International Journal of Productivity and Perfor
Manag

Industry 4.0 Maturity Assessment: A multi-dimensional indicator approach

Journal:	*International Journal of Productivity and Performance Management*
Manuscript ID	IJPPM-07-2022-0325.R2
Manuscript Type:	Standard Paper
Keywords:	Industry 4.0, Maturity, Readiness, Assessment, Indicators, Multi-dimensional

Industry 4.0 Maturity Assessment: A multi-dimensional indicator approach

Abstract

Purpose- Industry 4.0 has offered significant potential for manufacturing firms to alter and rethink their business models, production processes, strategies, and objectives. Manufacturing organizations have recently undergone substantial transformation due to Industry 4.0 technologies. Hence, to successfully deploy and embed Industry 4.0 technologies in their organizational operations and practices, businesses must assess their adoption readiness. For this purpose, a multi-dimensional analytical indicator methodology has been developed to measure Industry 4.0 maturity and preparedness.

Design/methodology/approach- A weighted average method was adopted to assess the Industry 4.0 readiness using a case study from a steel manufacturing organization.

Findings- The result revealed that the firm ranks between Industry 2.0 and Industry 3.0, with an overall score of 2.32. This means that the organization is yet to achieve Industry 4.0 mature and ready organization.

Practical Implications- The multi-dimensional indicator framework proposed can be used by managers, policymakers, practitioners, and researchers to assess the current status of organizations in terms of Industry 4.0 maturity and readiness as well as undertake a practical diagnosis and prognosis of systems and processes for its future adoption.

Originality/ value- Although research on Industry 4.0 maturity models has grown exponentially in recent years, this study is the first to develop a multi-dimensional analytical indicator to measure Industry 4.0 maturity and readiness.

Keywords: Industry 4.0; Maturity; Readiness, Assessment; Indicators; Multi-dimensional

Paper Type- Research Paper

1. Introduction

Industry 4.0 (I4.0) has offered significant potential for manufacturing firms to alter and rethink their business models, production processes, strategies, and objectives (Crnjac et al., 2017; Pirola et al., 2019; Himang et al., 2020). Scholars, industry leaders, and practitioners believe that I4.0 will stay long and is yet to reach its true potential (Kagermann et al., 2003; Liao et al., 2017; Ghobakhloo and Abbas, 2020). The I4.0 era is inevitable, and all economies must seize the chance since it will have an impact on every organization in the future (Kagermann et al., 2003; Mehra et al., 2017; Flores et al., 2020). Therefore, this revolution is equally important for developed and developing economies like India (Mehra et al., 2017).

Recently, manufacturing organizations have started adopting emerging technologies like the internet of things, cloud computing, 3D printing, advanced robotics, among others, to streamline and improve their production processes, quality and reduce production costs (Luthra et al., 2020; Kamble et al., 2019; Wagire et al., 2020). For the effective adoption of I4.0 technologies, manufacturing organizations must measure and assess their current status and organizational situation. In this context, indicators are considered an effective tool to assess and measure an organization's status to adopt I4.0 (Himang et al., 2020). Metrics establish a broad scientific framework to generate an indicative score for I4.0 technology and practice adoption in manufacturing processes, supply chains, products, and services. Thus, I4.0 maturity and readiness indicators offer a snapshot to facilitate the transition toward I4.0.

A systematic literature review was undertaken and models and evaluation methods were identified from top-ranked journals. The main keywords used were "Industry 4.0", "Maturity and Readiness", "Smart Manufacturing", "Cyber-physical system" and "industrial internet of things". Over the years, different evaluation methods have been proposed and tried, but none have produced an appropriate indication for gauging manufacturing organizations' preparedness for I4.0 (Schumacher et al., 2016; Himang et al., 2020). The currently existing I4.0 MR lack clear, complete, and well-documented stages of assessment as well as evolutionary paths, a granularity of dimensions, unambiguous standard indicators, measurement attributes, comprehensive and integrated assessment methods, and empirical validation (Table 1). To add, none of the existing models provides comprehensive details and a holistic view to derive gaps based on I4.0 evaluation paths. In this line, it has been found that there is a lack of a standard and multi-dimensional indicator assessment framework to assess the I4.0 MR (Schumacher et al., 2016; Bibby and Dehe, 2018). The literature has largely focused on theoretical and conceptual frameworks' development that lack empirical validation, see Section 2. Therefore, this study aims to contribute and fill this gap in the literature by proposing and validating a multi-dimensional framework for I4.0 MR measurement. The developed framework aims to aid manufacturing organizations in diagnosing and prognosing systems and processes. Consequently, the study addresses the following research questions:

1. What are the key indicators to assess and measure I4.0 maturity in manufacturing organizations?
2. How can an analytical indicator methodology be employed to measure Industry 4.0 maturity and preparedness for a manufacturing organization to identify gaps and directions for future improvement?

To address these questions, an indicator-based multi-dimensional framework to evaluate manufacturing organizations in their transition towards I4.0 is proposed. The framework is developed using the existing literature on I4.0 maturity models. The paper is structured to address the research questions as mentioned (Figure 1)

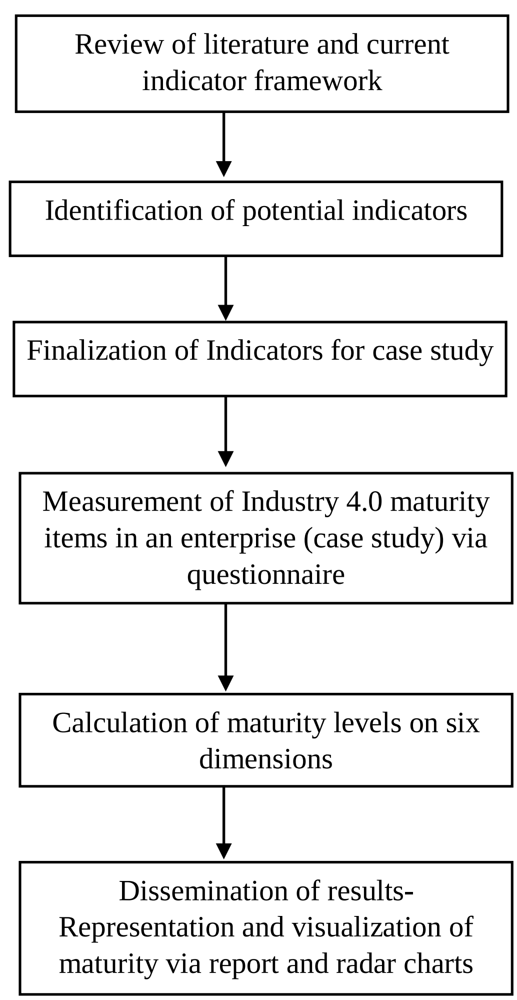

Figure 1. Procedure for Indicator development and its application (Balaban, 2013; Schumacher et al., 2016)

This study contributes to the existing literature on I4.0 by providing comprehensive multi-dimensional indicators for Industry 4.0 maturity assessment. In regards to its practical application, the study and its results can be beneficial for managers in assessing and providing measurable results as the model can be used as a self-assessment tool in a real-life setting to provide measurable results and identify gaps in the implementation of I4.0 technologies and practices in steel manufacturing organizations. The rest of the paper is organized as follows: the first part focuses on the literature review and based on the gaps identified the indicators have been developed. The third section discusses the dimensions across the organizations and the methodology adopted. The fifth and sixth elaborate on the results based on the findings. Based on the inferences drawn from the findings, the seventh section discusses the theoretical and managerial implications of the study. The paper concludes with the limitations of the study and provide scope for future research.

2. Literature Review- Industry 4.0 Maturity and Readiness Models

The I4.0 maturity model idea emerged following the creation of the phrase I4.0 in 2011. The Software Engineering Institute established the Capability Maturity Model in 1993. (Paulk et al., 2011). Since then, several preparedness models for various applications (Weber et al., 2008), such as in IT (Becker et al., 2009), knowledge management (Kulkarni and Freeze, 2004), and business process management (Hammer, 2007; Weber et al., 2008) have been created. The notion of maturity(M) is encapsulated by the idea of readiness(R). Both terms are distinct but not mutually exclusive. They explain the same entity and are interchangeably used to describe the same concept (Schumacher et al., 2016). According to De Carolis et al. (2017), the terms ‘readiness’ and ‘maturity’ are relatively related. In this regard, the study has used the ‘maturity’ term to discuss the same concept.

The maturity model consists of stages or sequences of levels from anticipated, the desired path from initial to complete maturity (Becker et al., 2009; Gottschalk, 2009; Kazanjian and Drazin, 1989). It brings out the level of abstraction, thus underpinning the theoretical foundation of evolution from one step to the other with respect to the domain of the entity under investigation or following improvement measures for the same (Benbasat et al., 1984; King & Kraemer, 1984).

In the same way, I4.0 readiness models consist of a sequence of stages that assess the current state of a manufacturing organization in its transformation towards more agile with a focus on technology, processes, and systems (Kagermann, 2017; Becker et al., 2009; Gottschalk, 2009; Kazanjian and Drazin, 1989). It evaluates and determines the level of preparedness, attitudes, and resources at all levels of the organization's system (Mittal et al., 2018). Accordingly, Caiado et al. (2020) and Asdecker and Felch (2018) suggest that maturity and readiness level assesses the anticipated management and practitioner view of the current and expected level.

IMPULS- I4.0 readiness was developed by Lichtblau et al. (2015) to assess Germany's small-scale and medium industries. The above model is used for the prescriptive purpose only focused on SMEs' and MSMEs' perspectives. On the other hand, Schumacher et al. (2016) developed an ordinal questionnaire based on a maturity index for German small-scale enterprises to assess smart manufacturing practices. Meanwhile, Ganzarain and Errasti (2016) proposed a three-stage maturity model envisioning, enabling and enacting five scales to evaluate SMEs in the Basque Autonomous Region (Table 1). Further, Leyh et al. (2016) developed a SIMMI4.0 (System Integration Maturity Model 4.0) with four dimensions -vertical, horizontal, digital product, and cross-sectional technology. Schuh et al. (2017) also developed a maturity index for manufacturing organizations but lacked details on assessment methods and validation. However, Scremin et al. (2018) and Akdil et al. (2018) designed a maturity model based on earlier models but lacked a precise assessment method. On the other hand, Bibby and Dehe (2018) contributed to the existing literature by designing an I4.0 maturity assessment focusing on technology, but it lacked generalization. Additionally, Akdil et al. (2018) combined and compared four models to develop a three-dimensional maturity model consisting of strategy and organization, products and services, and processes. Table 1(refer to table 1) is a summary of an extensive literature review. However, Section 2, which is a literature review section, discusses the contributions and the gaps of each of the evaluation models in as much depth as possible. The paper finally uses the dimensions developed by one of the authors, i.e. “Hajoary & Akhilesh (2021) developed eight dimensions: strategy, organization, business model, employee, manufacturing and operations, supply chain, production system, products and services.”

The selected indicators and levels were defined based on four level of technology usage complimenting to four industrial revolutions (refer to Table 2). The selected indicators are a fair mix of small, medium and large to cater the entire manufacturing industry. The paper's innovativeness lies more in creating the levels based on the industrial revolutions (Table no 2) than the dimensions alone. Future research will make way for a customized method for various industries and types of organizations. A summary of the previous literature on I4.0 MR is displayed in Table 1 below.

<<Please insert Table 1 here >>

3. Indicator-based framework for Industry 4.0 Maturity Assessment

Indicators may be counted, observed, analyzed, and tested (United Nations, 2010; Himang et al., 2020). Indicators help transform massive, complicated data into meaningful and identifiable information (Bossel, 2002). According to Cavdar and Aydin (2015), measures are essential for difficult-to-measure items. Further, OECD (2003) has defined an indicator as "a parameter which provides information about the state of a phenomenon". The United Nations (1996), however, states that indicators are easy to translate social and physical knowledge into a number that is easily understood. Measuring sustainable development (Hardi et al., 1997), regions (Hanley et al., 1999), and others utilize recognized indicators. Organizations thus need to develop an indicator for measuring and allocating effective digital transformation resources towards I4.0.

The framework has been developed using the guidelines provided by De Bruin et al (2005). The purpose of the framework is descriptive, primarily to document the 'as-is' of an organization. Parameters such as competency, capability and level of sophistication are used to assess maturity. The phases: scope, design, populate, test, deploy and maintain, are generic, however, their sequence is vital for design and testing purposes and influences the entire outcome of the exercise (De Bruin et al, 2005).

The phases of development are:

Scope---->Design----->Populate----> Test --->Deploy---> Maintain

Phase 1: Scope

The scope of the maturity framework is the most critical aspect of the development process, since it sets the external boundaries for the application of the framework, in terms of specificity and extensibility (De Bruin et al, 2005). The world's first "Smart Industry Readiness Index" was created by Singapore to determine the manufacturing organizations' transformation path to I4.0 (EDB, 2019). This index has the following dimensions: process, technology, and organization. Since then, several nations, like Malaysia, China, and Europe, have established their own I4.0 maturity and readiness assessment metrics. However, empirical validation of suitable indicators to assess I4.0 maturity is sparse in the literature. The study's purpose is to create a multi-dimensional analytical framework based on I4.0 maturity and validate it through a case study approach in a large multinational steel manufacturing organization operating in India. The proposed framework will aid practitioners and managers across the manufacturing sector to assess and categorize the current level of their organizations under the adoption of Industry 4.0.

Phase 2: Design

Metrics establish a broad scientific framework to generate an indicative score for I4.0 technology and practice adoption in manufacturing processes, supply chains, products, and services. Thus, I4.0 maturity indicators offer a snapshot to facilitate the transition towards I4.0. However, over the years, different evaluation methods have been proposed and tried, but none have produced an appropriate indication for gauging manufacturing organizations' preparedness for I4.0 (Schumacher et al., 2016; Himang et al., 2020). The existing I4.0 maturity lacks clear, complete and well-documented stages of assessment, evolutionary paths, a granularity of dimensions, unambiguous standard indicators, measurement attributes, comprehensive and integrated assessment methods and empirical validation (Table 1). To add, none of the existing models provides comprehensive details and a holistic view to derive gaps based on I4.0 evaluation paths. In this line, it has been found that there is a lack of a standard and multi-dimensional indicator assessment framework to assess the I4.0 maturity (Schumacher et al., 2016; Bibby and Dehe, 2018).

The proposed framework is intended for the internal use of Executives and Management for the self-assessment of their organizations. The respondents included a combination of Junior Managers (138 responses), Middle-level Managers (181 responses), Senior Managers (14 responses), and Vice Presidents (8 responses) to ascertain the true picture. The application of the model has a granular approach focusing on one entity at a time to aid in better planning and implementation of the 'to-be' state.

The study used a top-down approach with dimensionally linear stages (De Bruin et al, 2005) by writing the definitions of the stages following the industrial revolutions and subsequently, the measures have been developed for quantification. The first level denotes Industry 1.0, whereas the second denotes I2.0, the third denotes I3.0, and the fourth denotes I4.0. Indicators have four levels of evaluation according to the I4.0 phases (Table 2)

<<Please insert Table 2 here >>

The broader aspects of the framework were concretized during the scoping and designing phase. The populate phase was used to deep dive into the framework and identify the measuring dimensions and its components.

Phase 3: Populate

The framework in Figure 2 is designed to populate the I4.0 maturity of a steel manufacturing organization. The process began with a discussion with industry experts on the definition of “Industry 4.0 maturity and readiness” and continued with an extensive list of dimensions and indicators from the literature. Six dimensions and 32 indicators were derived from the literature (Table 1). Each of the indicators, although mutually exclusive, collectively measures the I4.0 maturity. The hierarchal indicator structure includes dimensions at the top level, sub-dimensions at the second level, and composite indicators at the third and fourth levels (Figure 2).

As outlined above, researching I4.0 maturity in a particular industry would contribute to the existing I4.0 literature. The multi-dimensional I4.0 maturity indicator framework was applied through a case study approach in a large multi-national steel manufacturing organization to test its usability, practicality, and generalizability. This is discussed in detail in the testing phase.

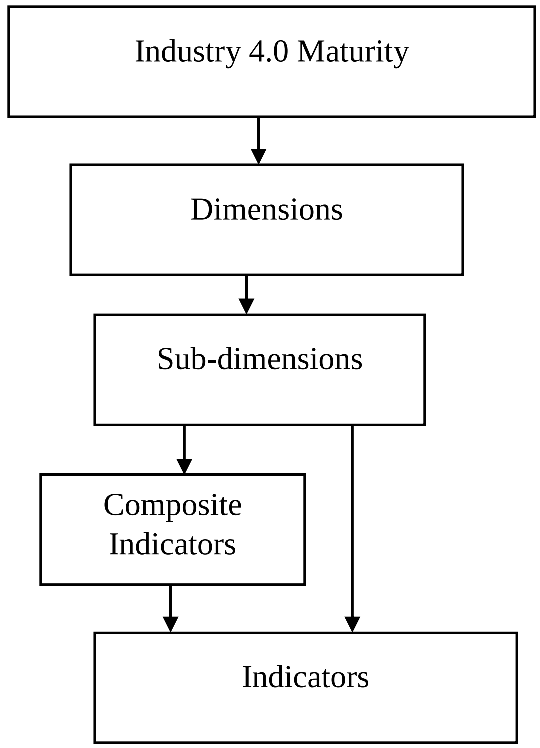

Figure 2. Schematic of Industry 4.0 maturity framework

Phase 4: Test

In this phase, the six dimensions of the I4.0 maturity model were tested for validity and reliability. The overall construct validity and internal consistency (Cronbach's alpha) for the I4.0 maturity model were found to be 0.870, which is above the threshold value of 0.60 to 0.70. This qualifies the questionnaire for data collection and further analysis (Drolet & Morrison, 2001; Diamantopoulos et al., 2012).

4. Dimensions of Industry 4.0 Maturity

This study adopted and adapted the dimensions and indicators from the previous studies undertaken by Schumacher et al. (2016); Agca et al. (2017); Axelsson et al. (2018); Akdil et al. (2018); Bandara et al. (2019); Santos & Martinho (2019); Hajoary & Akhilesh (2020); Wagire et al. (2020); Rafael et al. (2020) (Table 3).

The success of I4.0 adoption depends on the leadership team's understanding of the advantages of I4.0 and on making long-term and short-term choices for the business. When executives identify the I4.0 benefit, they should initiate processes to measure it like KPIs (key performance indicators). Traditional work culture and organizational structure are no longer effective and are increasingly more dynamic and cross-functional (Scremin et al., 2018). Organizations need to evaluate the current skill sets and reskill them with the latest technical skill sets. Hence the strategy and organization dimensions have six sub-dimensions that collectively measure the construct (Table 3).

Dynamic cloud-based data-centric business models are replacing conventional company models. Cloud as a service business model or a product-as-a-service business model is provided to customers (Schumacher et al., 2016). Data produced are utilized for business decisions and service provisioning. A catalogue-based business model in the retail sector has shifted to an online-based model. Meanwhile, businesses are implementing integrated customer experience channels across all channels. Thus, the three dimensions that comprise the business model measure the construct (Table 2).

The manufacturing and operations dimension has nine sub-dimensions that collectively correspond to the company's ability to control processes, infrastructure, and equipment through automation, ability to communicate through machine-to-machine, ability to upgrade existing machines, material handling equipment automation, self-optimizing capability, level of use of digital modeling technique in manufacturing & operations, self-diagnosing capability, level of data storage and use of the cloud to store data (Kagermann et al., 2016). These measures evaluate the manufacturing and operations state and its impact on the organization's I4.0 maturity.

The dimension supply chain has five sub-dimensions that measure the status of the organization in terms of its ability to use real-time data to optimize the supply chain, level of integration with suppliers and customers on order and delivery, end-to-end visibility throughout the value chain, and its ability to respond to changes in the market (Caiado et al., 2020).

<<Please insert Table 3 here >>

Besides, it also measures the company's lead time taken in pre-processing and post-processing stages in the entire supply chain process (Table 3).

In the products and services dimension, there are seven sub-dimensions (Table 3). The company's capability to personalize goods per client demand, using RFID, intelligent sensors, and online tracking, is assessed (Axelsson et al., 2018). The capacity to offer data-driven generate revenue out of the prior record is also measured. Furthermore, it monitors the state of the company's capacity to secure data and keep backups in the cloud. So, the state of products and services must be evaluated in the manufacturing organization.

5. Assessing Industry 4.0 Maturity Level - A Single Case Validation

The case organization is a multi-national company that has a global presence in more than 100 countries. The sample plant is one of the largest integrated steel manufacturing companies in the world. It has approximately 400 managers and 7,000 employees. This organization was undertaking extensive digitalization initiatives across its various departments. Since the nature and the magnitude of the change was large, it was essential to understand the current maturity and readiness levels within the organization. Therefore, this organization was considered an appropriate case to study. The sampling frame included individuals in the roles of Junior Managers (138 responses), Middle-level managers (181 responses), Senior Managers (14 responses), and Vice Presidents (8 responses) having more than five years of industrial experience working in a steel manufacturing setup. The structured questionnaire was shared with all 400 managers both offline and online in a single plant. A total of 381 responses were obtained from the survey with a response rate of 95%, and after screening the missing data, 341 responses were identified to be suitable for further analysis.

A three-step process: measure, determine and depict insights of the I4.0 manufacturing organization was used (Figure 3). The first develops the measurement indicator, followed by calculating the organization's I4.0 maturity. The questionnaire was designed using the selected indicators. The selected indicators and levels were defined based on four levels of technology usage complementing the four industrial revolutions (refer to Table 2). The selected indicators are a fair mix of small, medium and large to cater for the entire manufacturing industry. Upon further research and testing, the model can be customized. As a further step, the present I4.0 maturity of the organization is measured, and then actionable insights are provided on the grey areas for improvement.

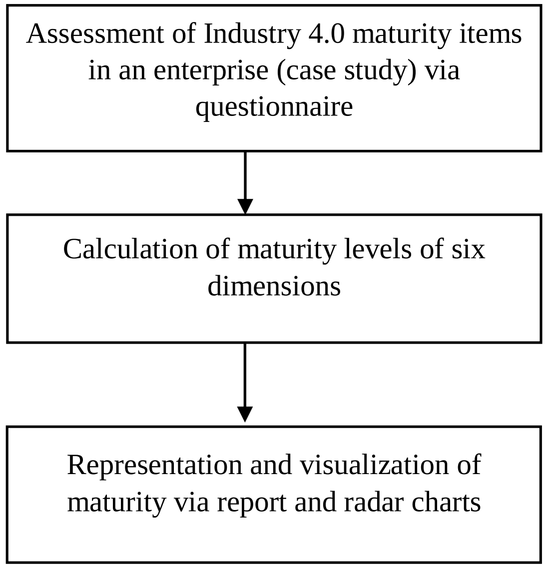

Figure 3. Procedures to assess Industry 4.0 maturity (Schumacher et al.,2016)

6. Calculation and Results of Industry 4.0 Maturity Score

A weighted average technique has been utilized to determine the values of each indicator, dimension, and overall weighted value of the organization. The following equations were used:

$$M_{D}= \frac{\sum_{i=1}^{n} MRdi1*gDIi}{\sum_{i=1}^{n} gDIi}$$, Where M_D is Maturity dimension

M_i is the Maturity score of indicators

n= number of maturity items

$gDIi$= weighting factor, D=dimension, i=indicator

Therefore, the Maturity score of Strategy and organizations ($M_{S\&O1}$) indicator one is calculated as:

$$M_{S\&O1}= \frac{\sum_{i=1}^{n} MRdi1*gDIi}{\sum_{i=1}^{n} gDIi}$$

$$= \frac{1(187)+2(117)+3(29)+4(8)}{187+117+29+8}$$

$$= \frac{540}{341}$$

= 1.58

The strategy and organization dimensions consist of six indicators that measure the construct. They are degree of strategy, leadership, measurement (KPIs), leadership, collaboration, employee capability, and skill acquisition. The weighted average of Indicator one (Degree of strategy) is $M_{S\&O1}$= 1.58. Similarly, for second indicator ($M_{S\&O2}$) = 3.24, for third indicator ($M_{S\&O3}$) =2.81, for fourth indicator ($M_{S\&O4}$) = 2.03, for fifth indicator ($M_{S\&O5}$) =1.87 and for sixth indicator ($M_{S\&O6}$) =1.84. The overall weighted average of the strategy and organization dimension is ($M_{S\&O}$) =2.22(Table 4).

<<Please insert Table 4 here >>

Similarly, the total weighted average value of each of the dimensions and associated indicators is computed in the same manner to provide I4.0 maturity insights. Next, the dimension-wise assessment of maturity level for I4.0 is discussed, and gaps are depicted graphically

6.1 Strategy and Organization Dimension

In this dimension, the strategy's weighted average indicator value is the lowest among the six metrics in the dimension. The weighted average value shown in Table 6 is 3.24 for the measurement (KPIs) and 1.58 for the degree of strategy. I4.0 strategy formulation is lagging in the organization. It has not fully defined a short-term and long-term plan for the transition toward I4.0. Meanwhile, the organization has KPIs to assess and monitor projects for effective implementation across departments for I4.0. This score is equal to 3.24, which is quite near to the I4.0 maturity level.

<<Please insert Table 5 here >>

This shows that the organization is at levels 2-3 and needs work to become an I4.0 mature organization. The total I4.0 maturity score is 2.22, which is about average. To accommodate I4.0, the company should acquire appropriate skill sets. I4.0 is a long-term plan. Implementing a short-term and long-term strategy would make managers aware of the advantages. The indicator's poorer performance is responsible for the lower value of the metric. In addition, the organization must focus on improving staff skills as they move to I4.0. A radar chart is depicted below, where 1 symbolizes I1.0, 2 represents I2.0, 3 represents I3.0, and 4 represents I4.0 (Table 6 & Figure 4). Thus, the company is still at I2.0, in terms of strategy and its approach to I4.0 execution.

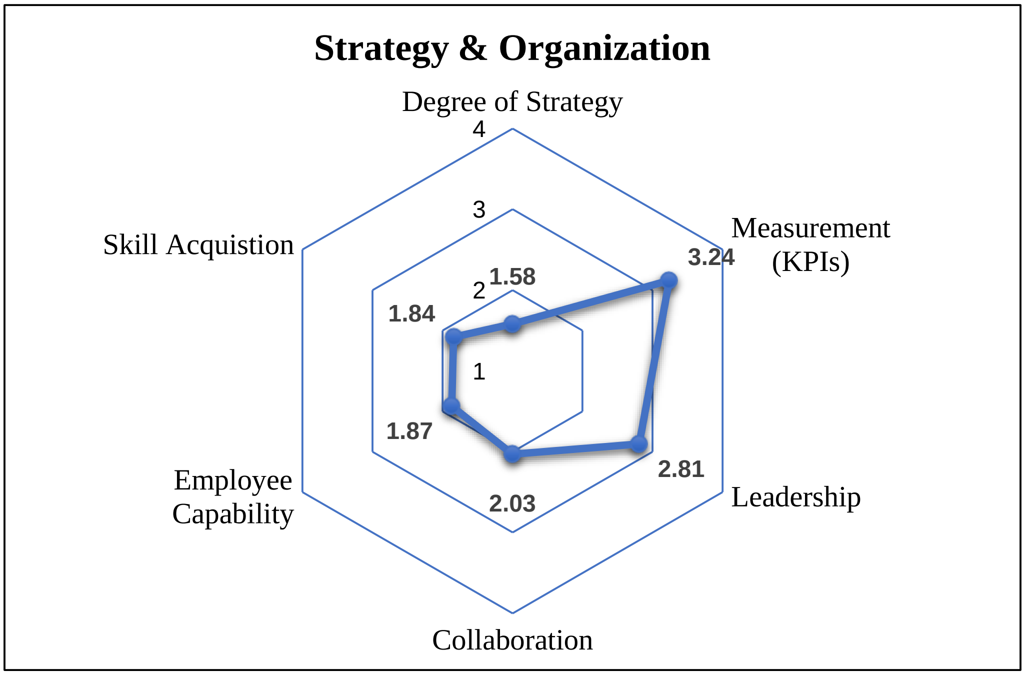

Figure 4. Industry 4.0 maturity level- Strategy and Organization

6. 2 Business model Dimension

In the case of the business model implementation, it is between 2.0 - 3.0(Table 6). An "as a service business model" implementation is the least with 2.10 in this dimension. The weighted average value of the dimension is 2.18, which is slightly over halfway. Focus on service business model implementation and online and offline integration of marketing efforts is a must. Also, make informed decisions on data collected from customers and consumers. The radar chart and weighted average value are shown in Figure 5. To remain competitive, the company should use innovative business models like the "service business model." The conventional business paradigms are obsolete. Businesses that embrace cloud-based and data-driven models use online and physical platforms to reach consumers and stakeholders.

<<Please insert Table 6 here >>

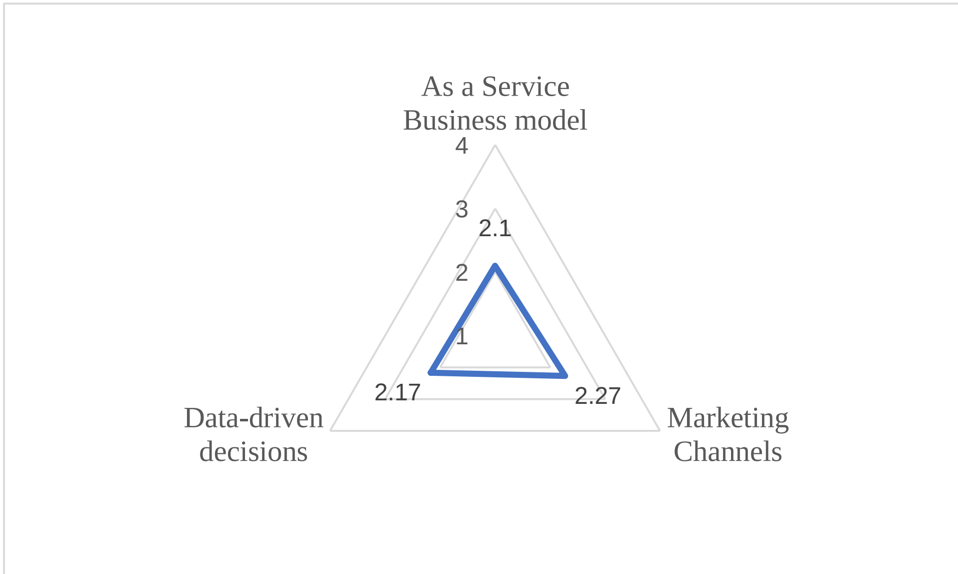

Figure 5. Industry 4.0 maturity level- Business model

6.3 Manufacturing and Operations Dimension

Manufacturing and operation dimensions are critical to any business (Agca et al., 2017). The study has nine indicators that are segmented into four different areas: technology integration (system automation, M2M integration), autonomous processes (self-optimizing processes, equipment automation), data (data usage, IT, data security, cloud usage) and resource capability (digital modeling, scheduling & maintenance). A clear picture of the organization's position regarding the specified indicators is presented in Table 7 & Figure 6. It is clear that the digital modelling indicator's performance is the lowest among all other dimensions. This is because most production and operating procedures utilize outdated digital modelling methods.

<<Please insert Table 7 here >>

The findings indicate that the manufacturing and operations dimensions have the third highest I4.0 maturity and readiness. As for cloud use, it has the highest maturity level, with IT and data security, material handling equipment automation, self-optimizing processes, scheduling, and maintenance close behind (2.20). However, the digital modelling (1.94) indication is the lowest among all dimensions' values. The adoption of digital modelling techniques in manufacturing and operating processes may be improved. I4.0 maturity must be pursued through cultivating resource capacity (digital modelling, scheduling, and maintenance) adoption. Most of the indicators fell between the levels of 2 and 3 (i.e., they were in the range of Industry 2.0 to Industry 3.0). I4.0 must be spearheaded by the organization. The manufacturing and operations dimension have a readiness level of 2.30, as is shown in the radar map below (Figure 6).

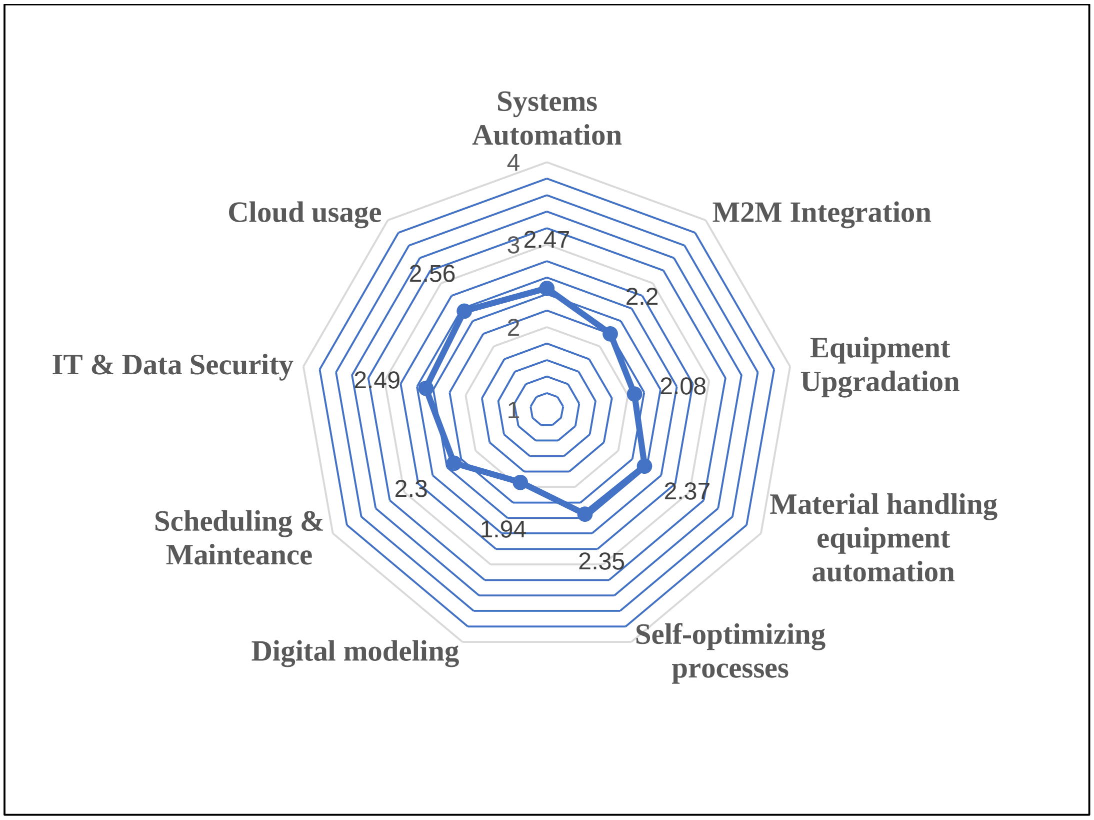

Figure 6. Industry 4.0 maturity level- Manufacturing & Operations

6.4 Supply Chain Dimension

The supply chain dimension includes five indicators that measure the construct. This includes real-time data management, supply chain integration, supply chain visibility, supply chain flexibility, and lead time. The average value of these indicators is 2.85, 2.62, 2.43, 2.42, and 2.47. Using real-time data management, inventory control has the greatest weighted average value, followed by supply chain integration, supply chain flexibility, and lead times (Table 8 and Figure 7). The weighted average supply chain dimension score is 2.55, the highest of all the I4.0 maturity evaluation dimensions. It shows that the supply chain adopts I4.0 technologies and processes in a better manner. Despite supply chain issues, the performance in these areas is still rather low.

<<Please insert Table 8 here >>

The organization's supply chain visibility and flexibility are both functioning effectively before and during pre and post-processing phases. The company must concentrate on integrating the supply chain with suppliers, customers, and end-to-end visibility of inventory, operation, and delivery to achieve I4.0 maturity. Currently, the supply chain dimension lies between I2.0 and I3.0. I4.0 is thus the primary goal for the company.

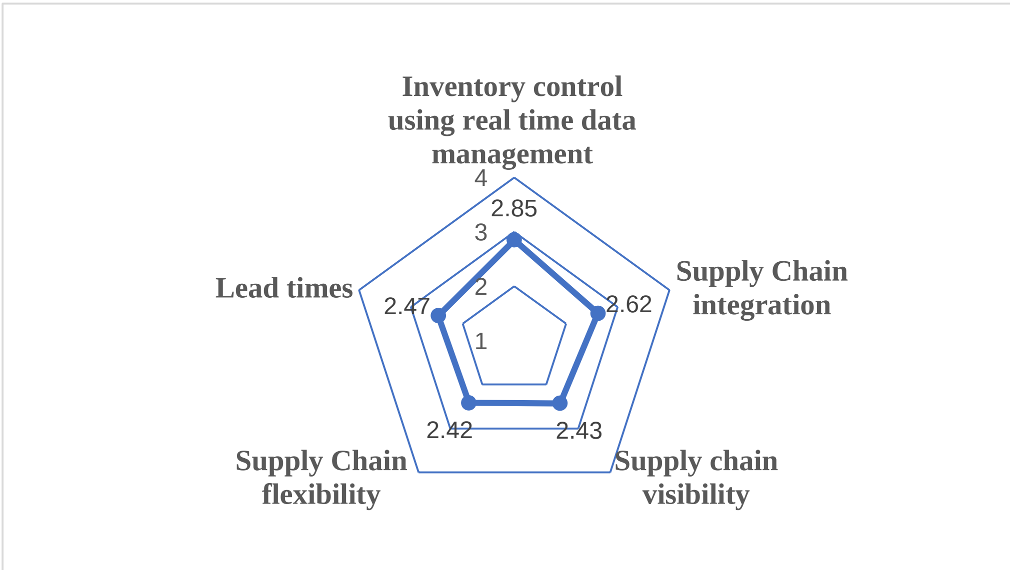

Figure 7. Industry 4.0 maturity level- Supply Chain

6.5 Products and Services Dimension

In the case of the products and services dimension, the organization lacks digital characteristics like RFID (Radio-frequency identification), IoT, sensors, NFC (Near field communication) for real-time information processing and monitoring of goods information. Notwithstanding, goods manufactured still include electro-mechanical elements with no digital tracking and monitoring devices. The share of revenue (2.58) has the higher weighted average value which is followed by product tracking (2.47), data-driven services (2.21), and data capturing mechanism (2.04) in the dimension.

<<Please insert Table 9 here >>

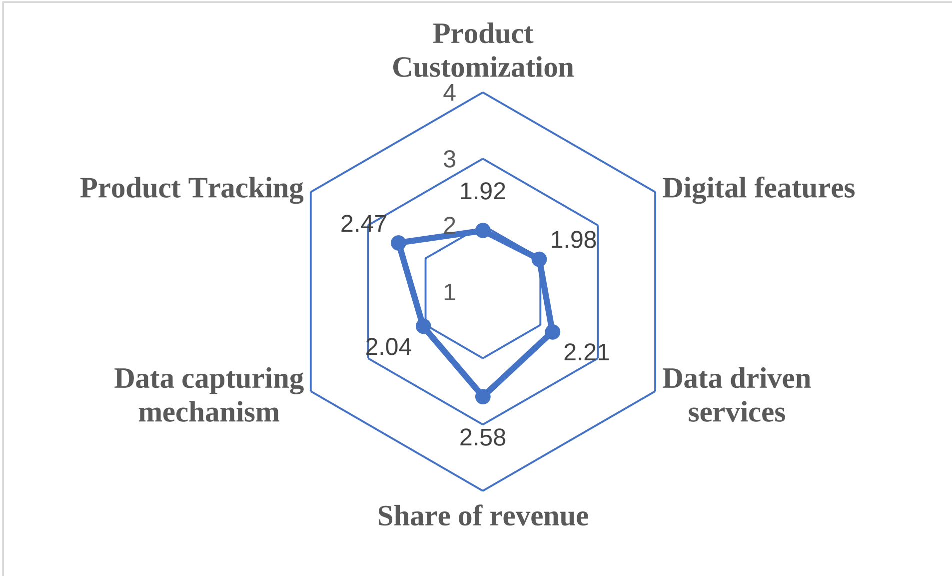

Figure 8. Industry 4.0 maturity level- Products and Services

The overall weighted average value is between I2.0 to I3.0 level with 2.20. The poor value may be attributed to low indicator values for customization and digital features.

6.6 Production Technology Dimension

In terms of production technology, Craft-based and TPS (Toyota Production System), Job shop, Just-in-time (JIT) are no longer competitive in the market. FMS, MES, and lean manufacturing are, as of now, utilized in production in the organization (Frank et al., 2019). Production technologies have a weighted average value of 2.42 in this regard. This indicates that the company is now using flow lines, TPS, job shops, Seru, and JIT to produce. Alternatively, equipment automation increases by 2.62 (Table 10). It's stated here that some of the manufacturing system and equipment is automated. The overall I4.0 maturity level of the organization lies between 2-3, as the production technology score is 2.52.

<<Please insert Table 10 here >>

7. Discussion of Findings

Overall, the level of all dimensions is between I2.0 and I3.0, with a final score of 2.32. 2.55 for the supply chain dimension, 2.52 for production technology, 2.30 for manufacturing and operations, 2.22 for strategy and organization, 2.20 for products and services, and 2.18 for business model (Table 12).

<<Please insert Table 11 here >>

While the business has an I4.0 strategy, it is not yet fully mature and ready to implement I4.0. Cross-departmental cooperation across various functional departments is scarce. While the leadership team knows and appreciates the advantages of I4.0, broad support is lacking. This is clear from the strategy and organization score being poor. According to the research of Tortorella & Fettermann (2018), analyzing business strategy is critical to gauging the relevance of the company's plan.

.

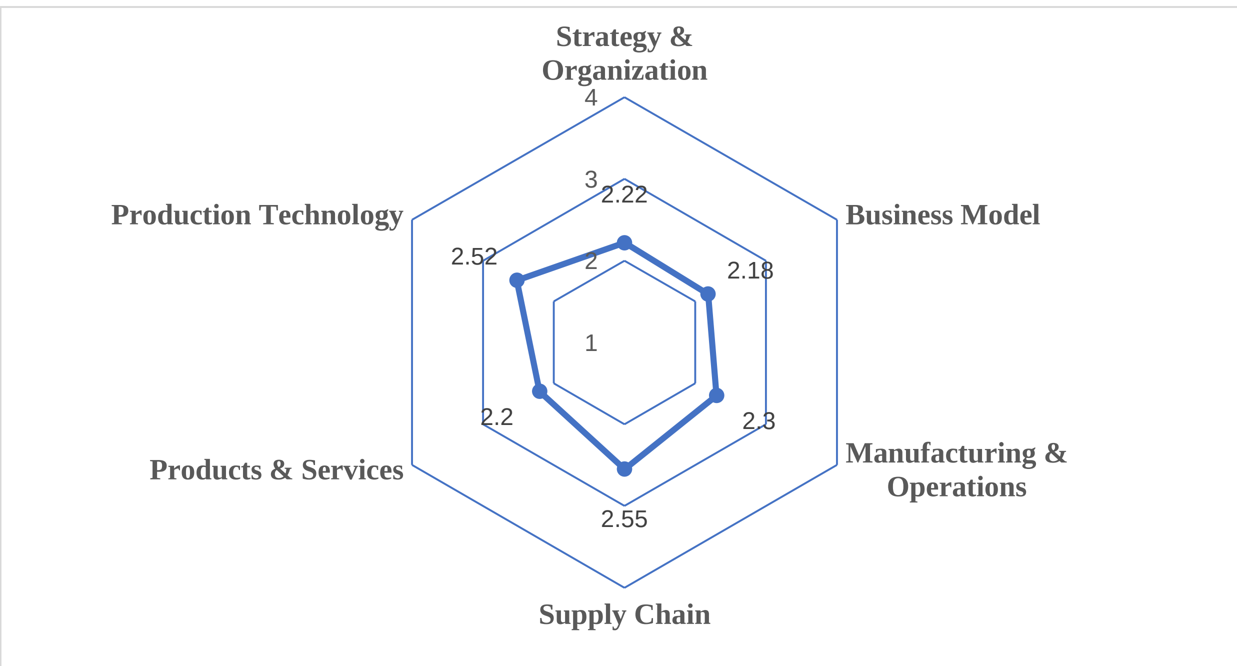

Figure 9. Overall Industry 4.0 Maturity level

While the business is implementing certain levels of real-time data management in the supply chain domain, products and services do not have digital features like RFID, IoT, RFC, barcodes, and ERP. Products are also produced in huge quantities with the absence of late-stage differentiation and customization. The company had problems using digital modelling methods in the development and prototype stages of the product's manufacturing and operational processes. Additionally, most of the procedures utilize computer-based design and prototyping, except for 3D modelling and simulation. Meanwhile, the business conducts both periodic and self-diagnosing real-time maintenance along with conventional maintenance. The only positive thing is that the company keeps data in the cloud, both internally and externally. Therefore, our research indicates that the majority of the indicators are immature or suitable for I4.0 implementation. A firm must invest in digital modelling techniques and implement production technologies like MES and FMS in their manufacturing operations.

To date, the business has no long-term or short-term plans for widespread I4.0 adoption. Additionally, manual data is gathered from the systems and processes, and the business saves data on the cloud. A service business model has not yet been adopted by the company. To achieve I4.0, the company must thus focus on improving cross-departmental collaboration, skill acquisition, employee capability, product customization, digital features, data capturing mechanism, supply chain flexibility, lead times, digital modelling technique, equipment up-grading, M2M integration and production technology. Therefore, the total state of the company lies between Industry 2.0 and Industry 3.0.

This research shows the practical use of a multinational company in a developing country. This is the first time I4.0 maturity evaluation has been used in a steel production company. More and more studies are needed to reduce the degree of abstraction in I4.0 literature (Bibby and Dehe, 2018). Additionally, multi-dimensional indicators provide managers with easy-to-understand and quantifiable outcomes and levels for them to adopt I4.0 technologies and processes.

8. Theoretical and Managerial implications

The primary goal of this study was to create multi-dimensional indicators for evaluating I4.0 maturity. The multi-method strategy included developing measuring indicators, as well as using quantitative and qualitative techniques for empirical validation. From a practical standpoint, the multi-dimensional indicators will enable organizations to identify their present strengths and weaknesses in order to progress towards an I4.0 mature and ready organization. The major theoretical contributions of this study are: (i) Reviewing and establishing the existing literature on I4.0 maturity models from a manufacturing perspective, (ii) developing comprehensive multidimensional indicators for I4.0 maturity assessment, (iii) Introducing production technology as a new dimension for I4.0 maturity assessment, (iv) Validating the applicability of the proposed multi-dimensional indicators through an exploratory case study, in a large multi-national steel manufacturing organization, to overcome the gap of limited empirical validation observed in the literature (Bibby and Dehe, 2018), (v) Providing a detailed descriptive & prescriptive assessment of the manufacturing organization status in terms of I4.0 maturity. Furthermore, (vi) the four levels of the I4.0 maturity assessment provided a greater differentiation that is easy to understand and avoids ambiguity by not using the concept of central tendency. Lastly, (vii) the model can be used as a self-assessment tool in a real-life setting to provide measurable results and identify gaps in the implementation of I4.0 technologies and practices in manufacturing organizations. An extensive study was carried out across the organization. The scale of each department is equivalent to the size of small organizations. Therefore, the study was able to collect responses from a large sample size and results can be extended to similar organizations. Additionally, this research provides manufacturing companies with a strong, practical and easy-to-use method for I4.0 maturity diagnostic.

In line with the theoretical contributions, the following managerial recommendations have been made for the case organization under study:

I. Managers should consider short-term and long-term plans for I4.0. This must be embedded into the business strategy to bring tangible outputs to the organization. I4. 0 adoption will lead to advantages through lowering operating costs and increasing business efficiency.

II. Although KPIs have been introduced throughout the company, they must be done across all departments for greater uptake and returns.

III. Employee capability and skill acquisition in I4.0 was insufficient, therefore managers needed to concentrate on investing in reskilling and upskilling workers with appropriate digital and analytical abilities.

IV. Business model innovation necessitates a clear integration of online and offline marketing platforms. Also, the organization must gather information to apply to company-level choices and adopt "as a service business model" for real-time customer experience. Additionally, managers must analyze recorded consumer data utilizing sophisticated analytics technologies for business decisions. This will, in turn, generate revenue and help to make informed decisions on the existing customers' needs, and acquire a new customer base.

V. Based on the assessment, the organization should create a long-term plan and demystify technologies and processes for I4.0 adoption.

9. Limitations and Future Research directions

Some of the limitations of the present study include the fact that the concept of I4.0 is evolving at a rapid pace, which triggers the need to revalidate the I4.0 maturity periodically. Although the multi-dimensional indicators were tested for their applicability in a multi-national steel manufacturing organization, a multi-case study is necessary to demonstrate the proposed framework's applicability and usability in other sectors. In the future, researchers can undertake a pre-assessment and post-assessment of I4.0 maturity to determine the level of abstraction for generalizing the indicators in other sectors like mining, railways, defence, textile, cement, pharmaceuticals, among others and also in SMEs and MSMEs. In future, researchers can also add more dimensions, e.g., legal and regulatory issues, as these can impact the adoption of I4.0 technologies and practices.

References

Asdecker, B., & Felch, V. (2018), "Development of an Industry 4.0 maturity model for the delivery process in supply chains", Journal of Modelling in Management, Vol. 13 No. 4, pp. 840-883.

Akdil, K. Y., Ustundag, A., & Cevikcan, E. (2018), "Maturity and readiness model for industry 4.0 strategy". In Industry 4.0: Managing the digital transformation, Springer, Cham, pp. 61-94.

Alcácer, V., Rodrigues, C., Carvalho, H., & Cruz-Machado, V. (2021), "Tracking the maturity of industry 4.0: the perspective of a real scenario". The International Journal of Advanced Manufacturing Technology, Vol 116 No 7, pp.2161-2181.

Agca, O., J. Gibson, J. Godsell, J. Ignatius, J. Wyn Davies, and O. Xu (2017), "An Industry 4 readiness assessment tool", Retrieved from https://warwick.ac.uk/fac/sci/wmg/research/scip/reports/final_version_of_i4_report_for_use_on_websites.pdf (Accessed on 17th Feb, 2021).

Anderl, R., Picard, A., Wang, Y., Fleischer, J., Dosch, S., Klee, B. and Bauer, J. (2015), "Guideline industrie 4.0-guiding principles for the implementation of industrie 4.0 in small and medium sized businesses", Vdma Forum Industrie, Vol. 4, pp. 1-31.

Axelsson, J., Fröberg, J. and Eriksson, P.(2018), "Towards a system-of-systems for improved road construction efficiency using lean and Industry 4.0", 13th Annual Conference on System of Systems Engineering, IEEE, pp. 576-582.

Bibby, L., & Dehe, B. (2018), “Defining and assessing industry 4.0 maturity levels–case of the defence sector”, Production Planning & Control, Vol.12 No. 29, pp.1030-1043.

Becker, J., Knackstedt, R. and Pöppelbuß, J. (2009), “Developing maturity models for IT management”, Business and Information Systems Engineering, Vol. 1 No. 3, pp. 213-222.

Basl, J., & Doucek, P. (2019), “A metamodel for evaluating enterprise readiness in the context of industry 4.0”, Information, Vol.10 No.3, pp.89.

Balaban, O. (2013), “The use of indicators to assess urban regeneration performance for climate-friendly urban development: The case of Yokohama Minato Mirai 21”, In Spatial Planning and Sustainable Development, Springer, Dordrecht, pp. 91-115.

Benbasat, I., Dexter, A. S., Drury, D. H., & Goldstein, R. C. (1984), “A critique of the stage hypothesis: theory and empirical evidence”, Communications of the ACM, Vol. 27 No 5, pp. 476-485.

Blatz, F., Bulander, R., & Dietel, M. (2018), “Maturity model of digitization for SMEs”. IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC*)*, IEEE, pp. 1-9.

Bandara, O., Vidanagamachchi, K., & Wickramarachchi, R. (2019), “A model for assessing maturity of industry 4.0 in the banking sector”, Proceedings of the International Conference on Industrial Engineering and Operations Management, pp.1141–1150.

Bossel, H. (2002), “Indicators for sustainable development—a systems analysis approach”, In Unveiling Wealth, Springer, Dordrecht, pp. 55-58.

BCG(2018), “Digital Acceleration Index”. Retrieved from https://www.bcg.com/capabilities/technology-digital/digital-accelerationindex.aspx (Accessed on 09 June 2019).

Colli, M., Berger, U., Bockholt, M., Madsen, O., Møller, C. and Wæhrens, B.V.(2019), “A maturity assessment approach for conceiving context-specific roadmaps in the industry 4.0 era”, Annual Reviews in Control, Vol. 48, pp. 165-177.

Castelo-Branco, I., Oliveira, T., Simões-Coelho, P., Portugal, J., & Filipe, I. (2022), “Measuring the fourth industrial revolution through the Industry 4.0 lens: The relevance of resources, capabilities and the value chain”. Computers in Industry, Vol 138, pp.103639

Crnjac, M., Veža, I., & Banduka, N. (2017), “From concept to the introduction of industry 4.0”. International Journal of Industrial Engineering and Management, Vol. 1 No. 8, pp.21.

De Carolis, A., Macchi, M., Kulvatunyou, B., Brundage, M. P., & Terzi, S.(2017), “Maturity models and tools for enabling smart manufacturing systems: comparison and reflections for future developments”. In ifib international conference on product lifecycle management, Springer, Cham pp. 23-35.

Caiado, R. G. G., Scavarda, L. F., Gavião, L. O., Ivson, P., de Mattos Nascimento, D. L., & Garza-Reyes, J. A. (2021), “A fuzzy rule-based industry 4.0 maturity model for operations and supply chain management”, International Journal of Production Economics, Vol. 231, pp. 107883.

Cavdar, S. C., & Aydin, A. D.(2015), “An empirical analysis about technological development and innovation indicators”, Procedia-Social and Behavioral Sciences, Vol. 195, pp. 1486-1495.

Deloitte (2018). Retrieved from https://www2.deloitte.com/content/dam/Deloitte/ch/Documents/manufacturing /ch-enmanufacturing-industry-4-0-24102014.pdf (Accessed on 26th July 2019).

De Bruin, T., Rosemann, M., Freeze, R., & Kaulkarni, U. (2005), “Understanding the main phases of developing a maturity assessment model”, In Australasian Conference on Information Systems (ACIS), Australasian Chapter of the Association for Information Systems, pp. 8-19.

EDI(2019), Retrieved from https://www.edb.gov.sg/en/about-edb/media-releases publications/advanced-manufacturing-release.html (Accessed on 11th December 2020).

Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019), “Industry 4.0 technologies: Implementation patterns in manufacturing companies”, International Journal of Production Economics, Vol. 210, pp. 15-26.

Flores, E., Xu, X., & Lu, Y. (2020), “Human Capital 4.0: a workforce competence typology for Industry 4.0”, Journal of Manufacturing Technology Management, Vol.31 No.4, pp. 687-703.

Gottschalk, P.(2009), “Maturity levels for interoperability in digital government”, Government information quarterly, Vol. 26 No.1, pp.75-81.

Ganzarain, J. and Errasti, N.(2016), “Three stage maturity model in SME’s towards industry 4.0”. Journal of Industrial Engineering and Management, Vol. 9 No. 5, pp. 1119-1128.

Gökalp, E., Sener, U. and Eren, P.E. (2017), “Development of an assessment model for industry 4.0: industry 4.0-MM”, International Conference on Software Process Improvement and Capability Determination, Springer, Cham, pp. 128-142.

Glogovac, M., Ruso, J., & Maricic, M. (2022), “ISO 9004 maturity model for quality in industry 4.0. Total Quality Management & Business Excellence”, Vol. 33 No. (5-6), pp. 529-547.

Ghobakhloo, M. and Fathi, M. (2020), “Corporate survival in Industry 4.0 era: the enabling role of lean digitized manufacturing”, Journal of Manufacturing Technology Management, Vol. 31 No. 1, pp. 1-30.

Himang, C., Ocampo, L., Obiso, J. J., Bongo, M., Caballes, S. A., Abellana, D. P., ... & Ancheta, R.(2020), “Defining stages of the Industry 4.0 adoption via indicator sets”, Engineering Management in Production and Services, Vol. 2 No.12, pp. 32-55.

Hajoary, P. K., & Akhilesh, K. B.(2020), “Conceptual framework to assess the maturity and readiness towards Industry 4.0”, In Industry 4.0 and Advanced Manufacturing, Springer, Singapore, pp. 13-23.

Hajoary, P. K. (2021), “Industry 4.0 Maturity and Readiness Models: A Systematic Literature Review and Future Framework”, International Journal of Innovation and Technology Management, Vol. 17, No. 07, pp. 2030005.

Hajoary, P. K. (2023), “Industry 4.0 Maturity and Readiness-A case of a Steel Manufacturing Organization”. Procedia Computer Science, Vol 217, pp. 614-619.

Harmoko, H.(2020), “Industry 4.0 readiness assessment: Comparison of tools and introduction of new tool for SME”, Tehnički glasnik, Vol. 14 No. 2, pp. 212-217.

Hardi, P., Barg, S., Hodge, T., & Pinter, L.(1997), “Measuring sustainable development: Review of current practice”, ETDE Web, Canada, pp.243.

Hanley, N., Moffatt, I., Faichney, R., & Wilson, M.(1999), “Measuring sustainability: a time series of alternative indicators for Scotland”, Ecological economics, Vol. 28 No. 1, pp.55-73.

Jung, K., Kulvatunyou, B., Choi, S. and Brundage, M.P.(2016), “An overview of a smart manufacturing system readiness assessment”, IFIP International Conference on Advances in Production Management Systems, pp. 705-712.

Kagermann, H.; Wahlster, W.; Helbig, J. (2013), “Recommendations for Implementing the Strategic Initiative Industry 4.0”, National Academy of Science and Engineering: Berlin,Germany.

KPMG(2016), “Digital auf der Höhe der Zeit?”. Retrieved from https://assets.kpmg.com/content/dam/kpmg/pdf/2016/04/digital-readiness-assessment-03-16.PDF (Accessed on 18th February 2020).

Kulkarni, U., & Freeze, R.(2004), “Development and validation of a knowledge management capability assessment model”, ICIS 2004 Proceedings, pp. 54.

Kubrick (2012), “Introducing the Six Dimensions of Digital Maturity, aka the dStrategy Digital Maturity Model™”, Retrieved from https://www.onlineauthority.com/blog/introducing-dstrategy-digital-maturitymodel/(Accessed on 12 August 2018).

Kazanjian, R. K., & Drazin, R.(1989), “An empirical test of a stage of growth progression model”. Management science, Vol. 35 No. 12, pp. 1489-1503.

King, J. L., & Kraemer, K. L.(1984), “Evolution and organizational information systems: an assessment of Nolan's stage model”, Communications of the ACM, Vol. 27 No. 5, pp. 466-475.

Liao, Y., Deschamps, F., Loures, E., de, F.R. and Ramos, L.F.P.(2017), “Past, present and future of Industry 4.0 – a systematic literature review and research agenda proposal”, International Journal of Production Research, Vol. 55 No. 12, pp. 3609-3629.

Lee, J., Kao, H.-A. and Yang, S. (2014), “Service innovation and smart analytics for industry 4.0 and big data environment”, Procedia CIRP, Vol. 16 No. 1, pp. 3-8.

Klötzer, C. and Pflaum, A. (2017), “Toward the development of a maturity model for digitalization within the manufacturing industry’s supply chain”, Proceedings of the 50th HI International Conference on System Sciences, pp. 4210-4219.

Lichtblau, K., Stich, V., Bertenrath, R., Blum, M., Bleider, M., Millack, A., Schmitt, K., Schmitz, E. and Schröter, M.(2015), "Industrie 4.0-readiness", IMPULS-Stiftung, Cologne.

Leyh, C., Bley, K., Schäffer, T. and Forstenhäusler, S. (2016), "SIMMI 4.0 – a maturity model for classifying the enterprise-wide it and software landscape focusing on Industry 4.0", 2016 Federated Conference on Computer Science and Information Systems (FedCSIS), IEEE, pp. 1297-1302.

Lee, J., Jun, S., Chang, T. W., & Park, J.(2017), "A smartness assessment framework for smart factories using analytic network process", Sustainability, Vol. 9 No. 5, pp. 794.

Luthra, S., Kumar, A., Zavadskas, E. K., Mangla, S. K., & Garza-Reyes, J. A. (2020), "Industry 4.0 as an enabler of sustainability diffusion in supply chain: an analysis of influential strength of drivers in an emerging economy", International Journal of Production Research, Vol. 58 No. 5, pp.1505-1521.

Mehra, S., S. Chouhan, P. Mehra, and A. Dasot.(2017), "India's Readiness for Industry 4.0 – A Focus on Automotive Sector". Retrieved from http://www.grantthornton.in/insights/articles/indiasreadiness-for-industry-4.0–a-focus-onautomotive-sector (Accessed on 7th January 2020).

Mittal, S., Khan, M. A., Romero, D., & Wuest, T.(2018), "A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs)", Journal of manufacturing systems, Vol. 49, pp. 194-214.

Moura, L. R., & Kohl, H. (2020), "Maturity Assessment in Industry 4.0–A Comparative Analysis of Brazilian and German Companies", Emerging Science Journal, Vol. 4 No. 5, pp. 365-375.

OECD(2003), "OECD environmental indicators development, measurement, and use". Retrived from https://www.oecd.org/env/indicators-modelling-outlooks/37551205.pdf (Accessed on 11th January 2021)

Pirola, F., Cimini, C., & Pinto, R.(2019), "Digital readiness assessment of Italian SMEs: A case-study research", Journal of Manufacturing Technology Management, Vol. 31 No.5, pp. 1045-1083.

Pacchini, A. P. T., Lucato, W. C., Facchini, F., & Mummolo, G.(2019), "The degree of readiness for the implementation of Industry 4.0". Computers in Industry, Vol. 113 No. 103125,

PricewaterhouseCoopers (PwC)(2016), "E Industry 4.0/digital operations self-assessment", Retrieved from https://industry-4.0-building-your-digital-enterprise-april-2016.pdf (Accessed on 15th July, 2021).

Paulk, M. C., Curtis, B., Chrissis, M. B., & Weber, C. V.(2011), "The capability maturity model for software", Software Process Improvement, pp. 1–26.

Rafael, L. D., Jaione, G. E., Cristina, L., & Ibon, S. L. (2020), "An Industry 4.0 maturity model for machine tool companies", Technological Forecasting and Social Change, Vol. 159 No. 120203.

Rockwell Automation.(2014), “The Connected Enterprise Maturity Model”. International Commission on Illumination, Retrieved from https://doi.org/10.15358/0935-0381-2015-8-9-515(Accessed on 13th July, 2021).

Schumacher, A., Erol, S., & Sihn, W.(2016), “A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises”, Procedia CIRP, Vol. 52, pp. 161–166.

Schuh, G., Anderl, R., Gausemeier J., ten Hompel, M., Wahlster, W.(2017), “Industrie 4.0 Maturity Index”. Managing the Digital Transformation of Companies (acatech STUDY), Munich: Herbert Utz Verlag, pp. 64.

Scremin, L., Armellini, F., Brun, A., Solar-Pelletier, L., & Beaudry, C.(2018), “Towards a Framework for Assessing the Maturity of Manufacturing Companies in Industry 4.0 Adoption”, In Analyzing the Impacts of Industry 4.0 in Modern Business Environments, IGI Global, pp. 224-254.

Sony, M., & Naik, S.(2019), “Key ingredients for evaluating Industry 4.0 readiness for organizations: a literature review”, Benchmarking: An International Journal, Vol. 27 No.7, pp. 2213-2232.

Santos, R.C. and Martinho, J.L.(2019), “An industry 4.0 maturity model proposal”, Journal of Manufacturing Technology Management, Vol. 31 No.5, pp. 1023-1043.

Santos, C., Mehrsai, A., Barros, A. C., Araújo, M., & Ares, E.(2017), “Towards Industry 4.0: an overview of European strategic roadmaps”, Procedia Manufacturing, Vol.13, pp. 972-979.

Trotta, D., & Garengo, P.(2019), “Assessing Industry 4.0 Maturity: An Essential Scale for SMEs”, Proceedings of 2019 8th International Conference on Industrial Technology and Management, ICITM 2019, pp. 69–74.

Tortorella, G. L., & Fettermann, D.(2018), “Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies”, International Journal of Production Research, Vol. 56 No. 8, pp. 2975-2987.

United Nations(2010), “Indicators”, Retrieved from https://www.endvawnow.org/en/articles/336-indicators.html (Accessed on 19th February 2019).

Wagire, A. A., Joshi, R., Rathore, A. P. S., & Jain, R. (2020), “Development of maturity model for assessing the implementation of Industry 4.0: learning from theory and practice”, Production Planning & Control, Vol. 32 No. 8, pp.1-20.

Westermann, T., Anacker, H., Dumitrescu, R., & Czaja, A.(2016), “Reference architecture and maturity levels for cyber-physical systems in the mechanical engineering industry”, ISSE 2016 - 2016 International Symposium on Systems Engineering, pp.1–6.

Weber, C., Königsberger, J., Kassner, L., & Mitschang, B.(2017), “M2DDM - A Maturity Model for Data-Driven Manufacturing”, Procedia CIRP, Vol. 63, pp. 173–178.

Yin, Y., Stecke, K. E., Swink, M., & Kaku, I.(2017), "Lessons from seru production on manufacturing competitively in a high-cost environment", Journal of Operations Management, Vol. 49 No. 51, pp. 67-76.

Yin, Y., Stecke, K. E., & Li, D.(2018), "The evolution of production systems from Industry 2.0 through Industry 4.0", International Journal of Production Research, Vol.56 No. 1-2, pp. 848-861.

Table 1. Summary of previous literature on Industry 4.0 maturity models

Author & Year	Name of the Model	Main contributions	Gaps	Our contribution
Kubrick (2012)	dStrategy Digital Maturity Model™	The model focused on digital maturity	The model has no maturity assessment method and empirical validation	The proposed model is empirically validated
Lichtblau et al. (2015)	IMPULS- I4.0 readiness	The study surveyed 232 employees of the manufacturing organization with six dimensions.	The model lacked a comparative and descriptive assessment method	The proposed model provides prescriptive and descriptive assessment methods and measurable results
Andrel et al. (2015)	RAM14.0	The model is conceptual and consists of six dimensions.	The model lacked a description of the assessment method and validation	The proposed model provides a detailed description of the measurement and assessment method
Westernman et al. (2016)	I4.0 readiness	The model is conceptual and designed for mechanical firms.	The model lacked granular dimensions, evolutionary paths, assessment, and empirical validation	The proposed model has comprehensive dimensions, four levels of evolution path and empirical validation
Schumacher et al. (2016)	I4.0 readiness & maturity	The model is linear with nine dimensions-strategy, leadership, customers, products, operations, culture, people, governance, and technology.	The model lacked clear indicators, evolutionary paths, measurement attributes and assessment method	The proposed model has 32 indicators that measure the maturity and has four levels of evolutionary path
PwC (2016)	I4.0/Digital Operations Self-Assessment	The model is a self-assessment tool on six dimensions-business model, processes, IT architecture, compliance, organization, and culture.	The model lacked a clear description of indicators and empirical validation	The proposed model has a clear description of the measured indicators and was validated with a case study
Ganzarain & Errasti (2016)	Three-Stage maturity model	The results showed the need to design a company-specific vision and planning.	The model lacked multi-dimensions, indicators, assessment methods and empirical validation	The proposed model considered the most important dimensions, indicators along with empirical validation
Leyh et al. (2016)	SIMMI4.0	The model consists of five stages-basic level, cross-departmental level, horizontal and vertical level, full digitalization level, and optimized full digitalization	The model lacked granular dimensions, a clear assessment method and empirical validation	The proposed model focused on important dimensions, a four-stage evolution path along with its application in a steel manufacturing organization
Jung et al (2016)	SMRL	The model focuses on ICT.	The model is limited to ICT and lacked an assessment method, description of indicators and assessment method	The proposed model considered people, process, and technology aspects along with measurement description and method

Continued (Table 1)

Author & Year	Name of the Model	Main contributions	Gaps	Our contribution
KPMG (2016)	Digital readiness assessment	The model focuses on four dimensions- development and purchasing, production, marketing, sales	The model lacked comprehensive dimensions, indicators and lacked empirical validation	The proposed model has comprehensive six dimensions, 32 indicators and empirical validation
Weber et al. (2017)	M2DDM	The model focuses on the IT industry and provides a development path.	The model is limited to IT and does not provide comprehensive dimensions	The proposed model has comprehensive dimensions and an assessment method for manufacturing organizations
Gokalp et al. (2017)	I4.0 MM	The model has six dimensions -asset management, data governance, application management, process transformation, and organizational alignment.	The model lacked empirical validation and a complete description of the assessment method	The proposed model has four levels of assessment and a measurement description of indicators with empirical validation
Schuh et al. (2017)	I4.0 maturity index	Provides an index-based maturity assessment	The model lacked multi-dimensional indicators, evolutionary paths, and assessment methods. It also lacked empirical validation	The proposed model considered six main dimensions and 32 indicators. It adopted four levels of the evolutionary path and applied in a steel manufacturing organization
Lee et al. (2017)	Smart Assessment using Analytical Network Process	Describes the analytical framework and demonstrates with a case study in SMEs	The model lacked a clear description of dimensions, indicators, descriptive and prescriptive assessment	The proposed model has a clear measurement description of dimensions, indicators and provides descriptive and prescriptive assessment
De Carolis et al. (2017)	DREAMY	Discusses four dimensions- process, monitoring, technology, and organization	The model does not cover comprehensive dimensions and indicators and lacked empirical validation	The proposed model considered six main dimensions and 32 indicators. It adopted four levels of an evolutionary path and applied in a steel manufacturing organization
Agca et al. (2017)	I4.0 readiness assessment tool	The model provides a description and comparative assessment of four dimensions.	The model does not provide evolutionary paths and lacked a clear description of the assessment method	The proposed model has four levels of assessment and a measurement description of indicators with empirical validation
Blatz & Dietel (2018)	Maturity model	The model is designed for SMEs.	The model is designed for SMEs and lacked an assessment method	The proposed model is designed and applied in a large steel manufacturing organization

Continued (Table 1)

Author & Year	Name of the Model	Main contributions	Gaps	Our contribution
Scremin et al. (2018)	Maturity model	The model is adopted from earlier studies and focuses on a general assessment	The model does not provide a prescriptive and descriptive assessment	The proposed model provides prescriptive and descriptive assessment results
Akdil et al. (2018)	Maturity and readiness model for I4.0 strategy	The model discusses the strategy part of the organization and is limited to the retail sector	The model is limited to retail and focuses only on the strategic dimension and lacked a clear assessment method	The proposed model has six main dimensions and 32 indicators and has clear measurement and assessment results
Bibby & Dehe (2018)	I4.0 assessment model	The model discusses on technological aspect and is focused on the defence sector	The model focuses only on the technological aspect without a clear evolutionary path and assessment method	The proposed model focuses on six aspects and has a clear four-level evolutionary path for assessment
Rajnai & Kocsis (2018)	Maturity model	The model is linear and lacks granularity in dimensions	The model lacks the granularity of dimensions and indicators	The proposed model considered six major dimensions and 32 indicators
Mittal et al. (2018)	I4.0 readiness	Identified sixteenth specific requirements for SMEs considering organization, information, performance, and connectivity.	The model is limited to SMEs and lacked a clear description of dimensions, indicators, and assessment method	The proposed model has a clear description of measurement indicators and dimensions. It also has assessment and empirical validation
Colli et al. (2019)	360 Digital maturity assessment	The model is linear and focuses on the digital aspects of the organization.	The model lacked multi-dimensional indicators as it only focuses on the digital aspect	The proposed model considered major dimensions and indicators of the manufacturing organization
Sony & Naik (2019)	I4.0 maturity model	Reviews existing literature and proposes generic assessment tools.	The model lacks empirical validation and framework	The proposed study demonstrated the empirical application of the framework
Basl & Doucek(2019)	Metamodel for I4.0 readiness	The model provides a linear assessment framework	The model lacks comprehensive dimensions, indicators, and empirical validation	The proposed model has a clear description of measurement indicators and dimensions. It also has assessment and empirical validation

Continued (Table 1)

Author & Year	Name of the Model	Main contributions	Gaps	Our contribution
Trotta & Garengo (2019)	I4.0 maturity	The model is designed for the linear assessment of SMEs.	The model lacks clear dimensions, indicators, and assessment methods. It also lacks an assessment method and empirical validation	The proposed model has a clear description of measurement indicators and dimensions. It also has assessment and empirical validation
Santos & Marthinho (2019)	I4.0 maturity	The model validation is based on experts' opinions with linear assessment in the automobile sector	The model is linear and lacks a clear description of the assessment method	The proposed model has a clear description of measurement indicators and dimensions. It also has assessment and empirical validation
Pacchini et al. (2019)	I4.0 degree of readiness	The model has single dimensions to assess readiness in the automobile sector.	The model lacked dimensions, indicators, and assessment method	The proposed model has a clear description of measurement indicators and dimensions. It also has assessment and empirical validation
Moura & Kohl (2020)	I4.0 maturity assessment	The model contributes to the assessment of manufacturing organizations in three dimensions	The model lacks dimensions, indicators, and a clear description of the assessment method	The proposed model has a clear description of measurement indicators and dimensions. It also has assessment and empirical validation
Caiado et al. (2021)	OSCM4.0	The model only focuses on the operation supply chain dimension	The model lacks dimensions, indicators, and a clear description of the assessment method	The proposed model has a clear description of measurement indicators and dimensions. It also has assessment and empirical validation
Harmoko et al. (2020)	I4.0 readiness	The model provides a conceptual framework for SMEs	The model lacks empirical validation and description of indicators and dimensions	The proposed model has six main dimensions and 32 indicators and has clear measurement and assessment results
Wagire et al. (2020)	I4.0 maturity model	The case study is based on the limited response from experts in India	The model lacks a description of the measurement of dimensions, indicators, and prescriptive assessment results	The proposed model has a clear description of the measurement of dimensions, indicators and provides prescriptive and descriptive assessment results

Continued (Table 1)

Author & Year	Name of the Model	Main contributions	Gaps	Our contribution
Rafael et al. (2020)	I4.0 maturity	The model contributes to the assessment of maturity in the machine tools industry	The model lacks the granularity of dimensions and a clear assessment method	The proposed model has granular dimensions, indicators, and a clear assessment framework
Hajoary P.K(2021)	I4.0 maturity and readiness	Systematic literature review and found out dimensions for Industry 4.0 maturity and readiness assessment	The model lacks empirical validation and assessment method	The proposed model has a clear description of measurement indicators and dimensions. It also has assessment and empirical validation
Ruso et al.(2022)	ISO 9004 maturity model	The model focused on the quality aspect in Serbia	The model lacked prescriptive assessment and does not provide a comprehensive framework	The proposed model is prescriptive and provides a comprehensive assessment
Castelo-Branco et al.(2022)	Industry 4.0	The model focused on Portuguese manufacturing and considered only five constructs	The study does not provide comprehensive dimensions	The proposed model provides comprehensive dimensions
Alcácer et al (2022)	Industry 4.0 maturity model	The study focused on the automobile industry and is descriptive. The model evaluates the internal value chain	The model is descriptive and does not provide comprehensive dimensions and indicators	The proposed model provides comprehensive dimensions
Hajoary. P.K(2023)	Industry 4.0 maturity and readiness	The model focused on steel manufacturing organization and is descriptive	The model is descriptive and does not provide comprehensive dimensions	The proposed model provides comprehensive dimensions

Table 2. Maturity levels

Maturity Value	Maturity Level	Definition
4.00	Level 4: Industry 4.0	The organization manually manufactures using mechanical equipment with no intervention of digital technologies
3.00	Level 3: Industry 3.0	The organization mass produces with the help of basic digital skills with low or no variety of products
2.00	Level 2: Industry 2.0	The organization mass customizes its products using selected automation
1.00	Level 1: Industry 1.0	The organization manufactures hyper-personalized products using advanced technologies

Table 3. Dimensions and Industry 4.0 maturity indicators

Author(s)	**Dimension**	**Indicators**	**Description of measurement indicators**
Brettel et al. (2014); Lichtblau et al. (2015); Santos et al. (2017); BCG (2018); Deloitte (2018); Moura & Kohl (2020); Wagire et al. (2020); Rafael et al. (2020); Hajoary & Akhilesh (2020)	Strategy & Organization	Degree of organizational strategy	The company's degree of organizational strategy to digital vision and roadmap towards Industry 4.0
		Measurement (KPIs)	The company's ability to measure Industry 4.0 plans and development in the entire value chain
		Leadership	The leadership team's level of awareness and widespread support for Industry 4.0
		Collaboration	The company's extent to collaborate with internal and cross-company to drive improvements
		Employee Capability	The level of employees' digital and analytical skills
		Skill acquisition	The company's level of acquisition of required Industry 4.0 skills and qualification
Rockwell Automation (2014); PwC (2016); Schumacher et al. (2016); Passi(2017); Agca et al. (2017); Hajoary & Akhilesh (2020)	Business Model	As a service business model	The company's extent to offer a product as a service to customers.
		Marketing Channels	The company's degree of use of online digital marketing channels across all channels-for example, integration of online and offline
		Data-driven decisions	The company's degree of customer data to make decisions
Lichtblau et al. (2015); Anderl et al. (2015); Schumacher et al. (2016); Agca et al. (2017); Bandara et al. (2019); Hajoary & Akhilesh (2020); Wagire et al. (2020); Rafael et al. (2020);	Manufacturing & Operations	Automation	The company's ability to control process equipment and system infrastructure through automation.
		M2M Integration	The company's ability to communicate information through machine-to-machine via network and interoperability in the entire value chain
		Equipment up-gradation	The company's ability to upgrade the existing machine, systems, and processes
		Material handling equipment automation	The company's level of automation of material handling equipment used in operations

Table 3(Continued)

Author(s)	**Dimension**	**Indicators**	**Description of measurement indicators**
Lichtblau et al. (2015); Anderl et al. (2015); Schumacher et al. (2016); Agca et al. (2017); Bandara et al. (2019); Hajoary & Akhilesh (2020); Wagire et al. (2020); Rafael et al. (2020);	Manufacturing & Operations	Self-optimizing processes	The company's level of self-optimization in the manufacturing process, i.e machine-driven self-optimizing processes.
		Digital Modeling	The company's level of use of digital modeling technologies like 3D printing and simulation for designing and prototyping.
		Scheduling & Maintenance	The company's ability to self-diagnose and schedule maintenance based on real-time data inputs from machines.
		IT & Data Security	The company's level of data storage and security in manufacturing and operations.
		Cloud Usage	The company's use of the cloud to store data and retrieve information from the cloud network.
Agca et al. (2017); Sony & Naik (2019); Hajoary & Akhilesh (2020); Caiado et al. (2020); Wagire et al.(2020); Hajoary(2021)	Supply Chain	Inventory control using real-time data management	The company's level of use of real-time data to optimize its supply chain.
		Supply Chain integration	The company's level of integration with suppliers and customers on order tracking and delivery
		Supply chain visibility	The company's end-to-end supply chain visibility in real-time throughout the inventory, operation, delivery etc.
		Supply Chain flexibility	The company's level of response time to changes in market and customer requirements.
		Lead times	The company's lead time is taken in pre-processing and post-processing stages in the supply chain.

Table 3(Continued)

Author(s)	**Dimension**	**Indicators**	**Description of measurement indicators**
Lee et al. (2014); Schumacher et al. (2016); Westermann et al. (2016); Leyh et al. (2016); Klötzer and Pflaum (2017); Agca et al. (2017); Liao et al. (2017); Blatz and Dietel (2018); Akdil et al. (2018); Canetta (2018); Axelsson et al. (2018); Bandara et al. (2019); Santos & Martinho (2019); Hajoary & Akhilesh (2020); Rafael et al. (2020)	Products and Services	Product Customization	The company's ability to customize products as per the needs of the customers.
		Digital features	The company's use of digital features like RFID, intelligent sensors, and online tracking of the products.
		Data-driven services	The company's ability to provide data-driven services by analyzing the historical data of products to the customers.
		Share of revenue	The level of the company's share of revenue accounted for data-driven services.
		Data capturing mechanism	The company's ability to capture data and back up continuously using cloud storage.
		Product Tracking	The company's ability to track products throughout their life cycle using technologies.
Authors own	Production Technology	Production Technology	The company's level of use of production technologies such as Lean, MES and FMS.
		Production System automation	The company's level of digitalization and automation of production systems at the factory level.

Table 4. Strategy and Organization weighted average value

Dimension	**Indicators**	**Weighted Average value**	**Overall weighted average value**
Strategy & Organization	Degree of organizational strategy	1.58	2.22
	Measurement (KPIs)	3.24	
	Leadership	2.81	
	Collaboration	2.03	
	Employee Capability	1.87	
	Skill acquisition	1.84	

Table 5. Strategy and Organization weighted average value

Dimension	Indicators	Weighted Average value	Overall weighted average value
Strategy & Organization	Degree of organizational strategy	1.58	2.22
	Measurement (KPIs)	3.24	
	Leadership	2.81	
	Collaboration	2.03	
	Employee Capability	1.87	
	Skill acquisition	1.84	

Table 6. Business model weighted average value

Dimension	Indicators	Weighted average value	Overall weighted average value
Business Model	As a service business model	2.10	2.18
	Marketing Channels	2.27	
	Data-driven decisions	2.17	

Table 7. Manufacturing and operations weighted average value

Dimension	Indicators	Weighted average value	Overall weighted average value
Manufacturing & Operations	Systems Automation	2.47	2.30
	M2M Integration	2.20	
	Equipment up-gradation	2.08	
	Material handling equipment automation	2.37	
	Self-optimizing processes	2.35	
	Digital Modeling	1.94	
	Scheduling & Maintenance	2.30	
	IT & Data Security	2.49	
	Cloud Usage	2.56	

Table 8. Supply chain-weighted average value

Dimension	Indicators	Weighted average value	Overall weighted average value
Supply Chain	Inventory control using real-time data management	2.85	2.55
	Supply Chain integration	2.62	
	Supply chain visibility	2.43	
	Supply Chain flexibility	2.42	
	Lead times	2.47	

Table 9. Products and Services weighted average value

Dimension	Indicators	Weighted Average value	Overall Weighted Average value
Products and Services	Product Customization	1.92	2.20
	Digital features	1.98	
	Data-driven services	2.21	
	Share of revenue	2.58	
	Data capturing mechanism	2.04	
	Product Tracking	2.47	

Table 10. Production Technology weighted average value

Dimension	Indicators	Weighted Average value	Overall Weighted Average value
Production Technology	Production Technology	2.42	2.52
	Production System automation	2.63	

Table 11. Overall Industry 4.0 Maturity value

Dimension	Weighted Average Value	Overall Weighted Average Value
Strategy & Organization	2.22	2.32
Business Model	2.18	
Manufacturing & Operations	2.30	
Supply Chain	2.55	
Products & Services	2.20	
Production Technology	2.52	

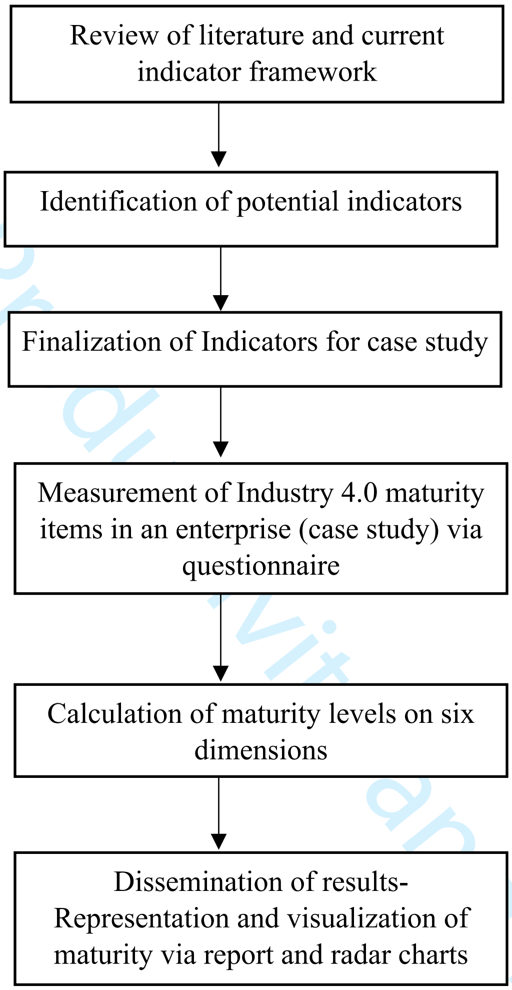

Figure 1. Procedure for Indicator development and its application (Balaban, 2013; Schumacher et al., 2016)

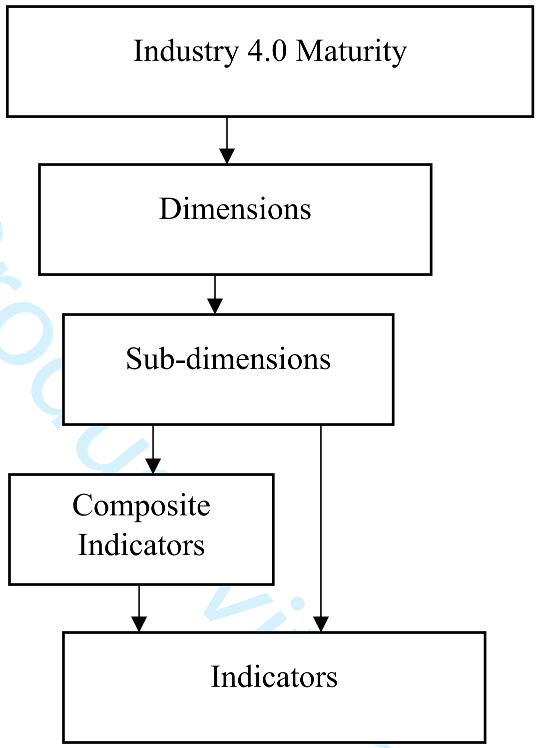

Figure 2. Schematic of Industry 4.0 maturity framework

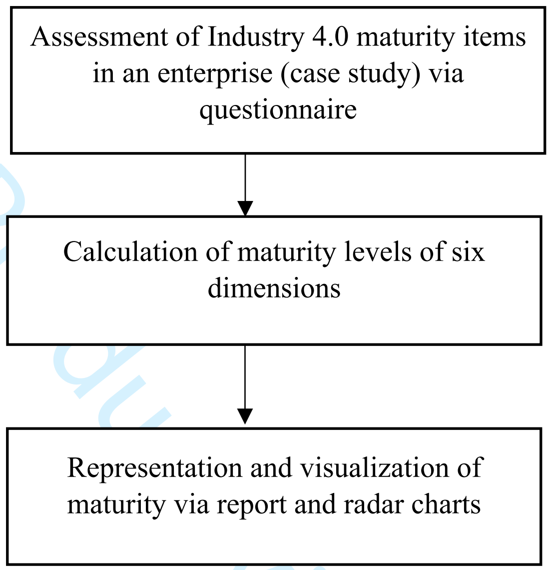

Figure 3. Procedures to assess Industry 4.0 maturity (Schumacher et al.,2016)

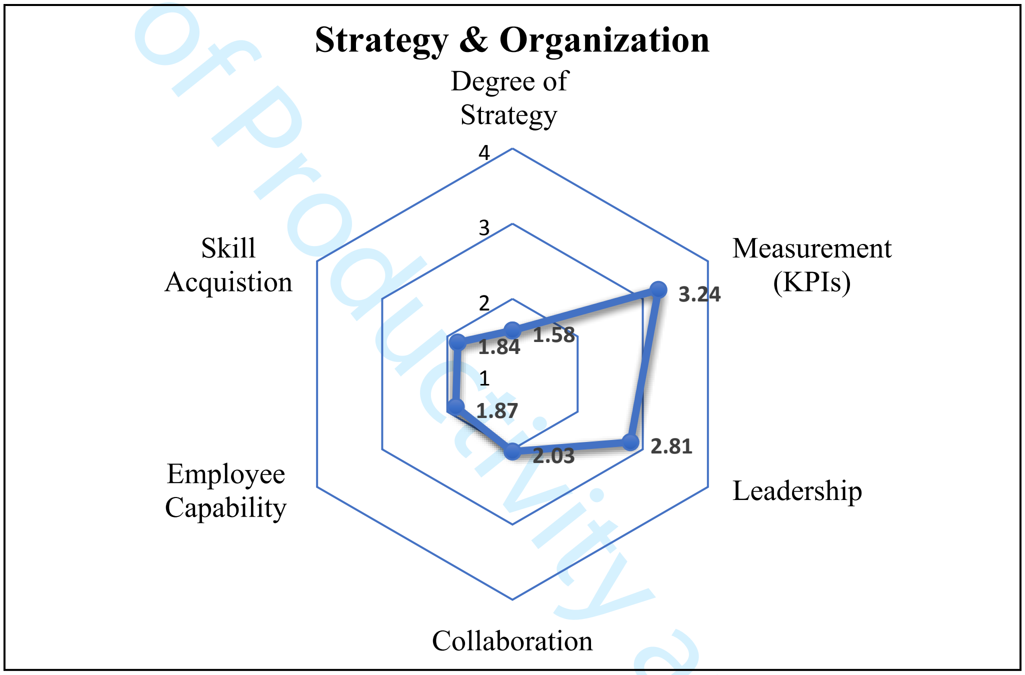

Figure 4. Industry 4.0 maturity level- Strategy and Organization

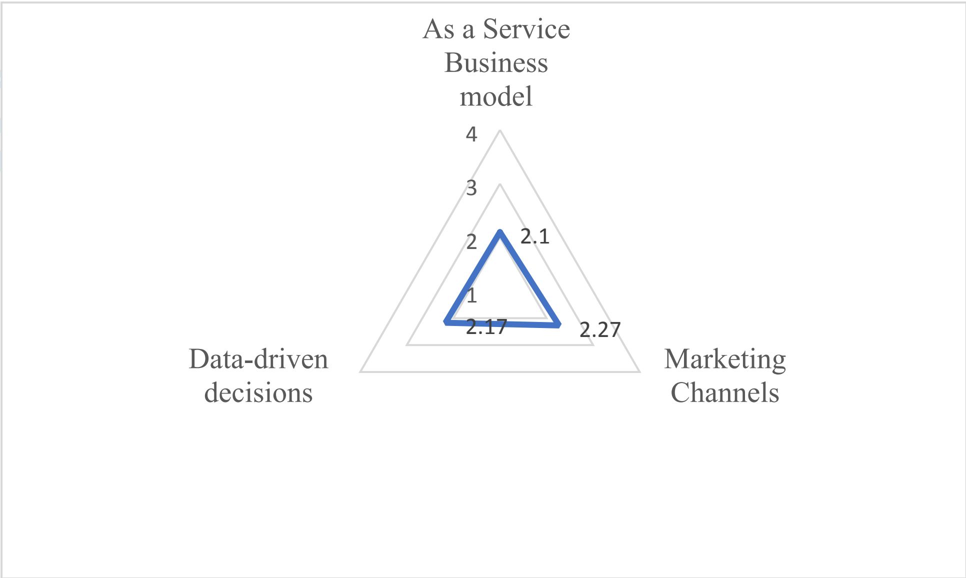

Figure 5. Industry 4.0 maturity level- Business model

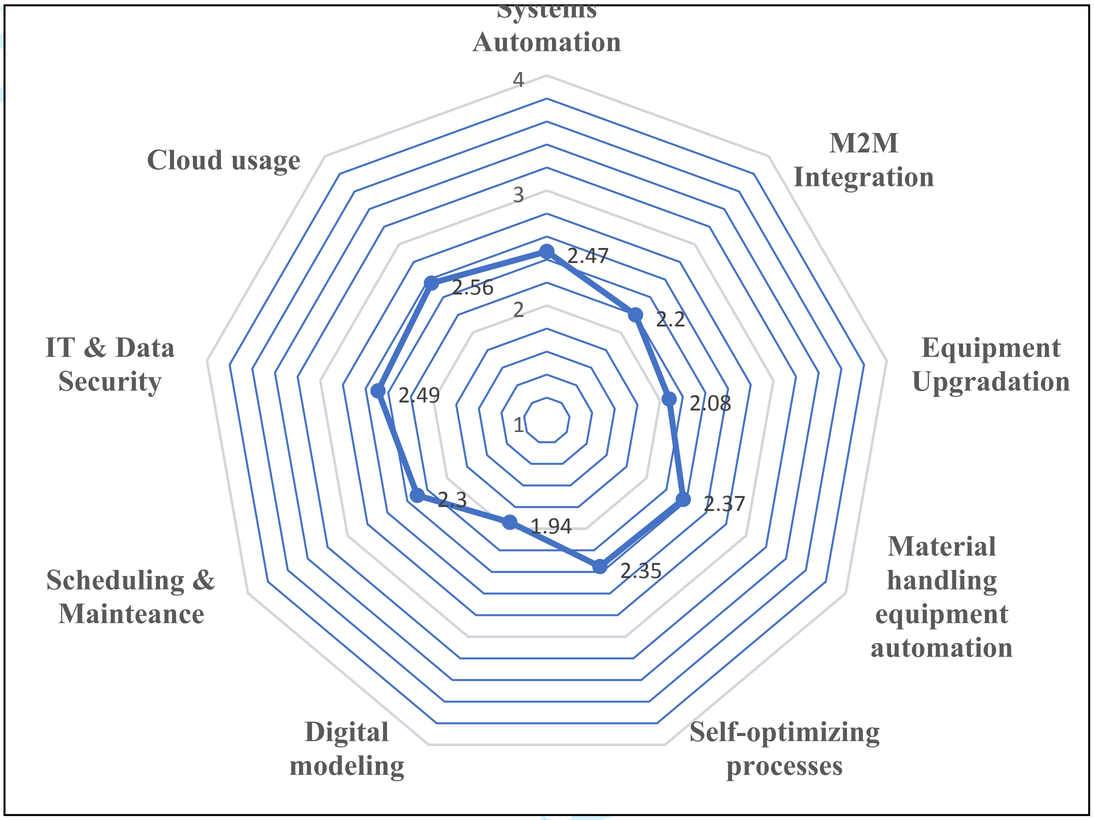

Figure 6. Industry 4.0 maturity level- Manufacturing & Operations

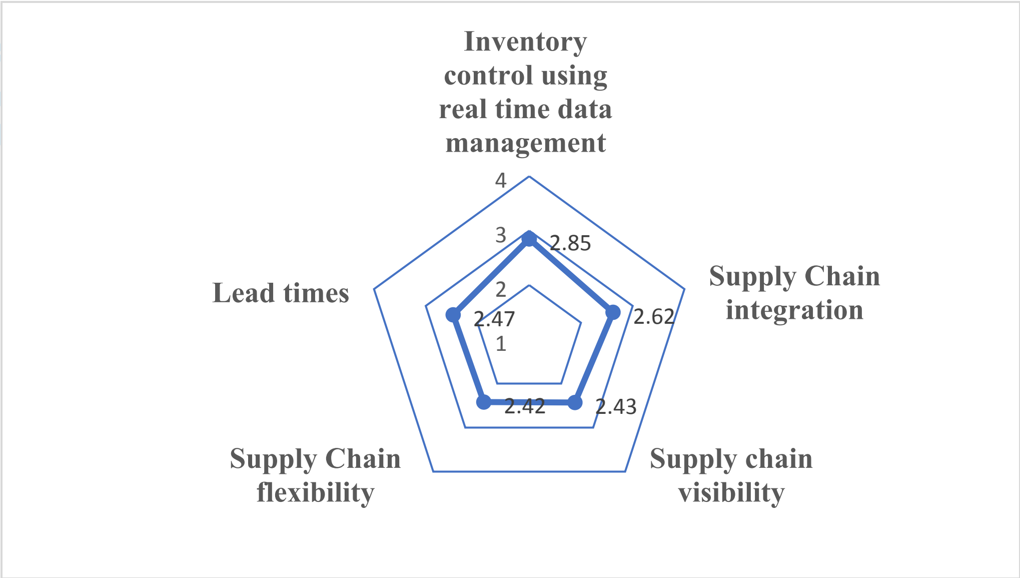

Figure 7. Industry 4.0 maturity level- Supply Chain

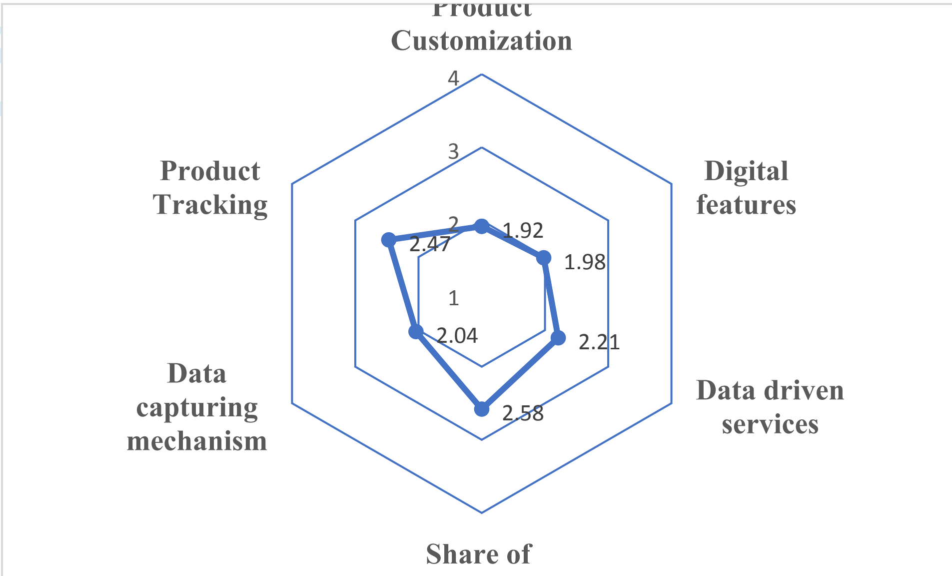

Figure 8. Industry 4.0 maturity level- Products and Services

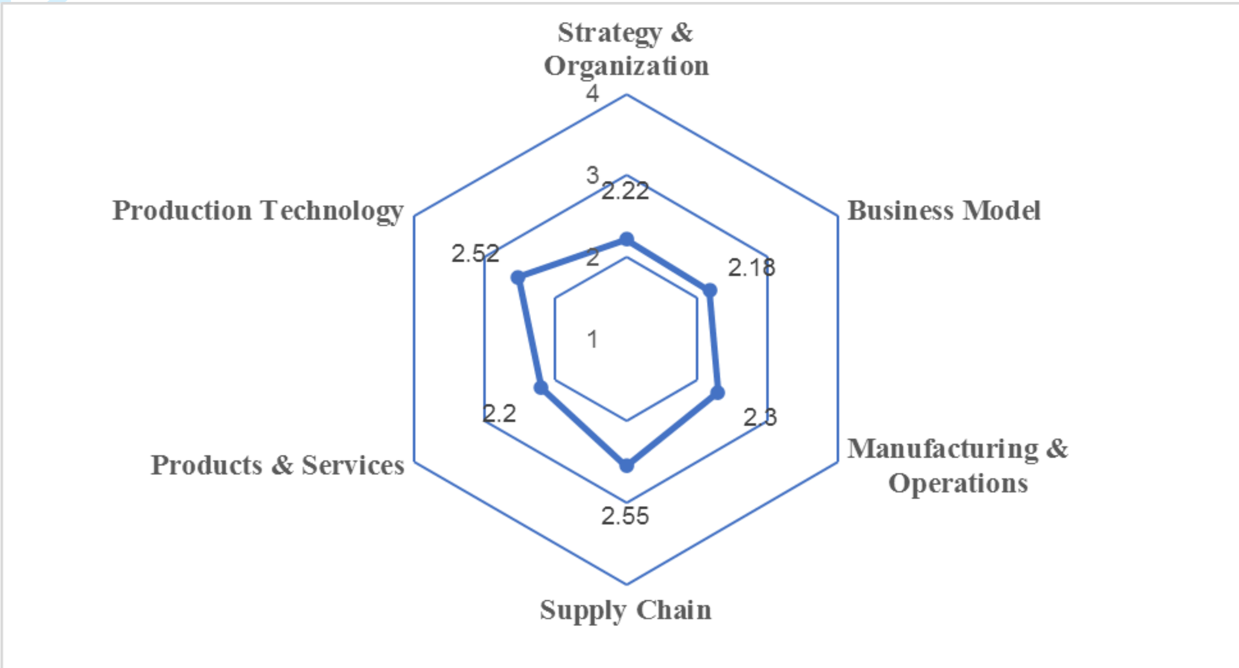

Figure 9. Overall Industry 4.0 Maturity level

Table 1. Summary of previous literature on Industry 4.0 maturity models

Author & Year	Name of the Model	Main contributions	Gaps	Our contribution
Kubrick (2012)	dStrategy Digital Maturity Model™	The model focused on digital maturity	The model has no maturity assessment method and empirical validation	The proposed model is empirically validated
Lichtblau et al. (2015)	IMPULS- I4.0 readiness	The study surveyed 232 employees of the manufacturing organization with six dimensions.	The model lacked a comparative and descriptive assessment method	The proposed model provides prescriptive and descriptive assessment methods and measurable results
Andrel et al. (2015)	RAM14.0	The model is conceptual and consists of six dimensions.	The model lacked a description of the assessment method and validation	The proposed model provides a detailed description of the measurement and assessment method
Westernman et al. (2016)	I4.0 readiness	The model is conceptual and designed for mechanical firms.	The model lacked granular dimensions, evolutionary paths, assessment, and empirical validation	The proposed model has comprehensive dimensions, four levels of evolution path and empirical validation
Schumacher et al. (2016)	I4.0 readiness & maturity	The model is linear with nine dimensions-strategy, leadership, customers, products, operations, culture, people, governance, and technology.	The model lacked clear indicators, evolutionary paths, measurement attributes and assessment method	The proposed model has 32 indicators that measure the maturity and has four levels of evolutionary path
PwC (2016)	I4.0/Digital Operations Self-Assessment	The model is a self-assessment tool on six dimensions-business model, processes, IT architecture, compliance, organization, and culture.	The model lacked a clear description of indicators and empirical validation	The proposed model has a clear description of the measured indicators and was validated with a case study
Ganzarain & Errasti (2016)	Three-Stage maturity model	The results showed the need to design a company-specific vision and planning.	The model lacked multi-dimensions, indicators, assessment methods and empirical validation	The proposed model considered the most important dimensions, indicators along with empirical validation
Leyh et al. (2016)	SIMMI4.0	The model consists of five stages-basic level, cross-departmental level, horizontal and vertical level, full digitalization level, and optimized full digitalization	The model lacked granular dimensions, a clear assessment method and empirical validation	The proposed model focused on important dimensions, a four-stage evolution path along with its application in a steel manufacturing organization
Jung et al (2016)	SMRL	The model focuses on ICT.	The model is limited to ICT and lacked an assessment method, description of indicators and assessment method	The proposed model considered people, process, and technology aspects along with measurement description and method

Continued (Table 1)

Author & Year	Name of the Model	Main contributions	Gaps	Our contribution
KPMG (2016)	Digital readiness assessment	The model focuses on four dimensions- development and purchasing, production, marketing, sales	The model lacked comprehensive dimensions, indicators and lacked empirical validation	The proposed model has comprehensive six dimensions, 32 indicators and empirical validation
Weber et al. (2017)	M2DDM	The model focuses on the IT industry and provides a development path.	The model is limited to IT and does not provide comprehensive dimensions	The proposed model has comprehensive dimensions and an assessment method for manufacturing organizations
Gokalp et al. (2017)	I4.0 MM	The model has six dimensions -asset management, data governance, application management, process transformation, and organizational alignment.	The model lacked empirical validation and a complete description of the assessment method	The proposed model has four levels of assessment and a measurement description of indicators with empirical validation
Schuh et al. (2017)	I4.0 maturity index	Provides an index-based maturity assessment	The model lacked multi-dimensional indicators, evolutionary paths, and assessment methods. It also lacked empirical validation	The proposed model considered six main dimensions and 32 indicators. It adopted four levels of the evolutionary path and applied in a steel manufacturing organization
Lee et al. (2017)	Smart Assessment using Analytical Network Process	Describes the analytical framework and demonstrates with a case study in SMEs	The model lacked a clear description of dimensions, indicators, descriptive and prescriptive assessment	The proposed model has a clear measurement description of dimensions, indicators and provides descriptive and prescriptive assessment
De Carolis et al. (2017)	DREAMY	Discusses four dimensions- process, monitoring, technology, and organization	The model does not cover comprehensive dimensions and indicators and lacked empirical validation	The proposed model considered six main dimensions and 32 indicators. It adopted four levels of an evolutionary path and applied in a steel manufacturing organization
Agca et al. (2017)	I4.0 readiness assessment tool	The model provides a description and comparative assessment of four dimensions.	The model does not provide evolutionary paths and lacked a clear description of the assessment method	The proposed model has four levels of assessment and a measurement description of indicators with empirical validation
Blatz & Dietel (2018)	Maturity model	The model is designed for SMEs.	The model is designed for SMEs and lacked an assessment method	The proposed model is designed and applied in a large steel manufacturing organization

Continued (Table 1)

Author & Year	Name of the Model	Main contributions	Gaps	Our contribution
Scremin et al. (2018)	Maturity model	The model is adopted from earlier studies and focuses on a general assessment	The model does not provide a prescriptive and descriptive assessment	The proposed model provides prescriptive and descriptive assessment results
Akdil et al. (2018)	Maturity and readiness model for I4.0 strategy	The model discusses the strategy part of the organization and is limited to the retail sector	The model is limited to retail and focuses only on the strategic dimension and lacked a clear assessment method	The proposed model has six main dimensions and 32 indicators and has clear measurement and assessment results
Bibby & Dehe (2018)	I4.0 assessment model	The model discusses on technological aspect and is focused on the defence sector	The model focuses only on the technological aspect without a clear evolutionary path and assessment method	The proposed model focuses on six aspects and has a clear four-level evolutionary path for assessment
Rajnai & Kocsis (2018)	Maturity model	The model is linear and lacks granularity in dimensions	The model lacks the granularity of dimensions and indicators	The proposed model considered six major dimensions and 32 indicators
Mittal et al. (2018)	I4.0 readiness	Identified sixteenth specific requirements for SMEs considering organization, information, performance, and connectivity.	The model is limited to SMEs and lacked a clear description of dimensions, indicators, and assessment method	The proposed model has a clear description of measurement indicators and dimensions. It also has assessment and empirical validation
Colli et al. (2019)	360 Digital maturity assessment	The model is linear and focuses on the digital aspects of the organization.	The model lacked multi-dimensional indicators as it only focuses on the digital aspect	The proposed model considered major dimensions and indicators of the manufacturing organization
Sony & Naik (2019)	I4.0 maturity model	Reviews existing literature and proposes generic assessment tools.	The model lacks empirical validation and framework	The proposed study demonstrated the empirical application of the framework
Basl & Doucek(2019)	Metamodel for I4.0 readiness	The model provides a linear assessment framework	The model lacks comprehensive dimensions, indicators, and empirical validation	The proposed model has a clear description of measurement indicators and dimensions. It also has assessment and empirical validation

Continued (Table 1)

Author & Year	Name of the Model	Main contributions	Gaps	Our contribution
Trotta & Garengo (2019)	I4.0 maturity	The model is designed for the linear assessment of SMEs.	The model lacks clear dimensions, indicators, and assessment methods. It also lacks an assessment method and empirical validation	The proposed model has a clear description of measurement indicators and dimensions. It also has assessment and empirical validation
Santos & Marthinho (2019)	I4.0 maturity	The model validation is based on experts' opinions with linear assessment in the automobile sector	The model is linear and lacks a clear description of the assessment method	The proposed model has a clear description of measurement indicators and dimensions. It also has assessment and empirical validation
Pacchini et al. (2019)	I4.0 degree of readiness	The model has single dimensions to assess readiness in the automobile sector.	The model lacked dimensions, indicators, and assessment method	The proposed model has a clear description of measurement indicators and dimensions. It also has assessment and empirical validation
Moura & Kohl (2020)	I4.0 maturity assessment	The model contributes to the assessment of manufacturing organizations in three dimensions	The model lacks dimensions, indicators, and a clear description of the assessment method	The proposed model has a clear description of measurement indicators and dimensions. It also has assessment and empirical validation
Caiado et al. (2021)	OSCM4.0	The model only focuses on the operation supply chain dimension	The model lacks dimensions, indicators, and a clear description of the assessment method	The proposed model has a clear description of measurement indicators and dimensions. It also has assessment and empirical validation
Harmoko et al. (2020)	I4.0 readiness	The model provides a conceptual framework for SMEs	The model lacks empirical validation and description of indicators and dimensions	The proposed model has six main dimensions and 32 indicators and has clear measurement and assessment results
Wagire et al. (2020)	I4.0 maturity model	The case study is based on the limited response from experts in India	The model lacks a description of the measurement of dimensions, indicators, and prescriptive assessment results	The proposed model has a clear description of the measurement of dimensions, indicators and provides prescriptive and descriptive assessment results

Continued (Table 1)

Author & Year	Name of the Model	Main contributions	Gaps	Our contribution
Rafael et al. (2020)	I4.0 maturity	The model contributes to the assessment of maturity in the machine tools industry	The model lacks the granularity of dimensions and a clear assessment method	The proposed model has granular dimensions, indicators, and a clear assessment framework
Hajoary P.K(2021)	I4.0 maturity and readiness	Systematic literature review and found out dimensions for Industry 4.0 maturity and readiness assessment	The model lacks empirical validation and assessment method	The proposed model has a clear description of measurement indicators and dimensions. It also has assessment and empirical validation
Ruso et al.(2022)	ISO 9004 maturity model	The model focused on the quality aspect in Serbia	The model lacked prescriptive assessment and does not provide a comprehensive framework	The proposed model is prescriptive and provides a comprehensive assessment
Castelo-Branco et al.(2022)	Industry 4.0	The model focused on Portuguese manufacturing and considered only five constructs	The study does not provide comprehensive dimensions	The proposed model provides comprehensive dimensions
Alcácer et al (2022)	Industry 4.0 maturity model	The study focused on the automobile industry and is descriptive. The model evaluates the internal value chain	The model is descriptive and does not provide comprehensive dimensions and indicators	The proposed model provides comprehensive dimensions
Hajoary. P.K(2023)	Industry 4.0 maturity and readiness	The model focused on steel manufacturing organization and is descriptive	The model is descriptive and does not provide comprehensive dimensions	The proposed model provides comprehensive dimensions

Table 2. Industry 4.0 Maturity Levels

Maturity Value	Maturity Level	Definition
4.00	Level 4: Industry 4.0	The organization manually manufactures using mechanical equipment with no intervention of digital technologies
3.00	Level 3: Industry 3.0	The organization mass produces with the help of basic digital skills with low or no variety of products
2.00	Level 2: Industry 2.0	The organization mass customizes its products using selected automation
1.00	Level 1: Industry 1.0	The organization manufactures hyper-personalized products using advanced technologies

Table 3. Dimensions and Industry 4.0 maturity indicators

Author(s)	Dimension	Indicators	Description of measurement indicators
Brettel et al. (2014); Lichtblau et al. (2015); Santos et al. (2017); BCG (2018); Deloitte (2018); Moura & Kohl (2020); Wagire et al. (2020); Rafael et al. (2020); Hajoary & Akhilesh (2020)	Strategy & Organization	Degree of organizational strategy	The company's degree of organizational strategy to digital vision and roadmap towards Industry 4.0
		Measurement (KPIs)	The company's ability to measure Industry 4.0 plans and development in the entire value chain
		Leadership	The leadership team's level of awareness and widespread support for Industry 4.0
		Collaboration	The company's extent to collaborate with internal and cross-company to drive improvements
		Employee Capability	The level of employees' digital and analytical skills
		Skill acquisition	The company's level of acquisition of required Industry 4.0 skills and qualification
Rockwell Automation (2014); PwC (2016); Schumacher et al. (2016); Passi(2017); Agca et al. (2017); Hajoary & Akhilesh (2020)	Business Model	As a service business model	The company's extent to offer a product as a service to customers.
		Marketing Channels	The company's degree of use of online digital marketing channels across all channels-for example, integration of online and offline
		Data-driven decisions	The company's degree of customer data to make decisions
Lichtblau et al. (2015); Anderl et al. (2015); Schumacher et al. (2016); Agca et al. (2017); Bandara et al. (2019); Hajoary & Akhilesh (2020); Wagire et al. (2020); Rafael et al. (2020);	Manufacturing & Operations	Automation	The company's ability to control process equipment and system infrastructure through automation.
		M2M Integration	The company's ability to communicate information through machine-to-machine via network and interoperability in the entire value chain
		Equipment up-gradation	The company's ability to upgrade the existing machine, systems, and processes
		Material handling equipment automation	The company's level of automation of material handling equipment used in operations

Table 3(Continued)

Author(s)	**Dimension**	**Indicators**	**Description of measurement indicators**
Lichtblau et al. (2015); Anderl et al. (2015); Schumacher et al. (2016); Agca et al. (2017); Bandara et al. (2019); Hajoary & Akhilesh (2020); Wagire et al. (2020); Rafael et al. (2020);	Manufacturing & Operations	Self-optimizing processes	The company's level of self-optimization in the manufacturing process, i.e machine-driven self-optimizing processes.
		Digital Modeling	The company's level of use of digital modeling technologies like 3D printing and simulation for designing and prototyping.
		Scheduling & Maintenance	The company's ability to self-diagnose and schedule maintenance based on real-time data inputs from machines.
		IT & Data Security	The company's level of data storage and security in manufacturing and operations.
		Cloud Usage	The company's use of the cloud to store data and retrieve information from the cloud network.
Agca et al. (2017); Sony & Naik (2019); Hajoary & Akhilesh (2020); Caiado et al. (2020); Wagire et al.(2020); Hajoary(2021)	Supply Chain	Inventory control using real-time data management	The company's level of use of real-time data to optimize its supply chain.
		Supply Chain integration	The company's level of integration with suppliers and customers on order tracking and delivery
		Supply chain visibility	The company's end-to-end supply chain visibility in real-time throughout the inventory, operation, delivery etc.
		Supply Chain flexibility	The company's level of response time to changes in market and customer requirements.
		Lead times	The company's lead time is taken in pre-processing and post-processing stages in the supply chain.

Table 3(Continued)

Author(s)	Dimension	Indicators	Description of measurement indicators
Lee et al. (2014); Schumacher et al. (2016); Westermann et al. (2016); Leyh et al. (2016); Klötzer and Pflaum (2017); Agca et al. (2017); Liao et al. (2017); Blatz and Dietel (2018); Akdil et al. (2018); Canetta (2018); Axelsson et al. (2018); Bandara et al. (2019); Santos & Martinho (2019); Hajoary & Akhilesh (2020); Rafael et al. (2020)	Products and Services	Product Customization	The company's ability to customize products as per the needs of the customers.
		Digital features	The company's use of digital features like RFID, intelligent sensors, and online tracking of the products.
		Data-driven services	The company's ability to provide data-driven services by analyzing the historical data of products to the customers.
		Share of revenue	The level of the company's share of revenue accounted for data-driven services.
		Data capturing mechanism	The company's ability to capture data and back up continuously using cloud storage.
		Product Tracking	The company's ability to track products throughout their life cycle using technologies.
Authors own	Production Technology	Production Technology	The company's level of use of production technologies such as Lean, MES and FMS.
		Production System automation	The company's level of digitalization and automation of production systems at the factory level.

Table 4. Strategy and Organization weighted average value

Dimension	Indicators	Weighted Average value	Overall weighted average value
Strategy & Organization	Degree of organizational strategy	1.58	2.22
	Measurement (KPIs)	3.24	
	Leadership	2.81	
	Collaboration	2.03	
	Employee Capability	1.87	
	Skill acquisition	1.84	

Table 5. Strategy and Organization weighted average value

Dimension	Indicators	Weighted Average value	Overall weighted average value
Strategy & Organization	Degree of organizational strategy	1.58	2.22
	Measurement (KPIs)	3.24	
	Leadership	2.81	
	Collaboration	2.03	
	Employee Capability	1.87	
	Skill acquisition	1.84	

Table 6. Business model weighted average value

Dimension	Indicators	Weighted average value	Overall weighted average value
Business Model	As a service business model	2.10	2.18
	Marketing Channels	2.27	
	Data-driven decisions	2.17	

Table 7. Manufacturing and operations weighted average value

Dimension	Indicators	Weighted average value	Overall weighted average value
Manufacturing & Operations	Systems Automation	2.47	2.30
	M2M Integration	2.20	
	Equipment up-gradation	2.08	
	Material handling equipment automation	2.37	
	Self-optimizing processes	2.35	
	Digital Modeling	1.94	
	Scheduling & Maintenance	2.30	
	IT & Data Security	2.49	
	Cloud Usage	2.56	

Table 8. Supply chain-weighted average value

Dimension	Indicators	Weighted average value	Overall weighted average value
Supply Chain	Inventory control using real-time data management	2.85	2.55
	Supply Chain integration	2.62	
	Supply chain visibility	2.43	
	Supply Chain flexibility	2.42	
	Lead times	2.47	

Table 9. Products and Services weighted average value

Dimension	Indicators	Weighted Average value	Overall Weighted Average value
Products and Services	Product Customization	1.92	2.20
	Digital features	1.98	
	Data-driven services	2.21	
	Share of revenue	2.58	
	Data capturing mechanism	2.04	
	Product Tracking	2.47	

Table 10. Production Technology weighted average value

Dimension	Indicators	Weighted Average value	Overall Weighted Average value
Production Technology	Production Technology	2.42	2.52
	Production System automation	2.63	

Table 11. Overall Industry 4.0 Maturity value

Dimension	Weighted Average Value	Overall Weighted Average Value
Strategy & Organization	2.22	2.32
Business Model	2.18	
Manufacturing & Operations	2.30	
Supply Chain	2.55	
Products & Services	2.20	
Production Technology	2.52	