A Systematic Review of Industry 4.0 Maturity Models for Assessing Industries Readiness

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***Abstract*—With the advent of the fourth industrial revolution, popularly known as Industry 4.0, the overall transformation of the manufacturing industry with digital integration and intelligent engineering has taken a giant leap forward in the direction of futuristic technology. However, the maturity models used to assess organisations' readiness to implement Industry 4.0 technologies are ambiguous because enterprises' aims, size, and scalability vary. This paper aims to examine the prevalence and trend of studies evaluating the maturity models to assess the enterprises' readiness in Industry 4.0. Furthermore, the purpose of this article is to identify research gaps in the existing body of knowledge and outline potential new directions for investigation. A systematic review of the literature was done to discover articles that propose or evaluate maturity models for determining the enterprise's readiness to embrace the fourth industrial revolution. The retrieved papers were then processed using a combination of descriptive and content analysis approaches to generate new conclusions, identify gaps in the literature, and identify novel research avenues. The findings revealed that the number of publications has expanded dramatically during the last three years, and the highest number of articles are published in 2021. Nonetheless, there is still potential for research in this area because existing research lacks conventional assessment frameworks, particularly for small and medium-sized firms in emerging nations.**

***Index Terms*—Industry 4.0, maturity models, Bibliometric Analysis, systematic review, SLR**

ICSSR-funded research project.[1]

I. INTRODUCTION

The fourth industrial revolution, or Industry 4.0, is one of the most researched topics in both industrial and academic spheres (Chiarello et al., 2018; Liao et al., 2017). Following industrialization (Industry 1.0), assembly lines (Industry 2.0), and digitalization (Industry 3.0), "Industry 4.0" is the next phase of automation and information sharing in manufacturing processes (Kagermann et al., 2013 and Matt, D. T et al. 2020). However, this new industrial stage is plagued by a technology architecture of production systems that is exceptionally complex (Lee et al., 2015). Systems integration, augmented reality, additive manufacturing, cyber-security, cloud computing, autonomous systems, simulation, the Internet of things, and big data are the nine pillars that support Industry 4.0's advancements. Implementing the technologies mentioned above enables companies to undergo a dramatic transformation into Cyber-Physical Systems (CPS). To stay alive in today's competitive market, organizations must constantly modify their operations to meet the ever-changing needs of their customers. Therefore, firms need the right tools and tactics to cope with and benefit from these new and sometimes disruptive technologies.

A maturity model is a conceptual structure made up of components that define the maturity or development state of a particular topic of study. Several of them depict and outline the processes that an organization should implement to achieve a desired future state. To identify competencies in specific focus areas, maturity

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models reflect characteristics of reality that can be utilized for internal analysis, competition research, and comparisons with industry standards. Dimensions and levels are often taken into account in these models (Donovan et al., 2016). By examining present conditions, these maturity models can be used to identify areas for improvement. Digital capabilities in manufacturing have increased significantly as a result of Industry 4.0, which has a ripple effect throughout a business. A thorough planning and implementation process is expected to take several years, with gradual stages, so that the benefits of efficiency gains can be reaped over time. Each business must determine which stage of growth best balances the costs and advantages of the change, given the specific conditions of the business, and with an eye toward a desirable future state at the conclusion of the transformation process (Schuh et al., 2017)

This research aims to conduct a systematic literature review on the various maturity assessment models in the domain of Industry 4.0. As a result, research gaps and future directions are discovered in research trends, publication outlets, and country-wise scientific production. To do this, a thorough examination of the most widely used Industry 4.0 maturity models was performed. Given this, the literature review's primary research objectives are:

1. To Investigate publication patterns in Industry 4.0 maturity model studies relating to time, journals, and geographically afflicted countries.
2. To comprehend the critical research areas and pivotal studies in Industry 4.0 industry maturity assessment model studies?
3. To look into the areas and gaps that future researchers should look into in Industry 4.0 maturity model studies.
4. To investigate the findings of previous research on Industry 4.0 enterprise maturity models.

The study's uniqueness comes in its examination of multiple Industry 4.0 maturity evaluation methodologies and their objectives. It's important to know what areas of research are still unexplored.

II. RESEARCH METHODOLOGY

A Systematic Review of the peer-reviewed literature was done to locate studies that examined the numerous Industry 4.0 maturity assessment models presented throughout the years and their dimensions, objectives and implementation. The systematic literature review (SLR) method handles scientific research papers with precision, transparency, and explicitness in an analysis. This method's systematic, explicit, and reproducible strategy (Tranfield et al., 2003) ensures rigor and understandability in the literature review process (Fink, 2005). The following steps, according to Popay et al., should be followed when doing a systematic literature review: (1) determining what studies will be reviewed, researched, and mapped (Scope formulation); (2) defining the research question; (3) selecting the studies to be reviewed; (4) extracting data and evaluating the studies' quality; (5) formulating conclusions; and, finally, (6) communicating and disseminating findings. To maintain transparency, these stages will be detailed in-depth throughout the article, including the approaches utilized to help with each one (Saunders et al., 2009).

2.1 Paper selection method: Web of Science (WoS) and Scopus databases provide comprehensive coverage of peer-reviewed journal articles across various disciplines, making them ideal for finding relevant research papers for this literature review. The search is restricted to engineering, computer science, and business & management. Non-relevant fields are not taken into consideration throughout the selection process. 'Industry 4.0' AND 'maturity' were used in the title, abstract, and keyword search fields, respectively. The first seeks to deal with all articles that mainly investigate Industry 4.0 related articles. The keyword "maturity," which has a more significant meaning, was used to identify all the papers that explore the various Industry 4.0 maturity assessment methods, allowing for later filtering of the articles and not losing information in the process.

Using the keywords search in WoS and Scopus, 481 papers were discovered, as shown in Table 1. There were twenty-one papers that were not authored in English, resulting in a 460-article list. There were 239 papers left after eliminating book chapters, conference papers, and other document formats. The final selection methodology included 183 articles after excluding all but those relevant to engineering, business, computer sciences, or other disciplines of study. Then, 135 papers were produced as a result of removing 48 duplicates with r-studio. Only documents that addressed Industry 4.0 maturity were then considered for publication. There were 52 publications

found irrelevant to the study or lacking in a complete approach after all abstracts were examined. After full-text reading, 43 studies were discarded since they did not discuss any Industry 4.0 maturity models. This resulted in the final papers for the study as 40. While numerous studies have looked at various aspects of the maturity of industry 4.0 in companies, only a tiny minority have examined the current Industry 4.0 models in-depth, and even fewer have proposed new assessment criteria. Instead, most research focuses on the fourth industrial revolution's implementation issues and the lack of appropriate assessment criteria.

Table 1. Paper selection criteria

Criteria	Description	Total number of papers remaining
Keyword search	There must be keywords in the title, abstract, or keywords of articles.	481
Language Exclusion	A selection of English-language articles	460
Source-type exclusion	Only selected journal articles (Excluded book chapters, conference papers, and other document formats)	239
Field of knowledge	Papers that are relevant to the area of study	183
Duplicates	Excluded duplicate papers	135
Abstract reading exclusion	Only those papers are selected which are relevant to the study	83
Full paper reading exclusion	Based on the full-text reading, papers are excluded which are not relevant to the topic	40
Final paper selection		40

III. LITERATURE REVIEW ANALYSIS AND FINDINGS

3.1 Descriptive Analysis: 40 articles met the final eligibility criteria. The selected articles have been classified according to various characteristics, including publication date, source of publishing, and method of study employed. Table 2 presents a comprehensive overview of the essential data. The study's period is 2016-2021, and according to the statistics, the average number of citations per document is 17.64. 142 authors have contributed to the literature related to Industry 4.0 maturity assessment models. There are 104 unique keywords in total.

Table 2. The fundamentals of published articles and their features

Data Information	Description	Frequency
Period	The total time period of the articles	2016:2021
Source	The frequency distribution of all the sources (Journals, Books, etc.)	33
Documents	The total number of articles retrieved from the database.	40
Average citations per document		17.68
Average citations per year per doc		5.733
Keywords (ID)	The total number of unique keywords was found in all of the articles.	98
Author's Keywords (DE)	The number of Keywords that appear in all of the articles mentioned by the Author.	141
Authors	Total number of authors	123
Authors of single-authored documents	The total number of individual writers for each article.	1
Authors of multi-authored documents		122
Author's collaboration		
Authors per document		3.08
Co-Authors per document		3.23
Collaboration Index		3.13

Source: Author's

Figure 1 displays the first classification, which is based on the date of publication of the selected publications. The papers were organized into one-year intervals beginning in 2016 and ending in 2021 to ensure greater clarity. According to the graph, Industry 4.0 maturity assessment models are becoming increasingly important in the literature. The diagram illustrates this well. The year 2020 received the most publications (15 out of 40).

However, since the data was retrieved on October 29, 2021, the data in this chart is limited to published papers until that point. Therefore, this does not represent the actual number of publications released within the calendar year of 2021.

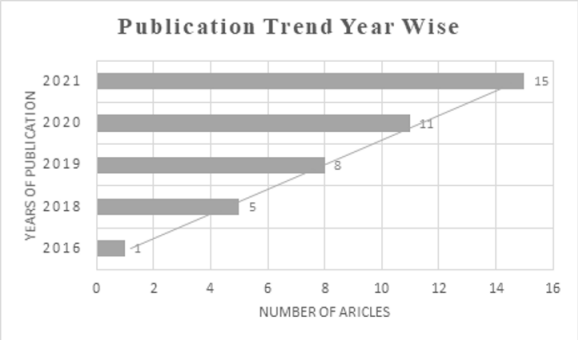

Figure 1. Distribution of Publications (Yearly Output)

Source: Authors

Table 3 ranks and displays the top publication sources according to the number of publications. The total global citations show the overall number of citations received by the Journal's published articles. In contrast, the H-index is the highest value of h at which an author/journal has published at least h publications, each of which has been referenced at least h times. According to the analysis, publications in the Planning & Production control Journal has received the highest number of citations (94 citations for 2 publications). For instance, if an author has published 4 articles and each article has been cited at least four times, then that Author's h-index will be 4. The top two contributing journals, International Journal of Computer Integrated Manufacturing and Journal of Manufacturing Technology Management, have four publications.

Table 3. Classification of articles according to their source of publication

Journal/Conference	Publications	Total Global Citations	H Index	Impact Factor (IF)
Journal of Manufacturing Technology Management	4	37	2	7.547
International Journal of Computer Integrated Manufacturing	3	25	3	3.205
Applied Sciences-Basel	2	21	1	0.773
Electronics	2	1	1	2.397
Information (Switzerland)	2	38	2	_
Logforum	2	21	2	1.29
Production Planning & Control	2	97	2	7.04

Source: The Author

As illustrated in Figure 2, 24 countries produced literature on maturity assessment tools and models related to Industry 4.0. Portugal leads the chart with 32.5 percent (13 of 40) of articles, followed by Brazil and India with 11 publications each.

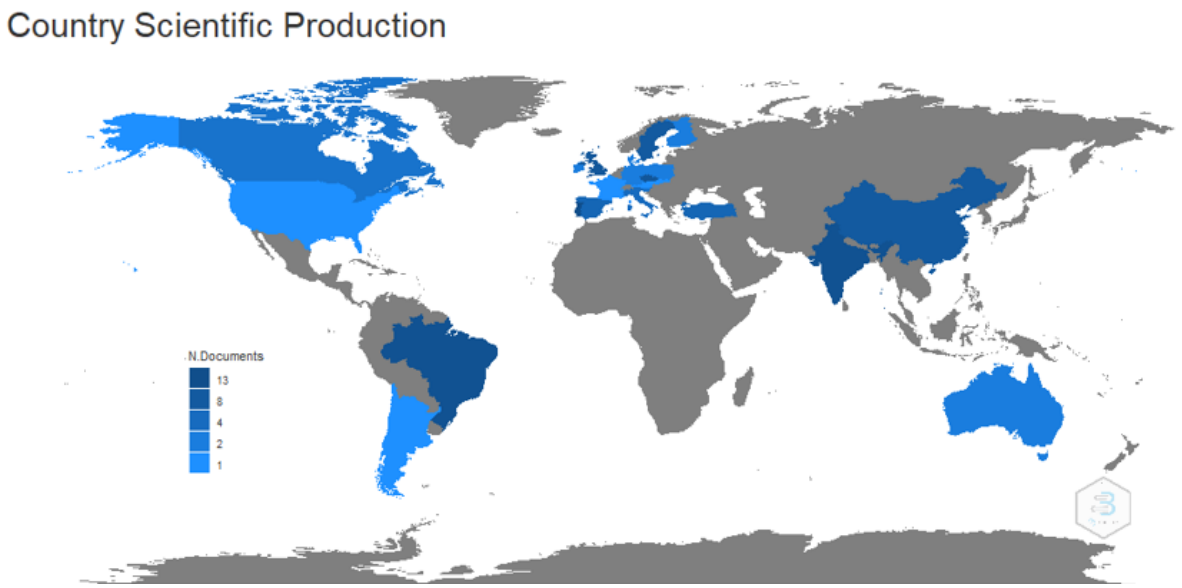

Figure 2. Country-wise scientific production Source: Author's elaboration using Biblioshiny

As illustrated in Figure 3, sixteen publications (40 percent of the total) suggested new industry 4.0 maturity evaluation models for businesses based on prior dimensions and research. Numerous authors built their models on previously established tools and added industry-specific dimensions (Sütová et al. 2020). In addition, 12 articles (30 percent of the total) used a combination of literature examination cases primarily to examine existing models. Case study approaches to understand industry features and comprehend the suggested model's actual implementation (Pirola et al. 2019, Machado et al. 2021, Gajsek et al. 2019, Lin et al.,2020). Some studies used expert interviews to better understand the practical condition of businesses and incorporate the aspects appropriately (Gajsek et al. 2019, Lin et al. 2020, Zoubek, M., & Simon, M. A, 2021). Most studies analyzed the most extensively used maturity models in the literature and provided new strategies to address the gaps. Only one of the final paper selection articles included a literature review. Hajoary, P. K. (2020) analyzed 53 publications published between 2013 and 2019 on Industry 4.0 maturity assessment models and offered a conceptual framework for the evaluation. L. Gaur and R. Ramakrishnan (2019) developed an Internet of Things Maturity Model (IoT-MM) that enterprises may use to determine their current state. A Logistics 4.0-based AI maturity model was created by Ellefsen et al. (2019).

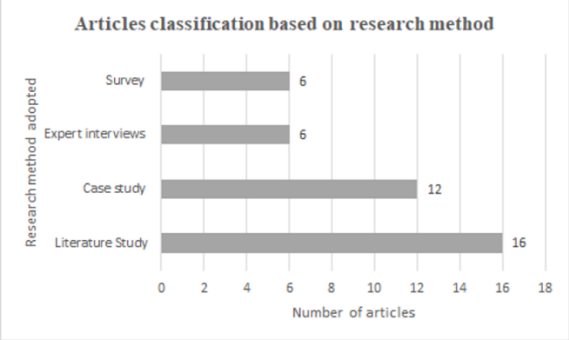

Figure 3. Articles classification based on the methodology adopted,
Source: The Authors

3.2 Content Analysis

3.2.1 Main maturity model dimensions and evaluation scales: According to the findings of study there are mainly three kinds of maturity model recommendations for Industry 4.0:

1. from major consulting firms, 2. from industry associations, and 3. from scientific journals. The investigated models assess maturity in dimensions, which are characterized by transformative capacities. Industry 4.0 maturity is measured by how well each transformation capability is implemented in each dimension.

The maturity models are evaluated from the categories (applicable dimensions) and the method by which these dimensions are evaluated (the applied rating scale). These two characteristics are critical for

evaluating Industry 4.0 maturity models. First, the widely adopted Industry 4.0 maturity assessment models are presented in Table 4. As its primary objective, these maturity models aim to assess a firm's digital maturity stage and recommend improvement activities to steer the organization to the next maturity stage following these models.

In Table 5. Various models proposed by different authors in the last three years (2019,2020, and 2021) and their dimensions are illustrated. In addition, to comprehend the recent trend in the domain, papers published in the previous three years are studied. The dimensions used by various authors and the evaluation scale parameters for available models are also presented in the table.

Table 4: Current available Maturity Models for assessing enterprises readiness for Industry 4.0

Maturity model name, reference, and Institution	Target	Description	Dimensions and levels
Industry 4.0 Maturity Model, Schumacher et al. (2016)	Manufacturing enterprises	Developed an Industry 4.0 maturity model and related tool for manufacturing companies. Unlike earlier models, this one contained organizational characteristics, making it more comprehensive.	Assessment in nine dimensions to assess readiness. Strategy, leadership, customers, products, operations, culture, people, governance, and technology
IMPULS– Lichtblau et al. (2015)	SMEs	One of Germany's leading manufacturers of hang gliders for beginners and flight instructors has created the IMPULS.	Six-dimensional assessment of readiness in five stages, encompassing 18 elements. Strategy and organization, smart factory, smart operations, smart products, data-driven services, employees
The Reference Architecture Model (RAMI4.0) Hankel, M., & Rexroth, B. (2015) Society for measurement, automation, and technology	Manufacturing enterprises	A three-dimensional framework demonstrates how to approach I4.0 in this model.	Six levels, seven dimensions. Business, functional, Information, Communication, integration & asset
System Integration Maturity Model Industry 4.0 (SIMMI 4.0), Leyh et al (2016)	SMEs	It allows a corporation to categorize its IT system landscape with an emphasis on Industry 4.0 criteria. SIMMI 4.0 is divided into five stages.	Five levels, four dimensions, Horizontal, vertical integration, digital product development and cross-sectional technology criteria
The Acatech Industrie 4.0 Maturity Index, Schuh et al. (2017), ACATECH, National Academy of Science and Engineering	Firms	The model depicts value-based development stages.	Six dimensions in 4 levels Resources, information systems, organizational structure, culture
The University of Warwick (WMG) MM Crimson & Co., Pinsent Masons	Firms	This approach includes an online self-assessment tool to determine the company's maturity.	Four levels, six dimensions, fifty-three items. Strategy and organization, Supply chain, Business model, legal considerations
Digital Readiness Assessment MM (DREAMY)	Manufacturing enterprises	Model helps to assist industrial companies in developing an Industry 4.0 integration strategy.	Five levels, four dimensions, Process, Monitoring and control, Technology, Organization
PwC Online Self-Assessment (PwC SA), PWC (2014)	Enterprise0073	The PWC Self-Assessment Tool measures current maturity against desired maturity along six dimensions, identifying action items and classifying current maturity level.	Six dimensions and four levels (1-4) Business models, product and service portfolio; market and customer access; value chains, process and systems; it architecture; compliance, risk, security, tax; and organization and culture

Source: Authors

Table 5: Various Maturity Models proposed in the last three years

	Name of the Author and Year	Dimensions in the models	Evaluation scale	Research method adopted
MM1	Santos, R. C., & Martinho, J. L. (2019)	Organizational strategy, structure and culture, Workforce, Smart factories, Smart processes, Smart products and services	Level 0: Low Level 1: Pilot actions Level 2: implementation of actions initiated Level 3: Partial implementation Level 4: Advanced implementation Level 5: reference in applying the concepts and implementing the technologies of Industry 4.0.	Comparative analysis of existing models; interviews with interviews with industry experts
MM2	Wagire et al (2021)	People and culture, Industry 4.0 awareness, Organizational strategy, Value chain and processes, Smart manufacturing technology, Product and services-oriented technology, Industry 4.0 base technology	Level 1: Outsider Level 2: Digital Novice Level 3: experienced Level 4: Expert	People and culture, Industry 4.0 awareness, Organizational strategy, Value chain and processes, Smart manufacturing technology, Products and services technologies, Industry 4.0 base technology
MM3	Rafael et al (2020)	Strategy and Organization, Smart factory, Smart operations, Smart products, data driven services	Level 0 to Level 5	Literature review and analysis
MM4	Amaral, A., & Peças, P. (2021).	Technology, Production processes, People, Product, organization, change	Level 0 to Level 5	Literature review and analysis
MM5	Caiado et al (2020)	SCM (Customer, Logistics, supplier) SCM & POM (Integration) POM (planning & control, Quality, Maintenance)	Level 0: non-existent Level 1: Conceptual Level 2: Managed Level 3: Advanced Level 4: Self-optimized	mixed-method study (Literature review, In-depth interviews & focus groups and a case study)
MM6	Saad, S. M., Bahadori, R., & Jafarnejad, H. (2021)	Design real time data management, Design system Flexibility, Design execution	Si=1 Beginner Si=2 Learner Si=3 Experienced Si=4 Leader	Literature study
MM7	Priola, F., Cimini, C., & Pinto, R. (2019).	Strategy, People, Processes, Technology, Integration	-	Case study
MM8	Kiraz et al (2020)	business models, products, and services, market and customer access, value chains and processes, IT architecture, compliance, risk, security, organization and corporate culture, leadership, strategy, culture, management, IoT (Internet of things) data protection, processing, and team expertise, and data integration for analysis	-	Survey
MM9	Zoubek, M., & Simon, M. A (2021)	Logistics model 4.0: Manipulation, Storage, Supply, Packaging, Material identification	Level 0-Level 5	Literature review

MM10	Gaur, L., & Ramakrishnan, R. (2019)	IOT Maturity Model: Strategy, Data, IT, Process, People, Assets, Products, Technology, Financial		Literature review and case study

Source: Authors

IV. KEY FINDINGS AND CONCLUSION

For researchers and professionals looking to select and understand the maturity models, Table 4 and Table 5 provides a comprehensive assessment of the most often utilized maturity models. Dimensions like Strategic leadership, technological innovation, supply chain, and culture are standard features in most models (Santos, R. C., & Martinho, J. L. 2019; Wagire et al. 2021, Amaral, A., & Peças, P 2021, Pirola et al. 2019, Kiraz et al. 2020). Table 6 provides the various common dimensions that are used in different models.

Table 6: Various common dimensions used in models

Model name	Strategy	Culture	Technology	Products	Services	Operations	Human resources
Industry 4.0 MM	1	2	3	4		5	6
IMPULS	7			8		9	10
DREAMY			11				
SIMMI4.O							
WMG MM	12						
RAMI4.O							
ACATECH		13					
PWC		14	15	16	17		
MM1	18	19		20	21		22
MM2	23	24	25	26			27
MM3	28			29			
MM4			30	31			32
MM5							
MM6							
MM7	33		34				35
MM8	36	37	38	39	40		
MM9							
MM10	41		42	43			44

Source: Authors

Smart products and services, Smart factory and smart manufacturing are also found in many of the published studies in the literature (Rafael et al. 2020; Kiraz et al. 2020). The majority of the newly developed models modified the dimensions of existing models and validated through to the case study.

Small and medium-sized businesses (SMEs) and other economic segments subject to unique constraints face significant challenges. SMEs, in particular, require assistance in figuring out how to turn the futuristic idea of Industry 4.0 into enhanced efficiency in the workplace (Ganzarain and Errasti, 2016). A deeper examination of a company's strategic vision, as well as its technological and human components, is required for maturity and readiness assessments for small and medium enterprises. Developing specialized maturity models for SMEs has focused by numerous researchers in the past three years (Pirola et al., 2019). However, As SMEs frequently lack a well-defined structure, both operationally and managerially, creating specialized maturity models for SMEs, particularly in emerging nations, is required. Therefore, SME maturity assessment models in emerging economies should be tailored to the sector's specific needs.

It is also observed that insufficient research has been done on how companies can figure out which approach to reshaping business models is most appropriate for their particular situation, i.e., whether they should use their efforts or seek support for generic maturity Industry 4.0 models or whether they identify the necessity of a specific strategy. However, limited studies aim to establish a framework that leads academics in the formulation and use of maturity

models, nor for enterprises who perceive the need for a specific development. Successful implementation of Industry 4.0 relies on a chain of cooperation. It is thus possible that there is a lack of national policies to implement this reality. Despite the fact that many countries have development plans, businesses might still perceive structural constraints as hurdles to individual efforts. Research to simplify models and implementation tools will benefit SMEs that lack the resources and means to seek specialist support to satisfy their particular implementation demands. Focusing on SMEs is crucial because they employ the most people and have the most difficulty acquiring advice on competitive strategies, business models, and organizational architectures.

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