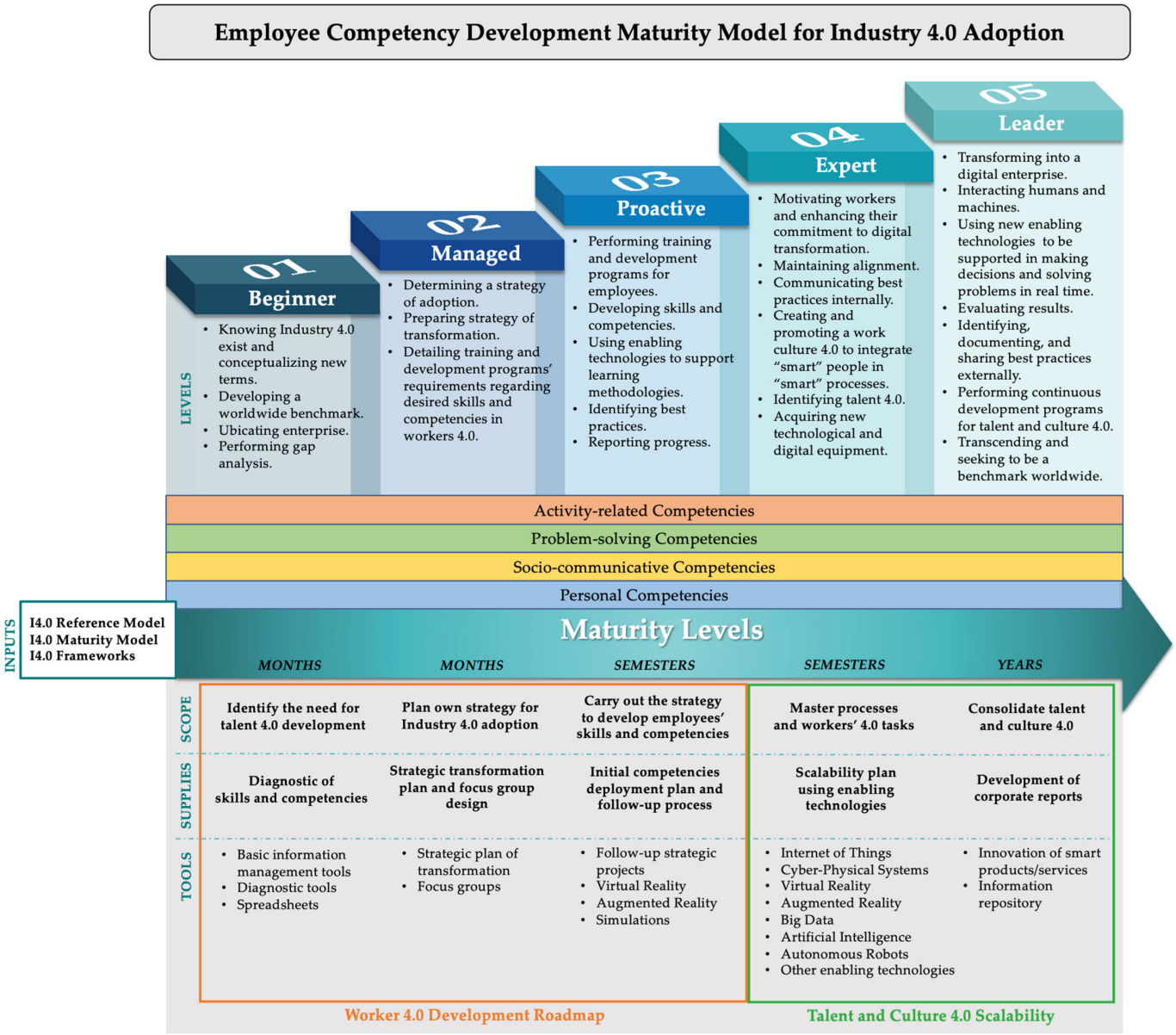

Figure 3. ECDMM4.0 for I4.0 Adoption.

5.2. Worker 4.0 Development Roadmap

After developing the SLR, the most relevant skills were acknowledged and categorized into the worker competencies required for embracing I4.0. From this categorization and the identification of the main elements proposed in previous existing models for I4.0 adoption, the ECDMM4.0 was developed. However, when performing the literature review, a clear path for embracing I4.0 was not evident in the model review. Consequently, a roadmap to achieve "worker 4.0" development was determined, intending to encourage employees to develop new competencies, improve those currently mastered, and aligned with the digital strategy adopted in their organization.

This proposed roadmap could be seen as a starting point to incorporate workers' desired skills and competencies for I4.0 adoption. Its main objective is to guide organizations toward developing and enhancing their employees in order to create a competitive workforce with the required qualifications. Figure 4 shows the proposed five-stage roadmap from a worker's perspective. It incorporates the maturity levels of the ECDMM4.0 such that the simultaneous advancement path can be visualized.

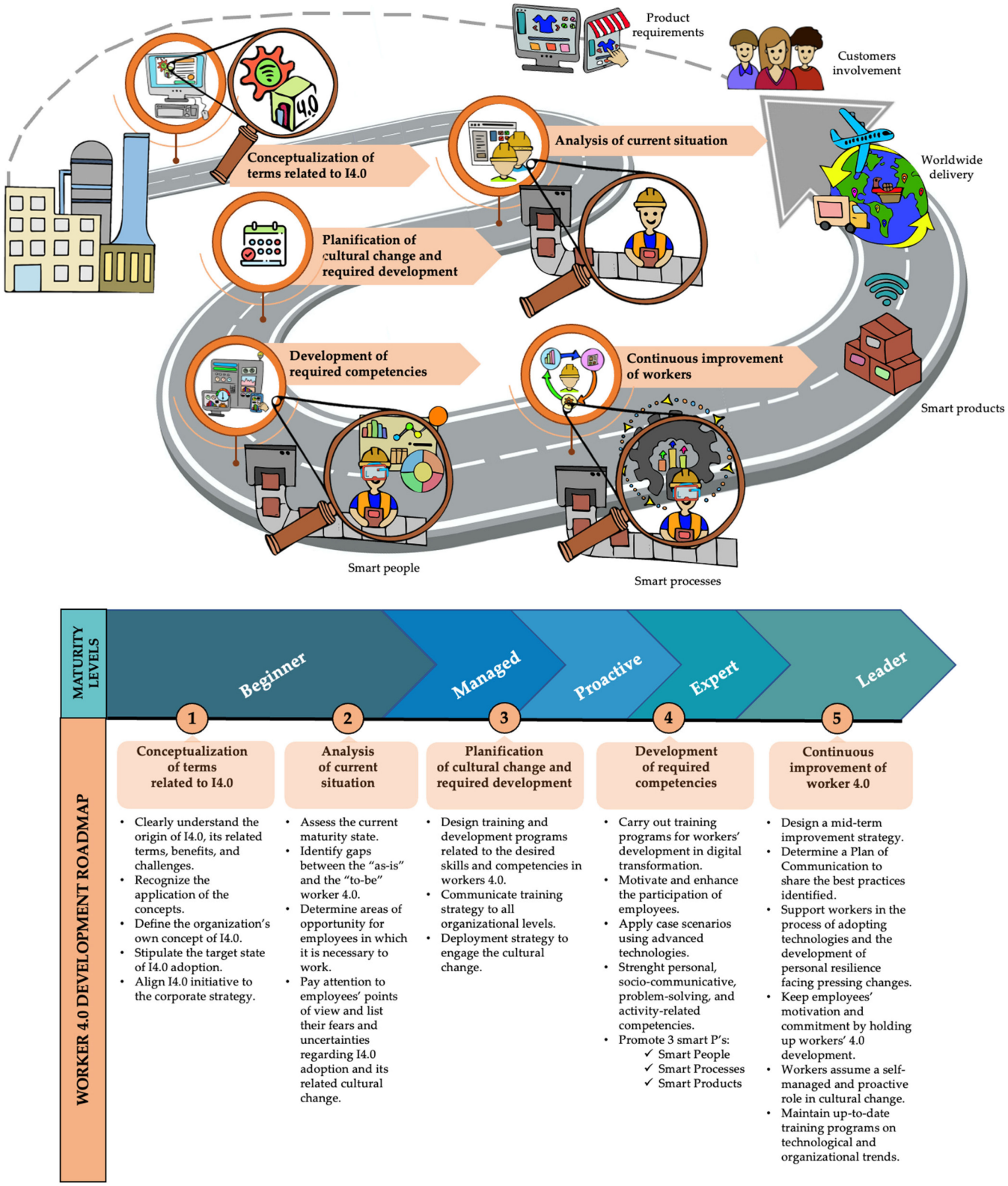

Figure 4. Worker 4.0 Development Roadmap.

In the first stage, a clear understanding of the relevant concepts is required, including I4.0, "operator 4.0", "worker 4.0", and enabling technologies, among others. Exploring the best practices implemented worldwide and developing a benchmark to define the target state of adoption are indicated. For this step, paying attention to employees' points of

view is significant since they possess valuable experience with their established tasks and can express critical uncertainties for the I4.0 adoption strategy. Workers' experiences and perspectives can provide important opinions and dynamic communication.

The second stage corresponds to an analysis of the current situation which must be performed, based on an assessment to recognize the human talent in the organization to detect the existing gaps between the "as-is" and "to-be" "worker 4.0" in this digital era in order to prioritize the main activities to be carried out and identify potential trainers for desired skills and competencies to create the implementation plan.

In the third stage, planning the main activities to be developed is relevant, specifically determining how the training and development programs will be implemented and what they will include. In this step, a communication plan is fundamental to inform workers about the strategy for embracing I4.0, particularly for developing employee skills and competencies.

The fourth stage involves conducting training programs in which workers can develop and improve their competencies, as well as motivate workforce participation and commitment, encouraging team and cross-functional collaboration between departments. Therefore, top managers should communicate and transfer their knowledge to other organizational levels [78]. Within this stage, it is intended that employees develop their competencies while using enabling technologies and interacting with "smart" devices to understand digital functionalities and their roles. These methods are aimed at procuring worker willingness to adapt and move forward, while keeping individual and organizational values in mind.

In the fifth stage, maintaining a sustainable and continuous improvement model of "talent 4.0", capable of adapting to digital and organizational changes, is achieved. Thereby, digitally enabled knowledge-sharing solutions are recommended to pursue the continuous improvement of multi-skilled employees.

Obviously, the I4.0 journey is complex and demands great determination and responsibility. Hence, following a path, such as the proposed roadmap, is necessary in order to successfully adopt this initiative. This method will help workers take ownership, join forces, and focus on the areas of opportunity that must be enriched to support organizational advancement. This roadmap can be used whenever needed to pursue continuous improvement in workers. Moreover, organizations should bear in mind that in line with the digital transformation process, the company's key strategies and procedures must be retained for greater competitiveness in adopting I4.0 [79].

5.3. Experts' Validation through the Delphi Method

To provide a clear vision of the ECDMM4.0 and ratify its purpose, validation is required. Therefore, the implementation of the Delphi method was selected. This is a research validation technique that supports communication with a group of experts to acquire valuable information and comments regarding the model [55]. This method has been used as a validation instrument in developing previous studies of maturity models, in which experts provide comments and suggestions to improve and validate the model [80].

Figure 5 demonstrates the methodology followed to implement the Delphi method. A questionnaire was designed and sent, along with a personal invitation, to each expert. After obtaining their answers, an analysis was developed, and when a complete validation of the ECDMM4.0 was achieved, a report based on their responses and opinions was generated. Using this method, it was necessary to send an iterative reformulation of the questions to the experts until approval was reached for the final version of the MM.

To conduct this validation method, the expert profile was defined as any person who works in the academic or industrial field and has an average of at least five years of knowledge and experience in innovation, technology, or I4.0. A total of 16 experts from academia and industry were asked to review the ECDMM4.0 generated in order to obtain their points of view regarding the model, its strengths, and the areas of opportunity. Throughout the validation process, enriching responses were received, among which the

suggestions were made that the model allows for the visualization of the progress in the levels by indicating the different steps in the process. With this visualization, the purpose of each stage is evident, and therefore, it is apparent that organizations cannot proceed to the next level until they have complied with what is stipulated in the current step. In addition, it is a model that covers any company and develops detailed leadership skills. Industry experts agreed that companies require this guidance for the timely advancement of the adoption of I4.0. The importance of the worker in this process was also recognized, even though, in many cases, companies tend to focus on operations, leaving the human being out of the equation. The human factor cannot be omitted from the competitive advantage equation of organizations, since it includes a talented and committed workforce that has a significantly favorable influence on the value chain. Based on this, worker is the backbone—the engine facing the most challenging changes—that will be required to leave comfort zones behind to be recognized as "talent 4.0".

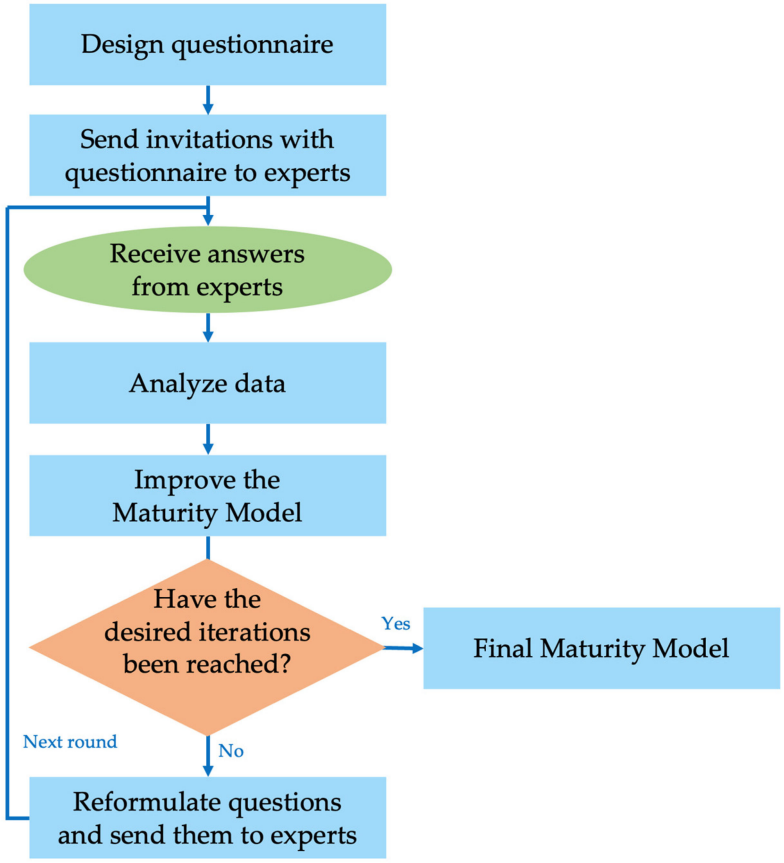

Figure 5. Delphi method process implemented for validation of the ECDMM4.0.

In turn, the experts shared suggestions to improve and strengthen the model. Comments included: (a) it would be appropriate to stipulate job profiles, and for each one, a description should be created for each ML. This is given according to the level of detail and the diversity of classifications in the worker's job profile. It was suggested and agreed upon that specifying job profiles could be addressed as future work according to the specific case of an organization, and (b) it would be advisable to detail timelines in order to obtain an idea of how the progress and completion of each stage vary concerning each company (according to its business, sector, and size, among other factors). When analyzing the answers provided by the experts, it is recognized that the current model serves as a basis for adopting I4.0 from a workforce development perspective. Consequently, the model meets the criteria of the desired objective. Hence, as a future step, it is proposed to implement

the recommendations provided by the experts who helped to delve deeper into the model, supporting specific job profiles and organizations.

Performing the Delphi method's iterative process, a final version of the ECDMM4.0 was obtained (presented in Section 5.1), which will help organizations embrace I4.0 from workers' perspectives, based on the development of their competencies. The final validated ECDMM4.0 (previously shown in Figure 3) focuses on achieving a leadership position in I4.0 adoption from the employees' perspective. It considers all industrial sectors and enterprise sizes.

6. Conclusions

Continuous technological and organizational training programs are necessary, primarily because "smart" technologies require people who can adapt quickly to unexpected changes. Organizations intend to pursue continuous improvement in their operations to achieve higher competitiveness. The appearance of the I4.0 initiative contributes to this goal; however, it has led to uncertainty regarding its implications and application. If organizations have no clear idea of how to follow an adoption strategy, how would they embrace I4.0? This paper contributes to the industrial, organizational, and academic fields by integrating the relevant concepts of existing models for I4.0 adoption and identifying, classifying, and prioritizing the skills and competencies desired for workers in order to face the challenging I4.0 era. These models seek to provide tools that foster digitalization from a workers' point of view, endeavoring to let organizations become leaders in I4.0. In this sense, an ECDMM4.0, a Worker 4.0 Development Roadmap, and a Talent and Culture 4.0 Scalability Model are proposed to orient companies in adopting the I4.0 and developing the desired employee competencies.

The ECDMM4.0 aims to guide enterprises in the I4.0 adoption process, based on the workers' perspective. This model emphasizes providing five maturity levels to let organizations design and implement strategies to lead the I4.0 initiative from a human-centered perspective. It was developed by identifying the main challenges of employees when embracing I4.0, especially when using enabling technologies and performing digital tasks. This is because workers are not digital experts and are not ready to coexist with these "smart" systems. Moreover, the model was designed by comparatively analyzing the existing models for I4.0 adoption and characterizing their relevant elements and by grouping skills according to the classification of the desired competencies for workers, who are continuously challenged by this initiative embracement. In this regard, the skills were categorized according to four identified competencies: personal, socio-communicative, problem-solving, and activity-related. Furthermore, the ECDMM4.0 was validated through the literature review developed and the consensus reached by the group of experts from academia and industry, using the Delphi method.

Within this framework, worker development in organizations is a promising strategy to face I4.0 adoption challenges. Thus, recognizing the main gaps in the current state of business enterprises is needed to further establish initiatives, according to human needs and digital trends. Organizations must start by understanding the situation, defining strategies, and implementing programs, which will lead to success and leading out in I4.0. Accordingly, this work proposed a Worker 4.0 Development Roadmap that seeks to prepare people to develop the desired skills and competencies for I4.0.

Developing digital competencies in employees and enhancing "talent and culture 4.0" in organizations is of interest to lead out in the adoption of I4.0. This goal requires commitment and motivation from companies and their workforce. Hence, through the five maturity levels proposed in the model, enterprises can improve their adoption status to become leaders in I4.0 by implementing training and development programs. With these programs, workers can develop their competencies and distinguish themselves by cultivating the capability to be resilient and adapt to changes with a strategic, planning mindset. Consequently, they can specialize and become experts in their working fields.

From the proposed model, talent and cultural development are distinguished as key factors in the adoption process. Organizations need to promote dynamism and develop a communication and deployment plan in which leadership centered around people plays a fundamental role. In addition, it was identified that I4.0 requires the continuous updating of education and sustainable approaches to company organizational culture. Managers, leaders, and all employees involved must partake in a shared vision to better structure and update their strategies.

From the framework proposed, future work is necessary in regard to research on the required skills, based on each organizational job profile level and on the perception of developing countries, as well as small and medium enterprises. This is relevant for determine strategic guidelines for different job profiles in regard to the size and sector of organizations. Additionally, potential research can be extended from this framework by incorporating future innovative, technological, and digital trends, specifically by linking the proposed model with new emerging initiatives with concepts such as industry 5.0 (I5.0) or society 5.0, which seek sustainable solutions by locating the human factor at the center of the model, for which human resources development (HRD) is crucial. Also, investigating the stakeholders involved in the I4.0 adoption is suggested, mainly because a strategic linkage between enterprises, government, and universities is required to seek human well-being in the event of the adoption of the I4.0 initiative. Lastly, although the developed maturity model was validated using the Delphi method, it could be validated through other validation methods, such as case studies, to enrich it.

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Appendix A

Table A1 lists the articles presenting existing models for I4.0 adoption and provides a comparative analysis of their main characteristics.

Table A1. Comparative analysis of existing models for I4.0 adoption.

Model Name	Reference	Year	Model Type [1]	Objective	Levels/Stages	Dimensions/ Drivers
The Connected Enterprise Maturity Model	[81]	2014	MM	To assess large companies' IT capability to identify their readiness to connect people, processes, and technologies to acquire more profits.	(5) Assessment; secure and upgraded network and controls; defined and organized working data capital; analytics; collaboration	(4) Information infrastructure; controls and devices; networks; security policies
Industry 4.0 Readiness—IMPULS	[82]	2015	RM	To evaluate the current readiness state of organizations to adopt the I4.0 initiative and provide a guideline with a strategy to increase their current level of I4.0 implementation.	(6) Outsider; beginner; intermediate; experienced; expert; top performer	(6) Strategy and organization; smart factory; smart operations; smart products; data-driven services; employees

Table A1. *Cont.*

Model Name	Reference	Year	Model Type [1]	Objective	Levels/Stages	Dimensions/ Drivers
McKinsey Digital Compass	[83]	2015	GM	To help enterprises identify the levels that are significant for them, which should focus on solving specific problems related to I4.0 implementation.	Not identified	(8) Resource/process; asset utilization; labor; inventories; quality; supply/demand match; time to market; service/after sales
A Digital Maturity Model for Telecommunications Service Providers	[84]	2016	MM	To help telecommunication service providers evaluate their maturity state.	(6) Not started; initiating; enabling; integrating; optimizing; pioneering	(7) Strategy; organization; customer; technology; operations; ecosystem; innovation
Industry 4.0/Digital Operations Self-Assessment	[85]	2016	AM	To provide a diagnostic tool in which the industries can recognize their actual level while comparing themselves with other organizations' current states.	(4) Digital novice; vertical integrator; horizontal collaborator; digital champion	(7) Digital business models and customer access; digitization of product and service offerings; digitization and integration of vertical and horizontal value chains; data and analytics as core capability; agile IT architecture; compliance, security, legal and tax issues; organization, employees, and digital culture
A Maturity Model of Industry 4.0 Readiness	[47]	2016	MM	To assess maturity for I4.0, focusing on manufacturing companies.	(5) From lack of attributes supporting I4.0 concepts to the state-of-the-art of required attributes	(9) Strategy; leadership; customers; products; operations; culture; people; governance; technology
SIMMI 4.0—System Integration Maturity Model Industry 4.0	[86]	2016	MM	To evaluate an enterprise's readiness regarding its IT system infrastructure.	(5) Basic; cross-departmental; horizontal and vertical; full; optimized full	(4) Vertical integration; horizontal integration; digital product development; cross-sectional technology criteria
The Digital Maturity Model 4.0	[87]	2016	MM	To help organizations assess their overall digital readiness.	(4) Skeptics; adopters; collaborators; differentiators	(3) Culture; technology; organization; insights
Three Stage Maturity Model in SMEs towards Industry 4.0	[88]	2016	MM	To guide and train organizations to identify new opportunities for diversification within I4.0.	(5) Initial; managed; defined; transformed; detailed BM	(3) Envision 4.0 vision; enable 4.0 roadmap; enact 4.0 projects
DREAMY—Digital Readiness Assessment Maturity Model	[89]	2017	MM	To assess the process that manufacturing industries have achieved regarding digital transformation.	(6) Initial; managed; defined; integrated and interoperable; digital-oriented	(4) Process; monitoring and control; technology; organization
Industry 4.0 Maturity Index—acatech	[90]	2017 (updated 2020)	MM	To help manufacturing organizations to identify their maturity level and the existing gaps between the current and the desired status and to advance in every stipulated stage of transformation.	(6) Computerization; connectivity; visibility; transparency; predictive capacity; adaptability	(5) Resources; information systems; organizational structure; culture

Table A1. *Cont.*

Model Name	Reference	Year	Model Type [1]	Objective	Levels/Stages	Dimensions/ Drivers
M2DDM—Maturity Model for Data-Driven Manufacturing	[91]	2017	MM	To evaluate the maturity of a manufacturing enterprise.	(6) Nonexistent IT integration; data and system integration; integration of cross-life cycle data; service-orientation; digital twin; self-optimizing factory	(6) Data storage and computer systems; service-oriented architecture; information integration; digital twin; advanced analytics; real-time capabilities
SPICE—Industry 4.0 Maturity Model—Software Process Improvement and Capability Determination	[92]	2017	MM	To specify process improvement and capability determination of multinational enterprises regarding software application.	(6) Incomplete; performed; managed; established; predictable; optimizing	(5) Asset management; data governance; application management; process transformation; organizational alignment
WMG Model—Industry 4.0 Readiness Assessment Tool	[93]	2017	AM	To measure company readiness.	(4) Beginner; intermediate; experienced; expert	(6) Products and services; manufacturing and operations; strategy and organization; supply chain; business model; legal considerations
A Maturity Model for Business Model Management in Industry 4.0	[94]	2018	MM	To assess an organization's current maturity level and propose steps to advance towards a business model and process mastery.	(5) Implicit; defined; validated/standardized/analyzed/optimized	(9) Customer segment; value proposition; channels; customer relationship; source of income; key resources; key activities; key partners; cost structure
A Preliminary Maturity Model for Leveraging Digitalization in Manufacturing	[95]	2018	MM	To identify an organizations' maturity level regarding smart factory implementation.	(4) Connected technologies; structured data gathering and sharing; real-time process analytics and optimization; smart, predictable manufacturing.	(3) People; process; technology
A Smart Manufacturing Maturity Model for SMEs (SM3E)	[96]	2018	MM	To support SMEs during digital transformation.	(5) Novice; beginner; learner; intermediate; expert	(5) Finance; people; strategy; process; product
DPMM 4.0—Industry 4.0 Maturity Model for the Delivery Process in Supply Chains	[97]	2018	MM	To provide guidance to organizations for the digitization of the delivery process in supply chain management in regard to I4.0 adoption.	(5) Basic digitization; cross-departmental digitization; horizontal and vertical digitization; full digitization; optimized full digitization.	(3) Order processing; warehousing; shipping
Maturity and Readiness Model for Industry 4.0 Strategy	[98]	2018	MM	To determine the maturity level of an organization to help it understand its current state regarding I4.0.	(4) Absence; existence; survival; maturity	(3) Smart products and services; smart business processes; smart strategy and organization
Towards a Maturity Model for Industry 4.0: A Systematic Literature Review and a Model Proposal	[99]	2018	MM	To assist organizations in their transitions to the utilization of I4.0 technologies/practices and to guide them in improving their capabilities in a standardized, objective, and repeatable way.	(6) Incomplete; performed; managed; established; predictable; optimizing.	(5) Asset management; data governance; application management; process transformation; organizational alignment

Table A1. *Cont.*

Model Name	Reference	Year	Model Type [1]	Objective	Levels/Stages	Dimensions/ Drivers
A Maturity Assessment Approach for Conceiving Context-Specific Roadmaps in the Industry 4.0 Era	[61]	2019	AM	To help organizations in their digital transformation, according to specific contextual factors.	(6) None; basic; transparent; aware; autonomous; integrated	(5) Governance; technology; connectivity; value creation; competencies
A Model for Assessing Maturity of Industry 4.0 in the Banking Sector	[100]	2019	AM	To assess an organization's I4.0 maturity, focusing on the banking sector.	(5) Initial; managed; defined; established; digital oriented	(7) Products and services; technology and resources; strategy and organization; operations; customers; governance; employees
Design of an Assessment Industry 4.0 Maturity Model: An Application for Manufacturing Companies	[101]	2019	MM	To help organizations measure their I4.0 maturity and readiness and visualize their current position.	Weighted average level based on specific features maturity items for each dimension	(6) Products and services; manufacturing; business model; strategy; supply chain; interoperability
IMA—Infrastructure Maturity Assessment	[102]	2019	AM	To assess the maturity of organizations, focusing on infrastructure.	(8) Administrative; tactical; fixed; mobile; externalized; integrated; contextualized; orchestrated	(5) Transport; collaboration; security; mobility; data center
Road Mapping towards Industrial Digitalization based on an Industry 4.0 Maturity Model for Manufacturing Enterprises	[103]	2019	MM	To evaluate manufacturing industries' I4.0 maturity.	Not identified	(6) Technology; products; customers and partners; value creation processes; data and information—corporate standards; employee strategy and leadership
SIRI—Smart Industry Readiness Index	[104]	2019	RM	To provide industries the required knowledge about I4.0 benefits, maturity levels, and the initiation of the adoption process and the improvement of state-of-the-art status	(5) The names of the levels vary for each of the dimensions.	(8) Process: operation; supply chain; product lifecycle; automation. Technology: connectivity; intelligence. Organization: talent readiness; structure and management
An Industry 4.0 Maturity Model	[105]	2020	MM	To guide a self-administered assessment of I4.0.	(6) Low or no degree of implementation; pilot actions being planned; implementation of actions initiated; partial implementation of actions; advanced implementation of actions; reference in applying I4.0	(6) Organizational strategy; structure and culture; workforce; smart factories; smart processes; smart products and services

Table A1. *Cont.*

Model Name	Reference	Year	Model Type [1]	Objective	Levels/Stages	Dimensions/ Drivers
An Industry 4.0 Maturity Model for Machine Tool Companies	[106]	2020	MM	To evaluate maturity of I4.0 for machine tool companies.	(6) Outsider; beginner; intermediate; experienced; expert; top performers	(5) Strategy and organization; smart factory; smart operations; smart products; data-driven services; employees
Developing an Industry 4.0 Readiness Model for Indian Engineering Industries	[63]	2020	RM	To evaluate I4.0 readiness of Indian organizations.	None identified	(6) Organizational strategy readiness of Indian engineering industry for Industry 4.0; digitization level of Indian engineering industries; digitization level of the supply chain of Indian engineering industries; level of smart products in Indian engineering industries; "employee adaptability" regarding industry 4.0 skills in Indian engineering industries; top management support and leadership for Industry 4.0 in Indian engineering industry
I4.0CMM—Industry 4.0 Competency Maturity Model	[64]	2020	MM	To assess I4.0 employees' maturity competency in regard to skills and knowledge requirements in industrial engineering.	(5) First Industrial Revolution; Second Industrial Revolution; Third Industrial Revolution; Fourth Industrial Revolution; future requirements	(2) Skills (soft and technical); knowledge
Manager Competency Assessment Model under Industry 4.0 Conditions	[62]	2020	AM	To assess the competencies of input managers and obtain a final assessment as a parameter for achieving strategic goals.	(3) Low level; middle level; high level	(4) Experience and term of work; education, cognitive, and creative potential; effective goal setting and development; communicative, leadership function, and managerial orthobiosis.
A Maturity Model to Assess Digital Employee Competencies in Industrial Enterprises	[65]	2021	MM	To measure maturity on an individual digital employee level.	(4) From a lack of the focused digital competence to a state of complete development compared to the current state-of-the-art	(4) Digital content; human–machine; human–human; personal
Development of Maturity Model for Assessing the Implementation of Industry 4.0: Learning from Theory and Practice	[46]	2021	MM	To assess the maturity level of manufacturing organizations.	(4) Outsider; digital novice; experienced; expert	(7) People and culture; industry 4.0 awareness; organizational strategy; value chain and processes; smart manufacturing technology; product and services oriented technology; industry 4.0-based technology

Table A1. *Cont.*

Model Name	Reference	Year	Model Type [1]	Objective	Levels/Stages	Dimensions/ Drivers
Industry 4.0 Maturity Model Assessing Environmental Attributes of Manufacturing Companies	[107]	2021	MM	To evaluate an organization's maturity regarding I4.0, based on environmental aspects.	(6) No implementations in production processes; very limited implementations in production processes; partial implementation in production processes; significant implementation in production processes; nearly complete implementation in production processes; complete implementation in production processes	(4) Production; logistics; maintenance; IT
Digital Transformation Capability Maturity Model	[108]	2022	CM	To develop a holistic maturity model in the digital transformation domain.	(6) Incomplete; performed; managed; established; predictable; innovative	(4) Strategic governance; information and technology; digital process transformation; workforce management
Digital Transformation Maturity Model Development framework based on Design Science	[109]	2022	MM	To evaluate I4.0 adoption level in organizations.	(5) Awareness; pilot; engagement; supply chain integration; optimization	(6) Strategy and governance; organization and corporate culture; smartness; employee; processes; customer
Frameworks of the Maturity Model for Industry 4.0 with Assessment of Maturity Levels using the Example of the Steel Enterprises Segment in Poland	[110]	2022	MM	To assess the maturity degree of steel industries in Poland, in regard to smart production and smart factories,	(5) Smart maturity on startup; smart maturity in building; smart maturity in growth; smart maturity in results; full smart maturity	(3) IT systems and internet; building smarter operations and processes; developing smarter operations and processes
Industry 4.0 Readiness Model	[111]	2022	RM	To measure the readiness level of manufacturing companies with respect to transitioning to I4.0.	(5) Not prepared; primary level; intermediate level; progressive level; prepared	(4) Cyber physical systems; additive manufacturing; Internet of things; industrial/autonomous robots
The SANOL Industry 4.0 Maturity Model	[112]	2022	MM	To assess I4.0 maturity in different sectors.	(6) Uninitiated; initiated; intermediate; advanced; very advanced; mature	(6) Strategy and management; customers and suppliers; employees and corporate culture (sense of belonging); technology (products); data and security; support and incentives

[1] MM: maturity model; RM: readiness model; AM: assessment model; CM: capability model; and GM: general model. No diagnostic model was found.

Appendix B

Table A2 details the maturity levels and dimensions (classified into four main competencies) of the ECDMM4.0.

Table A2. MLs and dimensions of the ECDMM4.0.

Competencies	ML1. Beginner	ML2. Managed	ML3. Proactive	ML4. Expert	ML5. Leader
Personal Competencies [33,64,68,70,113]	- Ability to learn concepts and applications - Curiosity when learning - Willingness to change from a managerial perspective	- Attention to detail - Cognitive flexibility	- Flexibility - Quick adaptability - Ability to learn I4.0 implementation - Attention to detail - Self-organization - Curiosity when adopting I4.0 - Motivation - Trust in new technologies - Willingness to change from workers' perspective	- Agile adaptability to a quickly changing environment - Emotional intelligence/ self-control - Interdisciplinary know-how - Intuition - Open minded thinking - Self-confidence	- Self-adaptability/ decentralization of job positions - Emotional intelligence/self-control - Self-awareness - Empathy - Ability to learn autonomously and proactively - Creativity/ innovation - Entrepreneurship - Future thinking - Initiative/ courageous action - Leadership - Responsibility
Socio-Communicative Competencies [64,68,113]	- Collaboration/ cooperation between managers - Accuracy - Verbal aptitude (vocabulary and reading)	- Collaboration/ cooperation between managers - Verbal aptitude (vocabulary, reading, and spelling)	- Accurate communication/language - Collaboration/ cooperation between internal team	- Effective communication/language - Collaboration/ cooperation between multidisciplinary teams - Mastery of I4.0 jargon - Negotiation/ commerciality - Usage of digital media	- Influencing communication/language - Networking - Collaboration/ cooperation between multidisciplinary and multicultural teams
Problem-Solving Competencies [64,68,113]	- Manually collecting and preparing data for analysis - Basic mathematical and statistical knowledge - Basic numeric and statistical analysis using spreadsheets - Operating steam engines and mechanical machines	- Recording and processing data using tabulating machines - Intermediate mathematical and statistical knowledge - Intermediate numeric and statistical analysis with usage of spreadsheets - Ability to control systems and machine display interfaces - Design thinking	- Ability to interact with machines - Advanced mathematical and statistical knowledge - Advanced numeric and statistical analysis with strong usage of spreadsheets - Analytical minded - Digital/technical capability to interact with "smart" devices - Problem-solving - Process understanding - Programming/ coding (SQL knowledge) - Retrieving, handling, and querying data using programming software - Ability to implement robotics, automation, and control systems - Human–machine interaction - Understanding IT/data/cybersecurity	- Ability to collaborate with machines - Ability to access digital and "smart" devices to visualize data and detect anomalies in real time - Agile problem detection/identification - Complex problem-solving - Big data analysis/analytical thinking - Critical/ systemic thinking - Data optimization - Data validation from different sources - Data trend identification - Data cleaning - Actionable insight detection from data - Ability to implement enabling technologies such as IoT, CPS, AR, VR, and smart manufacturing, among others - Human–machine interaction - Decision-making/judgment supported by enabling technologies - Programming/ coding (R, Python, among others)	- Ability to access data from multiple sources in real time - Implementation of algorithms and statistical programs to analyze real-time data - Complex handling, analysis, and interpretation of digital data - Big data analysis for decision making and problem solving in real-time, supported by programming software and data analytics technologies - Ability to implement, interact, and collaborate with enabling technologies such as IoT, CPS, AR, VR, smart manufacturing, autonomous robots, and artificial intelligence, among others - Human–machine interaction - External market focus - Identify trends in data and predict problems, supported by enabling technologies - Digital security

Table A2. *Cont.*

Competencies	ML1. Beginner	ML2. Managed	ML3. Proactive	ML4. Expert	ML5. Leader
Activity-related Competencies [64,68,113]	- Physical ability - Individual attitude - Interest in change	- Coordination between managers and leaders - Multi-skilled - Persistent minded	- Coordination between multidisciplinary teams - Manage complexity/change - Participatory/ proactive role	- Coordination between departments - Teamwork	- Coordination between all departments across the organization's value chain - People/client management - Service orientation/social service - Sustainable mindset - Willingness to share knowledge

References

1. Khin, S.; Kee, D.M.H. Factors Influencing Industry 4.0 Adoption. *J. Manuf. Technol. Manag.* **2022**, *33*, 448–467. [CrossRef]
2. Ma, D. Comprehensive Decision Analysis of Industry 4.0 Virtual Enterprises Considering the Personalized Customization Model of Product Life Cycle. *J. Sens.* **2022**, *2022*, 1175565. [CrossRef]
3. Kumar, P.; Bhamu, J.; Sangwan, K.S. Analysis of Barriers to Industry 4.0 Adoption in Manufacturing Organizations: An ISM Approach. *Procedia CIRP* **2021**, *98*, 85–90. [CrossRef]
4. Satyro, W.C.; de Almeida, C.M.V.B.; Pinto, M.J.A., Jr.; Contador, J.C.; Giannetti, B.F.; de Lima, A.F.; Fragomeni, M.A. Industry 4.0 Implementation: The Relevance of Sustainability and the Potential Social Impact in a Developing Country. *J. Clean. Prod.* **2022**, *337*, 130456. [CrossRef]
5. Kadir, B.A.; Broberg, O. Human Well-Being and System Performance in the Transition to Industry 4.0. *Int. J. Ind. Ergon.* **2020**, *76*, 102936. [CrossRef]
6. Leesakul, N.; Oostveen, A.M.; Eimontaite, I.; Wilson, M.L.; Hyde, R. Workplace 4.0: Exploring the Implications of Technology Adoption in Digital Manufacturing on a Sustainable Workforce. *Sustainability* **2022**, *14*, 3311. [CrossRef]
7. Gazzaneo, L.; Padovano, A.; Umbrello, S. Designing Smart Operator 4.0 for Human Values: A Value Sensitive Design Approach. *Procedia Manuf.* **2020**, *42*, 219–226. [CrossRef]
8. Fareri, S.; Fantoni, G.; Chiarello, F.; Coli, E.; Binda, A. Estimating Industry 4.0 Impact on Job Profiles and Skills Using Text Mining. *Comput. Ind.* **2020**, *118*, 103222. [CrossRef]
9. James, A.T.; Kumar, G.; Tayal, P.; Chauhan, A.; Wadhawa, C.; Panchal, J. Analysis of Human Resource Management Challenges in Implementation of Industry 4.0 in Indian Automobile Industry. *Technol. Forecast. Soc. Chang.* **2022**, *176*, 121483. [CrossRef]
10. Dregger, J.; Niehaus, J.; Ittermann, P.; Hirsch-Kreinsen, H.; ten Hompel, M. Challenges for the Future of Industrial Labor in Manufacturing and Logistics Using the Example of Order Picking Systems. *Procedia CIRP* **2018**, *67*, 140–143. [CrossRef]
11. Horváth, D.; Szabó, R.Z. Driving Forces and Barriers of Industry 4.0: Do Multinational and Small and Medium-Sized Companies Have Equal Opportunities? *Technol. Forecast. Soc. Chang.* **2019**, *146*, 119–132. [CrossRef]
12. Macke, J.; Casagrande, R.M.; Sarate, J.A.R.; Silva, K.A. Smart City and Quality of Life: Citizens' Perception in a Brazilian Case Study. *J. Clean. Prod.* **2018**, *182*, 717–726. [CrossRef]
13. Liao, Y.; Deschamps, F.; Loures, E.D.F.R.; Ramos, L.F.P. Past, Present and Future of Industry 4.0—A Systematic Literature Review and Research Agenda Proposal. *Int. J. Prod. Res.* **2017**, *55*, 3609–3629. [CrossRef]
14. Guy, F. The Global Environment of Business. *J. Econ.* **2009**, *101*, 197–198.
15. Hu, S.J. Evolving Paradigms of Manufacturing: From Mass Production to Mass Customization and Personalization. *Procedia CIRP* **2013**, *7*, 3–8. [CrossRef]
16. Lukač, D. The Fourth ICT-Based Industrial Revolution "Industry 4.0"—HMI and the Case of CAE/CAD Innovation with EPLAN P8. In Proceedings of the 2015 23rd Telecommunications Forum, TELFOR 2015, Belgrade, Serbia, 24–26 November 2015; pp. 835–838.
17. Tay, S.I.; Lee, T.C.; Hamid, N.A.A.; Ahmad, A.N.A. An Overview of Industry 4.0: Definition, Components, and Government Initiatives. *J. Adv. Res. Dyn. Control. Syst.* **2018**, *10*, 1379–1387.
18. Fernandez-Anez, V.; Fernández-Güell, J.M.; Giffinger, R. Smart City Implementation and Discourses: An Integrated Conceptual Model. The Case of Vienna. *Cities* **2018**, *78*, 4–16. [CrossRef]
19. Fantini, P.; Pinzone, M.; Taisch, M. Placing the Operator at the Centre of Industry 4.0 Design: Modelling and Assessing Human Activities within Cyber-Physical Systems. *Comput. Ind. Eng.* **2020**, *139*, 105058. [CrossRef]
20. Kurt, R. Industry 4.0 in Terms of Industrial Relations and Its Impacts on Labour Life. *Procedia Comput. Sci.* **2019**, *158*, 590–601. [CrossRef]
21. Ebrahimi, M.; Baboli, A.; Rother, E. A Roadmap for Evolution of Existing Production System toward the Factory of the Future: A Case Study in Automotive Industry. In Proceedings of the 2018 IEEE International Conference on Technology Management, Operations and Decisions (ICTMOD), Marrakech, Morocco, 21–23 November 2018; pp. 274–281.

22. Segura, Á.; Diez, H.V.; Barandiaran, I.; Arbelaiz, A.; Álvarez, H.; Simões, B.; Posada, J.; García-Alonso, A.; Ugarte, R. Visual Computing Technologies to Support the Operator 4.0. *Comput. Ind. Eng.* **2020**, *139*, 105550. [CrossRef]
23. Ustundag, A.; Cevikcan, E. *Industry 4.0: Managing the Digital Transformation*; Springer Series in Advanced Manufacturing; Springer: Cham, Switzerland, 2018; ISBN 978-3-319-57869-9.
24. Büchi, G.; Cugno, M.; Castagnoli, R. Smart Factory Performance and Industry 4.0. *Technol. Forecast. Soc. Chang.* **2020**, *150*, 119790. [CrossRef]
25. Peruzzini, M.; Grandi, F.; Pellicciari, M. Exploring the Potential of Operator 4.0 Interface and Monitoring. *Comput. Ind. Eng.* **2020**, *139*, 105600. [CrossRef]
26. Osterrieder, P.; Budde, L.; Friedli, T. The Smart Factory as a Key Construct of Industry 4.0: A Systematic Literature Review. *Int. J. Prod. Econ.* **2020**, *221*, 107476. [CrossRef]
27. Rauch, E.; Linder, C.; Dallasega, P. Anthropocentric Perspective of Production before and within Industry 4.0. *Comput. Ind. Eng.* **2020**, *139*, 105644. [CrossRef]
28. Romero, D.; Stahre, J.; Wuest, T.; Noran, O.; Bernus, P.; Fast-Berglund, Å.; Gorecky, D. Towards an Operator 4.0 Typology: A Human-Centric Perspective on the Fourth Industrial Revolution Technologies Digital Learning Platform for the Smart Digital Factory, E-DIG View Project towards an Operator 4.0 Typology: A Human-Centric Perspective on the Fourth Industrial Revolution Technologies. In Proceedings of the International Conference on Computers and Industrial Engineering (CIE46), Tianjin, China, 29–31 October 2016; pp. 29–31.
29. Romero, D.; Stahre, J.; Taisch, M. The Operator 4.0: Towards Socially Sustainable Factories of the Future. *Comput. Ind. Eng.* **2020**, *139*, 106128. [CrossRef]
30. Mazali, T. From Industry 4.0 to Society 4.0, There and Back. *AI Soc.* **2018**, *33*, 405–411. [CrossRef]
31. Ruppert, T.; Jaskó, S.; Holczinger, T.; Abonyi, J. Enabling Technologies for Operator 4.0: A Survey. *Appl. Sci.* **2018**, *8*, 1650. [CrossRef]
32. Grenčíková, A.; Kordoš, M.; Sokol, J. The Approach to Industry 4.0 within the Slovak Business Environment. *Soc. Sci.* **2019**, *8*, 104. [CrossRef]
33. Mazurchenko, A.; Maršíková, K. Digitally-Powered Human Resource Management: Skills and Roles in the Digital Era. *Acta Inform. Pragensia* **2019**, *8*, 72–86. [CrossRef]
34. Bosman, L.; Hartman, N.; Sutherland, J. How Manufacturing Firm Characteristics Can Influence Decision Making for Investing in Industry 4.0 Technologies. *J. Manuf. Technol. Manag.* **2020**, *31*, 1117–1141. [CrossRef]
35. Cimini, C.; Boffelli, A.; Lagorio, A.; Kalchschmidt, M.; Pinto, R. How Do Industry 4.0 Technologies Influence Organisational Change? An Empirical Analysis of Italian SMEs. *J. Manuf. Technol. Manag.* **2020**, *32*, 695–721. [CrossRef]
36. Müller, J.M.; Kiel, D.; Voigt, K.I. What Drives the Implementation of Industry 4.0? The Role of Opportunities and Challenges in the Context of Sustainability. *Sustainability* **2018**, *10*, 247. [CrossRef]
37. Kowal, B.; Włodarz, D.; Brzychczy, E.; Klepka, A. Analysis of Employees' Competencies in the Context of Industry 4.0. *Energies* **2022**, *15*, 7142. [CrossRef]
38. Sima, V.; Gheorghe, I.G.; Subić, J.; Nancu, D. Influences of the Industry 4.0 Revolution on the Human Capital Development and Consumer Behavior: A Systematic Review. *Sustainability* **2020**, *12*, 4035. [CrossRef]
39. Kaur, R.; Awasthi, A.; Grzybowska, K. Evaluation of Key Skills Supporting Industry 4.0—A Review of Literature and Practice. In *Sustainable Logistics and Production in Industry 4.0. EcoProduction*; Springer: Cham, Switzerland, 2020; pp. 19–29.
40. Schallock, B.; Rybski, C.; Jochem, R.; Kohl, H. Learning Factory for Industry 4.0 to Provide Future Skills beyond Technical Training. *Procedia Manuf.* **2018**, *23*, 27–32. [CrossRef]
41. Mohelska, H.; Sokolova, M. Management Approaches for Industry 4.0—The Organizational Culture Perspective. *Technol. Econ. Dev. Econ.* **2018**, *24*, 2225–2240. [CrossRef]
42. Sivathanu, B.; Pillai, R. Smart HR 4.0—How Industry 4.0 Is Disrupting HR. *Hum. Resour. Manag. Int. Dig.* **2018**, *26*, 7–11. [CrossRef]
43. Liboni, L.B.; Cezarino, L.O.; Jabbour, C.J.C.; Oliveira, B.G.; Stefanelli, N.O. Smart Industry and the Pathways to HRM 4.0: Implications for SCM. *Supply Chain Manag.* **2019**, *24*, 124–146. [CrossRef]
44. Helming, S.; Ungermann, F.; Hierath, N.; Stricker, N.; Lanza, G. Development of a Training Concept for Leadership 4.0 in Production Environments. *Procedia Manuf.* **2019**, *31*, 38–44. [CrossRef]
45. Dornelles, J.D.A.; Ayala, N.F.; Frank, A.G. Smart Working in Industry 4.0: How Digital Technologies Enhance Manufacturing Workers' Activities. *Comput. Ind. Eng.* **2022**, *163*, 107804. [CrossRef]
46. Wagire, A.A.; Joshi, R.; Rathore, A.P.S.; Jain, R. Development of Maturity Model for Assessing the Implementation of Industry 4.0: Learning from Theory and Practice. *Prod. Plan. Control* **2021**, *32*, 603–622. [CrossRef]
47. Schumacher, A.; Erol, S.; Sihn, W. A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. *Procedia CIRP* **2016**, *52*, 161–166. [CrossRef]
48. Becker, J.; Knackstedt, R.; Pöppelbuß, J. Developing Maturity Models for IT Management. *Bus. Inf. Syst. Eng.* **2009**, *1*, 213–222. [CrossRef]
49. Hevner, A.R.; March, S.T.; Park, J.; Ram, S. Design Science in Information Systems Research. *MIS Q.* **2004**, *18*, 75–105. [CrossRef]
50. Pranckutė, R. Web of Science (Wos) and Scopus: The Titans of Bibliographic Information in Today's Academic World. *Publications* **2021**, *9*, 12. [CrossRef]

51. Dalkey, N.; Helmer, O. An Experimental Application of the Delphi Method to the Use of Experts. *Manag. Sci.* **1963**, *9*, 458–467. [CrossRef]
52. Linstone, H.A.; Turoff, M.; Helmer, O. *The Delphi Method Techniques and Applications*; Addison-Wesley: Boston, MA, USA, 2002.
53. Moeuf, A.; Lamouri, S.; Pellerin, R.; Tamayo-Giraldo, S.; Tobon-Valencia, E.; Eburdy, R. Identification of Critical Success Factors, Risks and Opportunities of Industry 4.0 in SMEs. *Int. J. Prod. Res.* **2020**, *58*, 1384–1400. [CrossRef]
54. Rowe, G.; Wright, G.; Bolger, F.M.I. The Delphi Technique: A Re-Evaluation of Research and Theory. *Technol. Forecast. Soc. Chang.* **1991**, *39*, 235–251. [CrossRef]
55. Skulmoski, G.J.; Hartman, F.T.; Krahn, J. The Delphi Method for Graduate Research. *J. Inf. Technol. Educ.* **2007**, *6*, 1–21. [CrossRef]
56. Wendler, R. The Maturity of Maturity Model Research: A Systematic Mapping Study. *Inf. Softw. Technol.* **2012**, *54*, 1317–1339. [CrossRef]
57. Felch, V.; Asdecker, B.; Sucky, E. Maturity Models in the Age of Industry 4.0–Do the Available Models Correspond to the Needs of Business Practice? In Proceedings of the 52nd Hawaii International Conference on System Sciences, HICSS, Grand Wailea, HI, USA, 8–11 January 2019; pp. 5165–5174.
58. Bibby, L.; Dehe, B. Defining and Assessing Industry 4.0 Maturity Levels–Case of the Defence Sector. *Prod. Plan. Control* **2018**, *29*, 1030–1043. [CrossRef]
59. Janićijević, N. Business Processes in Organizational Diagnosis. *Manag. J. Contemp. Manag. Issues* **2010**, *15*, 85–106.
60. CMMI Product Team. *CMMI® for Development, Version 1.3, Improving Processes for Developing Better Products and Services*; Software Engineering Institute: Pittsburgh, PA, USA, 2010; pp. 433–454.
61. Colli, M.; Berger, U.; Bockholt, M.; Madsen, O.; Møller, C.; Wæhrens, B.V. A Maturity Assessment Approach for Conceiving Context-Specific Roadmaps in the Industry 4.0 Era. *Annu. Rev. Control* **2019**, *48*, 165–177. [CrossRef]
62. Dzwigol, H.; Dzwigol-Barosz, M.; Miskiewicz, R.; Kwilinski, A. Manager Competency Assessment Model in the Conditions of Industry 4.0. *Entrep. Sustain. Issues* **2020**, *7*, 2630–2644. [CrossRef]
63. Sony, M.; Aithal, S. Developing an Industry 4.0 Readiness Model for Indian Engineering Industries. *J. Manag. Technol. Soc. Sci.* **2020**, *5*, 141–153. [CrossRef]
64. Maisiri, W.; van Dyk, L. Industry 4.0 Competence Maturity Model Design Requirements: A Systematic Mapping Review. In Proceedings of the 2020 IFEES World Engineering Education Forum—Global Engineering Deans Council, WEEF-GEDC 2020, Cape Town, South Africa, 16–19 November 2020; pp. 1–6.
65. Steinlechner, M.; Schumacher, A.; Fuchs, B.; Reichsthaler, L.; Schlund, S. A Maturity Model to Assess Digital Employee Competencies in Industrial Enterprises. *Procedia CIRP* **2021**, *104*, 1185–1190. [CrossRef]
66. Kipper, L.M.; Iepsen, S.; Dal Forno, A.J.; Frozza, R.; Furstenau, L.; Agnes, J.; Cossul, D. Scientific Mapping to Identify Competencies Required by Industry 4.0. *Technol. Soc.* **2021**, *64*, 101454. [CrossRef]
67. Hernandez-de-Menendez, M.; Morales-Menendez, R.; Escobar, C.A.; McGovern, M. Competencies for Industry 4.0. *Int. J. Interact. Des. Manuf.* **2020**, *14*, 1511–1524. [CrossRef]
68. Hecklau, F.; Orth, R.; Kidschun, F.; Kohl, H. Human Resources Management: Meta-Study-Analysis of Future Competences in Industry 4.0. In Proceedings of the European Conference on Management, Leadership & Governance, London, UK, 11–12 November 2017; pp. 163–174.
69. Scharnhorst, A.; Ebeling, W. Evolutionary Search Agents in Complex Landscapes-a New Model for the Role of Competence and Meta-Competence (EVOLINO and Other Simulation Tools). *arXiv* **2005**, arXiv:physics/0511232.
70. Romero, D.; Gaiardelli, P.; Powell, D.; Wuest, T.; Thürer, M. Rethinking Jidoka Systems under Automation & Learning Perspectives in the Digital Lean Manufacturing World. *IFAC Pap.* **2019**, *52*, 899–903. [CrossRef]
71. Whysall, Z.; Owtram, M.; Brittain, S. The New Talent Management Challenges of Industry 4.0. *J. Manag. Dev.* **2019**, *38*, 118–129. [CrossRef]
72. Kagermann, H.; Anderl, R.; Gausemeier, J.; Schuh, G.; Wahlster, W. (Eds.) *Industrie 4.0 in a Global Context: Strategies for Cooperating with International Partners*; Herbert Utz Verlag: Munich, Germany, 2016.
73. Schuh, G.; Anderl, R.; Gausemeier, J.; Ten Hompel, M.; Wahlster, W. (Eds.) *Industrie 4.0 Maturity Index: Managing the Digital Transformation of Companies*; Herbert Utz Verlag: Munich, Germany, 2017.
74. Li, D.; Fast-Berglund, Å.; Paulin, D. Current and Future Industry 4.0 Capabilities for Information and Knowledge Sharing: Case of Two Swedish SMEs. *Int. J. Adv. Manuf. Technol.* **2019**, *105*, 3951–3963. [CrossRef]
75. Gallo, T.; Santolamazza, A. Industry 4.0 and Human Factor: How Is Technology Changing the Role of the Maintenance Operator? *Procedia Comput. Sci.* **2021**, *180*, 388–393. [CrossRef]
76. Joko, J.; Putra, A.A.P.; Isnawan, B.H. Implementation of IoT-Based Human Machine Interface-Learning Media and Problem-Based Learning to Increase Students' Abilities, Skills, and Innovative Behaviors of Industry 4.0 and Society 5.0. *TEM J.* **2023**, *12*, 200–207. [CrossRef]
77. Adami, P.; Rodrigues, P.B.; Woods, P.J.; Becerik-Gerber, B.; Soibelman, L.; Copur-Gencturk, Y.; Lucas, G. Effectiveness of VR-Based Training on Improving Construction Workers' Knowledge, Skills, and Safety Behavior in Robotic Teleoperation. *Adv. Eng. Inform.* **2021**, *50*, 101431. [CrossRef]
78. Demeter, K.; Losonci, D.; Nagy, J. Road to Digital Manufacturing—A Longitudinal Case-Based Analysis. *J. Manuf. Technol. Manag.* **2021**, *32*, 820–839. [CrossRef]

79. Ghobakhloo, M.; Fathi, M. Corporate Survival in Industry 4.0 Era: The Enabling Role of Lean-Digitized Manufacturing. *J. Manuf. Technol. Manag.* **2020**, *31*, 1–30. [CrossRef]
80. Garcia Reyes, H.; Giachetti, R. Using Experts to Develop a Supply Chain Maturity Model in Mexico. *Supply Chain Manag. Int. J.* **2010**, *15*, 415–424. [CrossRef]
81. Allen-Bradley; Rockwell Software. *The Connected Enterprise Maturity Model*; Rockwell Automation: Milwaukee, WI, USA, 2014; pp. 1–12.
82. Lichtblau, K.; Stich, V.; Bertenrath, R.; Blum, M.; Bleider, M.; Millack, A.; Schmitt, K.; Schmitz, E.; Schröter, M. *INDUSTRIE 4.0 READINESS*; Impuls-Stiftung: Frankfurt, Germany, 2015; pp. 1–78.
83. McKinsey & Company. *Industry 4.0: How to Navigate Digitization of the Manufacturing Sector*; McKinsey & Company: Detroit, MI, USA, 2015; pp. 1–62.
84. Valdez-De-Leon, O. A Digital Maturity Model for Telecommunications Service Providers. *Technol. Innov. Manag. Rev.* **2016**, *6*, 19–32. [CrossRef]
85. Geissbauer, R.; Vedso, J.; Schrauf, S. *2016 Global Industry 4.0 Survey What We Mean by Industry 4.0/Survey Key Findings/Blueprint for Digital Success*; PwC: London, UK, 2016; pp. 1–36.
86. Leyh, C.; Bley, K.; Schaffer, T.; Forstenhausler, S. SIMMI 4.0—A Maturity Model for Classifying the Enterprise-Wide It and Software Landscape Focusing on Industry 4.0. In Proceedings of the 2016 Federated Conference on Computer Science and Information Systems, FedCSIS 2016, Gdansk, Poland, 11–14 September 2016; pp. 1297–1302.
87. Gill, M.; Vanboskirk, S. *The Digital Maturity Model 4.0 Benchmarks: Digital Business Transformation Playbook*; Forrester: Cambridge, MA, USA, 2016; pp. 1–17.
88. Ganzarain, J.; Errasti, N. Three Stage Maturity Model in SME's towards Industry 4.0. *J. Ind. Eng. Manag.* **2016**, *9*, 1119–1128. [CrossRef]
89. De Carolis, A.; Macchi, M.; Negri, E.; Terzi, S. A Maturity Model for Assessing the Digital Readiness of Manufacturing Companies. In Proceedings of the IFIP Advances in Information and Communication Technology, Hamburg, Germany, 3–7 September 2017; Springer New York LLC.: New York, NY, USA, 2017; Volume 513, pp. 13–20.
90. Schuh, G.; Anderl, R.; Dumitrescu, R.; Krüger, A. *Industrie 4.0 Maturity Index*; Acatech STUDY: Berlin, Germany, 2020; pp. 1–64.
91. Weber, C.; Königsberger, J.; Kassner, L.; Mitschang, B. M2DDM—A Maturity Model for Data-Driven Manufacturing. *Procedia CIRP* **2017**, *63*, 173–178. [CrossRef]
92. Gökalp, E.; Şener, U.; Eren, P.E. Development of an Assessment Model for Industry 4.0: Industry 4.0-MM. In Proceedings of the Communications in Computer and Information Science, Palma de Mallorca, Spain, 4–5 October 2017; Springer: Berlin/Heidelberg, Germany, 2017; Volume 770, pp. 128–142.
93. Agca, O.; Gibson, J.; Godsell, J.; Ignatius, J.; Davies, C.W.; Xu, O. *An Industry 4 Readiness Assessment Tool*; University of Warwick: Coventry, UK, 2017; pp. 1–11.
94. Rübel, S.; Emrich, A.; Klein, S.; Loos, P. A Maturity Model for Business Model Management in Industry 4.0. In *Multikonferenz Wirtschaftsinformatik*; Institut für Wirtschaftsinformatik, Leuphana Universität Lüneburg: Lüneburg, Germany, 2018.
95. Sjödin, D.R.; Parida, V.; Leksell, M.; Petrovic, A. Smart Factory Implementation and Process Innovation: A Preliminary Maturity Model for Leveraging Digitalization in ManufacturingMoving to Smart Factories Presents Specific Challenges That Can Be Addressed through a Structured Approach Focused on People, Processes, and Technologies. *Res. Technol. Manag.* **2018**, *61*, 22–31. [CrossRef]
96. Mittal, S.; Romero, D.; Wuest, T. Towards a Smart Manufacturing Maturity Model for SMEs (SM3E). In Proceedings of the IFIP Advances in Information and Communication Technology, Seoul, Republic of Korea, 26–30 August 2018; Springer New York LLC.: New York, NY, USA, 2018; Volume 536, pp. 155–163.
97. Asdecker, B.; Felch, V. Development of an Industry 4.0 Maturity Model for the Delivery Process in Supply Chains. *J. Model. Manag.* **2018**, *13*, 840–883. [CrossRef]
98. Akdil, K.Y.; Ustundag, A.; Cevikcan, E. Maturity and Readiness Model for Industry 4.0 Strategy. In *Industry 4.0: Managing the Digital Transformation*; Springer Series in Advanced Manufacturing; Springer: Cham, Switzerland, 2018; pp. 61–94.
99. Sener, U.; Gökalp, E.; Şener, U.; Eren, P.E. Towards a Maturity Model for Industry 4.0: A Systematic Literature Review and a Model Proposal. *Industry* **2018**, *4*, 291–303.
100. Bandara, O.; Vidanagamachchi, K.; Wickramarachchi, R.; Lanka, S. A Model for Assessing Maturity of Industry 4.0 in the Banking Sector. In Proceedings of the International Conference on Industrial Engineering and Operations Management, Bangkok, Thailand, 5–7 March 2019; pp. 1141–1150.
101. Azevedo, A.; Santiago, S.B. Design of an Assessment Industry 4.0 Maturity Model: An Application to Manufacturing Company. In Proceedings of the International Conference on Industrial Engineering and Operations Management, Toronto, ON, Canada, 23–25 October 2019; pp. 208–217.
102. Williams, P.A.H.; Lovelock, B.; Cabarrus, T.; Harvey, M. Improving Digital Hospital Transformation: Development of an Outcomes-Based Infrastructure Maturity Assessment Framework. *JMIR Med. Inf.* **2019**, *7*, e12465. [CrossRef]
103. Schumacher, A.; Nemeth, T.; Sihn, W. Roadmapping towards Industrial Digitalization Based on an Industry 4.0 Maturity Model for Manufacturing Enterprises. *Procedia CIRP* **2019**, *79*, 409–414. [CrossRef]
104. Kiang, L.K.; Fen, F.P.; Tah, A.C.; Yinghui, X.; Ong, B.; Foo, C. *The Singapore Smart Industry Readiness Index: Catalysing the Transformation of Manufacturing*; Singapore Economic Development Board: Singapore, 2017; pp. 1–48.

105. Santos, R.C.; Martinho, J.L. An Industry 4.0 Maturity Model Proposal. *J. Manuf. Technol. Manag.* **2020**, *31*, 1023–1043. [CrossRef]
106. Lizarralde Dorronsoro, R.; Ganzarain Epelde, J.; López, C.; Serrano Lasa, I. An Industry 4.0 Maturity Model for Machine Tool Companies. *Technol. Forecast. Soc. Chang.* **2020**, *159*, 120203. [CrossRef]
107. Michal, Z.; Tomas, B.; Josef, B.; Michal, S. Industry 4.0 Maturity Model Assessing Environmental Attributes of Manufacturing Company. *Appl. Sci.* **2021**, *11*, 5151. [CrossRef]
108. Gökalp, E.; Martinez, V. Digital Transformation Maturity Assessment: Development of the Digital Transformation Capability Maturity Model. *Int. J. Prod. Res.* **2022**, *60*, 6282–6302. [CrossRef]
109. Kırmızı, M.; Kocaoglu, B. Digital Transformation Maturity Model Development Framework Based on Design Science: Case Studies in Manufacturing Industry. *J. Manuf. Technol. Manag.* **2022**, *33*, 1319–1346. [CrossRef]
110. Gajdzik, B. Frameworks of the Maturity Model for Industry 4.0 with Assessment of Maturity Levels on the Example of the Segment of Steel Enterprises in Poland. *J. Open Innov. Technol. Mark. Complex.* **2022**, *8*, 77. [CrossRef]
111. Dadash Pour, P.; Nazzal, M.A.; Darras, B.M. The Role of Industry 4.0 Technologies in Overcoming Pandemic Challenges for the Manufacturing Sector. *Concurr. Eng. Res. Appl.* **2022**, *30*, 190–205. [CrossRef]
112. Ünal, C.; Sungur, C.; Yildirim, H. Application of the Maturity Model in Industrial Corporations. *Sustainability* **2022**, *14*, 9478. [CrossRef]
113. Flores, E.; Xu, X.; Lu, Y. Human Capital 4.0: A Workforce Competence Typology for Industry 4.0. *J. Manuf. Technol. Manag.* **2020**, *31*, 687–703. [CrossRef]