Article: DOI: 10.70906/20251903024041

Assessing Industry 4.0 Readiness in Karnataka's Manufacturing Industries using AHP Analysis

Samapika Satapathy*
M A Rasheed**
Santanu Kumar Das***

Abstract

A
b
s
t
r
a
c
t

Industry 4.0 shows a major transformation in manufacturing processes by implementing advanced digital technologies. Understanding an organization's level of preparedness for implementing these technologies is crucial. Therefore, the main aim of this study is to demonstrate a detailed readiness assessment model for I4.0 implementation, specifically targeting the industrial suburbs of Karnataka. Through an extensive literature review, we identify key enabling technologies and examine existing maturity models, which together serve as the foundation for our proposed readiness model. This framework will help organizations assess their current capabilities and determine the necessary steps for an effective transition to I4.0. Using the Analytic Hierarchy Process (AHP), we construct a conceptual method to evaluate organizational readiness. Our research highlights six critical I4.0 readiness constructs, which serve as the pillars for integrating advanced technologies. Expert opinions were gathered to prioritize these constructs, ensuring consistency in the degree of readiness evaluation for adopting I4.0. A questionnaire-based model, developed with insights from industry experts, provides a scoring system to assess readiness dimensions and sub-dimensions. The resulting scores reveal the current preparedness levels, pinpointing areas for improvement and opportunities for technological integration. The readiness model presented in this study offers an industrial personalized tool to assess their readiness to adapt to I4.0. It is recommended to explore the interdependencies of readiness dimensions and extend the assessment to other industrial sectors and regions outside the industrial estate of Karnataka in the future research scope.

Keywords: industry 4.0, readiness assessment, industry 4.0 implementation, ahp analysis, digital transformation.

How to Cite: *Satapathy, S., Rasheed, M. A., & Das, S. K. (2025). Assessing Industry 4.0 readiness in Karnataka's manufacturing industries using AHP analysis. Journal of Management and Entrepreneurship, 19(3), 24–41.*

DOI: 10.70906/20251903024041

* Ph.D. Research Scholar, School of Management Studies, GIET University, Gunupur, Odisha, India, Email:samapika.satapathy@giet.edu, Mobile Number: 9741144660

** Professor, School of Management Studies, GIET University, Gunupur, Odisha, India, E-mail- rasheed.mhrm@gmail.com

*** Dean Academics, Gandhi Global Business Studies, Berhampur, Odisha, India, E- mail- santanu.das.kumar@gmail.com

1. Introduction

The progression of industrial revolutions began with Industry 1.0 in the late 18th century, driven by steam-powered mechanization, followed by Industry 2.0 in the late 19th century with the rise of electricity and mass production. Industry 3.0 emerged in the mid-20th century, introducing computers and automation. Building on these foundations, Industry 4.0 leverages digital connectivity and intelligent systems to reshape industrial ecosystems and foster sustainable innovation (Rupp et al., 2021, Schwab, 2017). The digital revolution marks a fundamental shift from analogue systems to a modern, digitally interconnected world. Within this broader transformation, Industrial Revolution 4.0 (IR 4.0) represents a paradigm shift in manufacturing and production industries, characterized by increasing automation and seamless data exchange across technologies and processes. Core technologies driving IR 4.0 include artificial intelligence (AI), cloud computing, cognitive computing, cyber-physical systems (CPS), and the Internet of Things (IoT). These technologies enable the development of smart factories and smart manufacturing systems, where physical assets are digitally connected and managed to enhance efficiency, responsiveness, and innovation (Shah et al., 2024). Industry 4.0, indicates a substantial transformation in the manufacturing industry, poised to revolutionize manufacturing systems by enhancing organizational efficiency, minimizing waste, and reducing repetitive tasks. Essentially, Industry 4.0 technologies aim to digitally, horizontally, and vertically integrate the physical and virtual domains of industrial operations.

I4.0 technologies have the potential to improve the utilization of energy, equipment, and human resources (Castelo-Branco et al., 2019). Essentially, I4.0 technologies aim to associate physical machines with the virtual worlds digitally, horizontally, and vertically (Sanghavi et al., 2019). A smart factory seamlessly integrates production technology, logistics, marketing and operational management to create an efficient and responsive manufacturing environment. This holistic approach ensures that all aspects of the production process work together harmoniously, leveraging advanced technologies to optimize performance and adapt to changing market demands (Kumar et al., 2022)

I4.0 has been considered as an industrial wave to significantly transform manufacturing systems by practitioners in improving organizational competence by reducing waste and repetitive tasks. The implementation of smart factories, technology integrations, and automation of various manual systems pose significant challenges for existing manufacturing firms. There is a knowledge gap and a lack of understanding regarding technology development and improvement in business demands (Kumar et al., 2022).

To facilitate organizational change, it is essential to identify the present state of the organization and prepare it for technological transformation with I4.0. Critical readiness assessments lay the groundwork for companies to initiate I4.0 transformation (Faisal et al., 2023). Therefore, comprehending the present preparedness level of the organizations for I4.0 is crucial (Genest & Gamache, 2020). These assessments enable organizations to make informed decisions about integrating advanced technologies, ensuring a smooth transition and successful implementation of I4.0 principles.

The principal objective of this paper is to aid organizations in assessing their readiness for the essential prerequisites required to initiate the implementation of I4.0 (Khin & Kee, 2022). This readiness assessment framework supports industries to access their current state and prepare for the technological transformation necessary to adapt I4.0 principles, ensuring a smoother transition and successful integration of advanced technologies. By providing a structured approach to evaluating readiness, this paper aims to support organizations in identifying gaps, making informed decisions, and planning effective strategies to initiate I4.0 implementation.

2. Review of Literature

Industry 4.0, also known as the Fourth Industrial Revolution, marks a transformative shift in manufacturing and industrial operations through the integration of advanced digital technologies. These include cyber-physical systems, the Internet of Things (IoT), artificial intelligence (AI), big data analytics, cloud computing, autonomous robotics, and additive manufacturing. The objective is to create smart factories where interconnected systems and intelligent automation enable real-time decision-making, mass customisation, and optimised production processes (Ajayi et al., 2022). I4.0 emphasises manufacturing organisations' automation of processes, techniques and procedures (C. Yang et al., 2016). Techniques within I4.0 are capable of enhancing the utilization of energy, equipment, and human resources (Stawiarska et al., 2021). Before implementing these advanced technologies, it is crucial to understand the organisation's readiness level. Readiness specifies whether an organisation is equipped to adapt to advanced technologies, while maturity reflects the level of advancement and capability of the organisation regarding the analysed process (Pacchini et al., 2019).This distinction helps organizations identify both their current state of preparedness and their progress in developing and refining their processes. By understanding these two aspects, organizations can better plan and implement strategies for continuous improvement and successful technological integration.(Genest & Gamache, 2020) Organizations need to adopt certain parameters to assess their preparedness for I4.0 implementation.(Axmann & Harmoko, 2020) These parameters are essential for the organzations to be assessed and identify the current readiness(Genest & Gamache, 2020). Various mature models were studied during the literature review as part of this research. These models provide valuable insights into the factors that influence organizational readiness and help develop a comprehensive framework for evaluation.

The Reference Architectural Model I4.0 (RAMI 4.0) is based on a three-dimensional coordinated system, which defines all the critical features of I4.0. The three dimensions are:

- The hierarchy levels (right horizontal axis) represent different industry components within industries, such as products, enterprises, workspaces, connected worlds, stations, field machines, and control devices.
- The Layers (vertical axis) define the machine and its properties: Business, Communication, Information, Functional, Integration, and Assets.
- The Life Cycle & Value Stream, represented on the left horizontal axis, illustrates the facilities and products lifecycles, distinguishing between "types" and "instances." A "type" refers to the conceptual stage, including design and prototyping, while an "instance" refers to the actual product being manufactured and operational (Çınar et al., 2021).

I4.0 readiness and maturity of the organization, as proposed by (Sony & Naik, 2019), is assessed through a model encompassing 62 mature items clustered into nine different dimensions. The dimensions, Products, Operations, Technology and Customers, evaluate the enablers, while Strategy, Governance, Leadership, People and Culture justify organizational characteristics. Each item progresses through five levels of maturity: level 1 indicates the absence of I4.0 attributes, while level 5 signifies advanced attributes. The maturity measurement follows a three-step procedure:

- Measurement: Assessing mature items via a survey/questionnaire.
- Calculation: Determining the maturity levels of nine dimensions with the support of software.
- Representation: Visualizing maturity through reports and radar charts.

The IMPULSE Readiness model, developed by the IMPULS Foundation of the German Engineering Federation, VDMA, is a well-structured approach for companies looking to navigate Industry 4.0 adoption smoothly. By evaluating key dimensions—like strategy, smart operations, and data-driven services—it offers a roadmap for assessing current capabilities and planning future steps. The model provides a systematic approach for companies to measure their present state and plan necessary steps to achieve higher levels of readiness, ensuring a smooth transition to I4.0 technologies and practices (Schumacher et al., 2016).

The SIMMI 4.0 maturity model presents a structured pathway for enterprises to assess and progress through I4.0 maturity, which seems invaluable for companies aiming to digitize operations systematically. The five maturity stages, i.e from Basic to Optimized Full Digitization, offer a clear benchmark for evaluating digital transformation efforts. With dimensions covering vertical and horizontal integration, digital product development, and cross-sectional technology criteria, the model ensures organizations can pinpoint specific gaps and formulate strategies accordingly. The maturity stages and dimensions are determined based on responses to a questionnaire, which is then used to calculate the 'Overall Maturity Level.' This comprehensive approach helps organizations measure their present maturity level, classify gaps, and develop strategies to advance their I4.0 readiness (Leyh et al., 2017).

The Connected Enterprise® Maturity Model by Rockwell Automation integrates operations and information technology to improve performance and reduce risks through a five-stage approach: assessment, Analytics, Secure and Upgraded Network and Controls, Defined and Organized Working Data Capital, and Collaboration. Each stage includes typical measures that indicate its stability and the need for change.

The acatech I4.0 Maturity Index is structured around a series of maturity stages, or value-based development levels, that monitor the organization through the transformation process from elementary I4.0 requirements to full implementation. These six stages of the Connected Enterprise® Maturity Model highlight a progressive path toward full digital transformation. From Computerization—the foundation of digital systems—to Adaptability, where enterprises leverage advanced technologies for dynamic decision-making, the model ensures organizations can systematically enhance their I4.0 capabilities.

Finally, the I4.0 Toolbox (VDMA, 2017) was designed specifically for medium-sized manufacturing companies to utilize the features of I4.0 and identify areas for growth in products and manufacturing processes. The toolbox primarily focuses on Products, Services, and technical data requirements and machine-to-machine connectivity and communication.

The I4.0 Assessment model by Matt et al. is a five-stage method for familiarising I4.0 to SMEs (Sony & Naik, 2019). This model functions as a self-assessment tool, it is designed to analyse the potential and create a detail implementation plan. The maturity of SMEs is determined by responding to a set of questions those extend four areas of consideration: Operation, Organization, Socio-culture, and Technology. This comprehensive approach enables SMEs to identify their present state of readiness, pinpoint areas for improvement, and develop a structured plan for I4.0 integration. The I4.0 Quick Check (INLUMIA (2019)) assesses maturity through an online questionnaire covering three dimensions: Technology, Business, and People.

The I4.0 Maturity Model developed by WZL, RWTH Aachen (Da Silva et al., 2021) assesses the current state and future goals regarding the application of I4.0 Set of questionnaires divided into eight areas based on corporate functions: Marketing & Distribution (M&D), Product Development (PD), Supply Chain Management & Purchasing(SM&P), Manufacturing Planning and Control (MP&P), Logistics, Manufacturing, Quality Assurance, and Supporting Features. By evaluating these areas, organizations can identify present maturity levels and set objectives for advancing I4.0 capabilities.

The I4.0 Maturity Model (INTRO 4.0) is part of a four-stage process model for presenting I4.0. The organization maturing is identified through responses to an online questionnaire i.e. resources, information systems, organization structure, and organization culture (Shao et al., 2020). Based on the thorough literature review of the aforementioned maturity models, it is evident that each model has identified specific dimensions to measure an Industry's maturity level.(Brozzi et al., 2018) These dimensions provide a structured approach to evaluate the present state of readiness and guide organizations in their journey toward I4.0 implementation (Govindan & Arampatzis, 2023).

To evaluate an organization's readiness for effectively implementing I4.0 technologies, it is crucial to understand the minimum viable requirements for I4.0 tools. Previous maturity models have focused on studying several maturity models to determine

I4.0 preparedness, however some of the essential prerequisites are overlooked. While further deep drive into other literature reviews, some of the essential prerequisites, such as management support, financial support, investment, operations, skill competencies, and logistic support are being discussed in detail. (Çınar et al., 2021,Genest & Gamache, 2020) author specifies the need of technology upgrade for I4.0 implementation , but also highlighted the prerequisite requires i.e knowledge/ skill ,Business strategies, financial capacity , Real time Data accessibility, Manufacturing flexibility, to support these technologies upliftment. It is vital for organizations to measure these basic parameters before embarking on I4.0 implementation. In case of (Sony & Naik, 2019) through SLR methodologies identified key ingredients of assessing I4.0 readiness, i.e top management involvement and commitment, Employee adaptability with Industry 4.0, readiness of organizational strategy. Level of organization digitization, Smart Product and Services and Digitization of Supply chain and interdependencies of these factors, in case of (Pacchini et al., 2019,Ghadge et al., 2020) focused on digital supply chain in context of I4.0, identified key drivers and as financial constraints , lack of management support ,Lack of expertise and Lack of digital infrastructure. Considering these various literature reviews and expert opinions, Where researchers have specified involvement of key ingredient require to implement I4.0 for manufacturing organization , this research identifies six prerequisites for determining the preparedness of I4.0 implementation: Technology Enabler, Integrated Business Process, Financial Support, Logistic Support, Management Support, and Skill Competencies. These prerequisites ensure that organizations can effectively prepare for and implement I4.0 technologies (Rajbhandari et al., 2022).

This research mainly focuses on the state of Karnataka, India, with the primary objective of determining the capabilities of small and medium-sized organizations to implement advanced technologies. Implementing these technologies can help industries to automate manual and monotonous processes, increase agility to adapt to market changes, produce customized products on-demand, improve operational efficiency, reduce costs through data-driven decision-making, and gain advantage by enabling faster innovation and quicker response times. By assessing these capabilities, the research aims to provide perceptions and references for organizations in Karnataka to successfully transition to I4.0 and achieve significant assistance in their operations and competitiveness.

Research Objectives

- Assessing I4.0 readiness through the six prerequisites: Technology Enabler, Integrated Business Process, Financial Support, Logistic Support, Management Support, and Skill Competencies.
- Identifying areas that need improvement to implement I4.0 technologies.

3. Research Methodology

This research identifies six basic prerequisites to implement I4.0 tools: Technology Enabler, Integrated Business Process, Financial Support, Logistic Support, Management Support, and Skill Competencies. These prerequisites are named I4.0 Readiness Constructs.

Technology Enabler: I4.0 is considered as a combination of advanced technologies in manufacturing processes. The Internet of things, Collaborative Robots, Big Data, Additive Manufacturing, Cloud Computing Technology, Augmented reality, Cyber-physical systems and Artificial Intelligence are some of these advanced technologies.

- **Internet of things (IOT)** : IOT is one of the most important , which connects physical machines to the internet , allowing machines to collect and exchange data/information through machine to machine connections (Yang et al., 2016, Hou et al., 2016). IOT is primarily used in smart factories to monitor and control machinery, track inventory, and optimize production processes.
- **Collaborative Robot**: Collaborative robots (Cobots) are designed to work safely along with humans. Cobots are equipped with advanced sensors and safety features that allow them to interact directly with human

workers, enhancing productivity and efficiency in various industries.

- **Big Data**: Big Data is generally used to analyse and derive valuable insights from the large set of data generated by industrial processes (Zhang et al., 2016), It involves deriving valuable insights from these large datasets. It supports in enhancing decision-making, improving efficiency, and identifying trends in production(Raut et al., 2020).
- **Additive manufacturing**: Additive manufacturing is a process, where materials are built layer by layer to create three-dimensional objects from digital designs. The key objective is to prepare complex and customized products that were previously impossible or difficult to make using traditional manufacturing methods (Rylands et al., 2016).
- **Cloud computing technology**: Cloud computing allows organizations and individuals to access and manage resources, such as servers, storage, databases, networking, software, and analytics (Vrchota & Pech, 2019), over the internet Storing and process large datasets, enabling remote monitoring and controlling industrial processes.
- **Augmented reality**: AR technologies that overlay digital information and virtual objects onto the real world .Key applications are in Training, maintenance, and remote assistance in industrial settings (H. Yang et al., 2019).
- **Cyber-physical system**: CPS is the integrations of physical processes with computational systems. Real-time monitoring through embedded systems, sensors and actuators to control manufacturing processes. The primary objective is to increase machine efficiency and reduce unwanted downtime (H. Yang et al., 2019).
- **Artificial Intelligence**: AI involves a wide range of technologies and techniques that enable machines to perform tasks that typically require human intelligence. Some of the key activities like predictive maintenance, quality control, and process optimization in manufacturing.

Integrated Business Process: Integrated business process combines various functions and workflows within an organization to streamline operations, improve efficiency, and enhance collaboration across departments. Technological Integration, Centralized Data Management, Automated Workplace, Interdepartmental Collaboration, Real-Time Monitoring and Analytics, Scalability and Flexibility are key components of the Integrated Business Process. It supports improving decision-making, improving efficiency, cost effectiveness and better customer experience.

Financial support : Financial support is critical for the effective implementation of I4.0 technologies for several reasons: high Initial investment on infrastructure and Technology, Skill development of employees , Research and development for innovation and prototype models, Upgrade and integration of departments to ensure intercommunication between department is established, Mitigate risk factors due to uncertainties (Rauch et al., 2020), access various government support schemes (SAMARTH Udyog Bharat 4.0 Initiative). By providing financial support, businesses can overcome the impediments to implementing I4.0 technologies and fully leverage their potential to drive growth and innovation (Bhatia & Kumar, 2020).

Logistic Support: Logistics support is a critical factor of I4.0, as it ensures the seamless incorporation of advanced technologies along with the supply chain (Ghadge et al., 2020) and logistics processes (Vrchota & Pech, 2019). Some of the important aspects of logistics support are Digitalization and automation of logistics systems through smart warehousing and real-time tracking. Advanced analytics to predict demand and optimize inventory tools, predict maintenance of transport vehicles, provide real-time traceability of goods, inventory and transport systems, implement green logistics to optimize routes to reduce fuel consumption and emissions (Shao et al., 2020),using advanced technologies to minimize waste and improve resource utilization.

Management Support: Management support is another essential component for the execution of

I4.0 tools for several key reasons: strategy alignments (Rauch et al., 2020), long-term commitment , providing skill resources , support change management and risk management , monitoring progress and continuous improvement and manage stalk holder.

Skill Competencies: skill competencies are critical for I4.0 technology implementation. As industries transition to more advanced, automated, and interconnected systems, (Rauch et al., 2020) the workforce must possess the right skills and expertise to effectively operate and manage these technologies. The skilled employee will effectively utilize technology, adapt change, bring problem solving and decision making skill, collaboration and communication, safety and risk management.

The Industry 4.0 Readiness Constructs (IRC) was further broken down into sub-dimensions through a structured survey conducted among 20 industry experts from various manufacturing organizations in Karnataka. The expert panel included Directors, Managers from key functional areas—such as Human Resources, Logistics, Finance, Quality, Technical Implementation, and Information Technology—as well as Subject Matter Experts specializing in digital transformation and operational excellence. These participants represented a diverse range of sectors, including Aircraft Components, Automobile Parts, Agricultural Machinery Components, Chemical Products, and Construction Machinery Components. The survey was administered online using Google Forms, allowing respondents to participate asynchronously while ensuring confidentiality and data integrity. The questionnaire comprised multiple-choice items designed to evaluate the relevance, clarity, and applicability of the proposed sub-dimensions under each IRC. All responses were carefully reviewed for completeness and consistency. To assess the internal reliability of the collected data, Cronbach's alpha was calculated for each dimension. As presented in Table 1, all constructs recorded alpha values above 0.70, indicating acceptable to high reliability across the sub-dimensional structure and confirming the robustness of the framework for further analysis and application.

Table 1:

Cronbach's alpha value of I4.0 Readiness Constructs

I4.0 Readiness Constructs	Sub-Dimensions'	Cronbach's alpha
Technology Enabler	Industrial Internet of things	0.849
	Cyber Physical System	
	Big data collection and analysis	
	Additive manufacturing	
	Cloud computing technology	
	Collaborative / Autonomous Robots	
	Augmented/virtual Reality	
	Artificial intelligence	
Integrated Business Process	Interdepartmental Collaboration	0.747
	Centralized Data Management	
	Automated Workplace	
	Integrated Real-time Monitoring system	
	Modern ICT Availability	
Financial Support	Financial Resource investment	0.731
Logistic Support	Inventory Control	
	Supply Chain	
	Real-time tracking	
	Warehouse and storage Automated monitoring	
	Transparency to Customer	
Management Support	Innovation strategy	0.725
	Monitoring new technology	
	Tracking Market change	
	Assessing Customer Trend	
	Creating healthy Work culture	
	Building people connection	
	Investment	
	Governance	

Skill Competencies	Training Program	0.797
	Removing Insecurity towards Technology	
	Embracing Innovative work model	

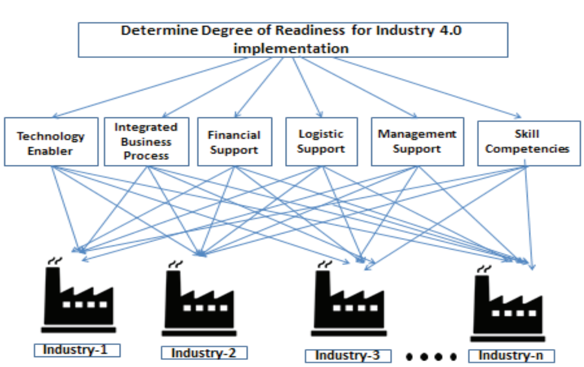
AHP analysis to determine criteria weights:

Even though these readiness dimensions are identified through detailed literature review and expert opinions. It is necessary to determine the weighted criteria for the identified readiness dimensions, which are important aspects for implementing I4.0 tools .The Analytical Hierarchy Process (AHP) is a well-established method for assigning weights to various factors during the multi-criteria decision-making process (Faisal et al., 2023). It organizes decision-making goals, criteria, and alternatives into a hierarchical structure. Forming a pair-wise comparison matrix is the most important step. Then, the goal, criteria, and all potential alternatives are determined.

In Figure 1, the goal is to determine the "Degree of Readiness for I4.0 implementation." The six readiness dimensions identified are considered the "criteria," and the industries are considered the "alternatives." This scoring process for the weighted readiness dimensions leads to generating a total score for each alternative, which is used to rank them.

Figure1:

Hierarchical structure of the AHP model



In this research, expert opinion has been considered for developing the pairwise comparison matrix. This matrix helps in understanding the relative importance of each I4.0 Readiness Constructs (IRC) and facilitates a more accurate assessment of an industry's preparedness towards I4.0 tools implementation. The insights from these experts provide a solid foundation for determining the most critical factors that need attention before moving forward with advanced technology integration. As mentioned in (Table 2) all Readiness Dimensions are named as IRC1, IRC2, IRC3, IRC4, IRC5 and IRC6.

Table 2:

Naming conventions for I4.0 Readiness Constructs

Naming conventions		
IRC1	Technology Enabler	TE
IRC2	Integrated Business Process	IBP
IRC3	Financial Support	FS
IRC4	Logistic Support	LS
IRC5	Management Support	MS
IRC6	Skill Competencies	SC

AHP analysis is following relatively importance measuring scale (Table 3). Based on this scale each IRC will be measured against another IRC , whether one IRC is equally important or moderately important or Strongly important than the other . Similarly the comparison needs to be done between all IRC.

Table 3:

Relative importance scale of pair-wise comparison.

Relative importance scale of pair-wise comparison	
Relative Importance	**Definition**
1	Equal importance
3	Moderate Importance
5	strong importance
7	Very strong importance
2,4,6	Intermediate importance

Based on the expert opinion and survey conducted through the industry experts and considering the relative importance scale as mentioned in Table 3, a pair-wise comparison matrix M_{IRC} is formed.

Table 4:

AHP Calculations (Pair-wise comparison matrix M_{IRC})

	TE	FS	IBP	DO	MS	SC
TE	1.00	0.25	3.00	2.00	3.00	2.00
FS	4.00	1.00	3.00	3.00	2.00	5.00
IBP	0.33	0.33	1.00	4.00	0.50	2.00
DO	0.50	0.33	0.25	1.00	0.50	0.50
MS	0.33	0.50	2.00	2.00	1.00	0.50
SC	0.50	0.20	0.50	2.00	2.00	1.00

The sum of six dimensions starting from TE to SC are calculated and mentioned in Table 5.

Table 5:

AHP Calculations (Take sum of pair-wise matrix)

	TE	FS	IBP	DO	MS	SC
TE	1.00	0.25	3.00	2.00	3.00	2.00
FS	4.00	1.00	3.00	3.00	2.00	5.00
IBP	0.33	0.33	1.00	4.00	0.50	2.00
DO	0.50	0.33	0.25	1.00	0.50	0.50
MS	0.33	0.50	2.00	2.00	1.00	0.50
SC	0.50	0.20	0.50	2.00	2.00	1.00
SUM	**6.67**	**2.62**	**9.75**	**14.00**	**9.00**	**11.00**

In Table 6, matrix is normalized by dividing all the values of readiness dimensions in the column with the total sum of the same columns and in step-2 criteria weights is determined by taking up average of each row values.

Table 6:

AHP calculation (determination of criteria weights).

	TE	FS	IBP	DO	MS	SC	Criteria Weights
TE	0.15	0.10	0.31	0.14	0.33	0.18	0.20
FS	0.60	0.38	0.31	0.21	0.22	0.45	0.36
IBP	0.05	0.13	0.10	0.29	0.06	0.18	0.13
DO	0.08	0.13	0.03	0.07	0.06	0.05	0.07
MS	0.05	0.19	0.21	0.14	0.11	0.05	0.12
SC	0.08	0.08	0.05	0.14	0.22	0.09	0.11

In Table 7, In order to check the consistency, after determining the criteria weights (Table 6), A matrix is formed by multiplying row wise pair-wise comparison matrix M_{IRC}(Table 4) with criteria weights determined in (Table 6). Then the Weighted Sum Values is calculated by taking row wise sum of all multiplied values for IRC.

Table 7:

AHP calculation (Calculate the consistency).

	TE	IBP	FS	LS	MS	SC	Weighted Sum Values	Criteria Weights
TE	0.20	0.09	0.40	0.13	0.37	0.22	1.42	0.20
IBP	0.81	0.36	0.40	0.20	0.25	0.55	2.57	0.36
FS	0.07	0.12	0.13	0.27	0.06	0.22	0.87	0.13
LS	0.10	0.12	0.03	0.07	0.06	0.05	0.44	0.07
MS	0.07	0.18	0.27	0.13	0.12	0.05	0.83	0.12
SC	0.10	0.07	0.07	0.13	0.25	0.11	0.73	0.11

The AHP model calculations are performed from Table 4 to Table 7 to calculate consistency ratio, Consistency ratio is calculated by dividing consistency index with reliability index (Equation-2), consistency index(Equation-1) is calculated by determining Lambda max (λmax) value and number of dimensions(n). Lambda max is the average value of ratio calculated by dividing weighted sum values with criteria weight, as per Table7, the Lambda max value determined as 6.558.

$$\mathrm{CI} = \frac{\lambda max - n}{n-1}$$ ----------------- (Equation 1)

$$= \frac{6.558-6}{6-1} = 0.1116$$

Here, CI is Consistency Index is 0.1116

Consistency Ratio = $\frac{\text{Consistency Index}}{\text{Reliability Index}}$ ----------------- (Equation 2)

Consistency Ratio (CR) = 0.1116/1.24 = 0.09

Here Reliability Index (RI) for n = 6 is 1.24, and n is considered as the number of IRC.

Since the Consistency Ratio (CR) value is less than 0.10, the pair-wise comparison matrix

(M_{IRC}) is consider to be "Consistent" and used for further evaluation (Faisal et al., 2023).

Determine Degree of Readiness

The approach followed in this research paper to measure the readiness level of a manufacturing organization for implementing I4.0 tools is a combination of various evaluation methods, thorough literature review, expert surveys, and AHP analysis. Each prerequisite is measured

Level 0 (L0): Indicates that the company has no infrastructure to support tool implementation, also referred to as the "Novice" status.

Level 1 (L1): Signifies that the company has basic infrastructure to support tool implementation, referred to as the "Basic" status.

Level 2 (L2): Indicates that the company has medium infrastructure to support tool implementation, referred to as the “Intermediate” status.

Level 3 (L3): Signifies that the company has complete infrastructure to support tool implementation, referred to as the “Complete” status.

This structured approach ensures that organizations are thoroughly assessed and prepared before embarking on I4.0 implementation, facilitating a smoother transition and more effective adoption of advanced technologies.

Each I4.0 Readiness Constructs (IRC) comprises certain sub-dimensions, which define essential requirements for enabling the IRC. These sub-dimensions are measured using a scoring approach. A set of questionnaires is defined for each sub-dimension, with each level assigned a specific point value: L0 (Level 0)– 0 points, L1 (Level 1) – 1 point, L2 (Level 2) – 2 points, and L3 (Level 3) – 3 points.

Based on Lucato et al. the degree of readiness for each sub-dimension is calculated by dividing the actual points obtained for one question by the sum of the maximum possible points for that question (Pacchini et al., 2019). This process is repeated for all questionnaires under the sub-dimensions, and the sum of these calculated scores represents the degree of readiness for each sub-dimension.

The Degree of Readiness (Equation 3) for an IRC is determined by dividing all sub-dimensions’ combined degree of readiness by the number of sub-dimensions identified. This approach provides a inclusive evaluation of an industry’s preparedness to implement I4.0 tools.

$$DRIRC = \frac{\sum \boldsymbol{DR}sub-dimension}{n} \quad \text{-------------------------------- (Equation 3)}$$

To identify the degree of readiness on I4.0 implementation for an organization (Equation 4), an approach involving the consideration of multiple IRC is employed. These IRC are identified through the AHP and expert reviews. The summative aggregate of the degree of readiness of the IRC will provide an overall measure of the organization’s readiness to adapt to I4.0.

$$DROrg = \frac{\sum \boldsymbol{DR}IRC}{n} \quad \text{-- (Equation 4)}$$

DR_{Org} = Degree of Readiness for the Organization.

DR_{IRC} = Degree of Readiness of the I4.0 Readiness Constructs

n = Number of IRC identified, in this research 6 IRC are

identified, consider n=6

Here’s a step-by-step outline of this approach:

- **Identify I4.0 Readiness Constructs (IRC):** Based on literature reviews, expert opinions, and the AHP process, determine the essential IRC that influence I4.0 readiness.
- **Assign Weights:** Use AHP to assign weights to each IRC, reflecting their relative importance in the overall readiness assessment.
- **Evaluate Sub-dimensions:** Each IRC consists of sub-dimensions, which define essential requirements. Develop a pairwise comparison matrix to evaluate these sub-dimensions using data from expert surveys.

- **Scoring System:** Implement a scoring system where each sub-dimension is assessed through a set of questionnaires. Assign points to each response based on predefined levels (e.g., L0, L1, L2 and L3).
- **Calculate Degree of Readiness for Sub-dimensions:** For each sub-dimension, calculate the degree of readiness by dividing the actual points obtained by the maximum possible points.
- **Aggregate Sub-dimension Scores:** Sum the calculated scores of all sub-dimensions within each IRC to obtain the Degree of Readiness for that IRC.
- **Summative Aggregate:** Combine the Degrees of Readiness of all IRC to determine the overall readiness score for the organization.

This comprehensive approach ensures that an industrial organization's readiness to implement I4.0 adoption is thoroughly assessed, taking into account various critical dimensions and their respective sub-dimensions. The Degree of Readiness (DR%) is defined on a percentage scale, providing a clear and intuitive understanding of readiness levels. This scale helps individuals and organizations ensure they are prepared for various tasks and challenges by identifying gaps early, facilitating better decision-making, improving planning, and mitigating risks. This structured approach provides an inclusive evaluation of an industry's readiness to adopt I4.0, helping them to understand where they stand and what areas need improvement for successful implementation.

Here's a breakdown of the Degree of Readiness (DR) levels (Pacchini et al., 2019):

Table 8:

Level of Degree of Readiness

DR in %	Level of Readiness	Description
Elementary	0% ≤ DR% ≤ 25%	The organization has a low preparation level for I4.0 implementation.
Primary	26% ≤ DR% ≤ 50%	The organization is in the primary stage of preparation. It has the basic facilities and has taken moderate steps to implement I4.0 tools.
Intermediate	51% ≤ DR% ≤ 75%	The organization is in the intermediate stage of preparation. It is moderately prepared with the facilities required for I4.0 implementation.
Advance	76% ≤ DR% ≤ 90%	The organization is in the advanced stage of preparation. It has already developed the facilities required to implement I4.0 but needs to further work on implementation.
Equipped	91% ≤ DR% ≤ 100%	The organization is in the fully developed stage of preparation for I4.0 implementation. All necessary elements are in place and functioning well.

Case Study

In this research study, six prerequisites critical for the implementation of I4.0 tools were identified and named I4.0 Readiness Constructs (IRC). These IRCs are further broken down into sub-dimensions. Expert surveys, AHP analysis and reliability tests were conducted to determine the consistency of these IRCs. The research study was further validated by industry experts through a case study.

The company identified for this activity is an automotive part manufacturing SME located in Karnataka, India, which has been in operation for the last 15 years. This company was chosen to conduct an I4.0 feasibility study to understand the degree of readiness of each IRC.A semi-structured meeting was arranged with the top management and engineering staff responsible for I4.0 implementation. Initially, respondents were contacted personally through telephone, emails, and in-person visits to explain the research process. The interviewer provided an overview of the case study. After several discussions, the staff went through the list of questionnaires prepared for each IRC and their respective sub-dimensions. The survey responses were carefully reviewed in consultation with subject matter experts to ensure the inclusion of only relevant data for further analysis. Out of 65 responses collected from the automotive part manufacturing SME considered for this case study, only 43 were deemed valid and selected for further analysis, which represents 66.1% of the total responses received.

Table 9:

Demographic table

Respondent Age	**Percentage**
Upto 25 years	56%
26 to 35 years	23%
36 to 45 years	14%
46 to 50 years	7%
Duration in the Organisation	-
Upto 1 year	42%
1 to 5 year	28%
6 to 10 year	19%
10 to 15 year	12%
Respondent's Department	-
IT Project Manager	26%
Logistic Manager	9%
Finance Manager	12%
HR Manager	7%
Quality Engineering Manager	14%
General Manager	9%
Technician	23%

These questionnaires were designed to measure the organization's readiness level for each IRC. For example, Technology Enabler is one of the IRC, with the IOT as a sub-dimension. The questionnaires aim to evaluate the organization's preparedness for implementing IOT. Each questionnaire is assessed based on the level of implementation, defined within the questionnaires.

The evaluation is executed by identifying four possible answers to each statement: Level 0 (L0), Level 1(L1), Level 2 (L2) and Level 3 (L3). Based on the responses collected for each sub-dimension from the interviewees, scores are assigned to each level (L0, L1, L2, and L3), corresponding to the values (0, 1, 2, and 3). The score of each individual sub-dimension is then divided by the sum of the maximum possible points for the sub-dimension. For example, Technology Enabler is one of the I4.0 Readiness Constructs (IRC), which has 8 sub-dimensions. The total score for Technology Enabler will be 24, calculated by multiplying the highest score (Pacchini et al., 2019) by the number of sub-dimensions (Rauch et al., 2020).

The final score for each IRC is the summation of the individual sub-dimension scores (Equation 5). This process provides a thorough evaluation of each IRC and clear understanding of the organization's readiness level for I4.0 implementation.

Degree of Readiness IRC = $\frac{\sum DRsub-dimension}{n}$ --------------------- (Equation 5)

Based on the above scoring system, the degree of readiness for individualI4.0 Readiness Constructs is calculated. For example, Technology Enabler is one of the IRC. The total score generated by adding the individual sub-dimension scores is 37.5 (Equation 6), which falls under the "Primary" category (Table 9).

Similarly, the Degree of Readiness score is calculated for other IRCs, including Integrated Business Process, Financial Support, Logistic Support, Management Support, and Skill Competencies.

Degree of Readiness TE = DRIIOT+DRCPS+DRBDA+DRAM+DRCC+DRAR+DRVR+DRAI ---------------- (Equation 6)

This systematic approach ensures that each IRC is thoroughly evaluated, providing a clear understanding of the organization's overall readiness for I4.0 implementation. By identifying the readiness levels across various dimensions, organizations can better plan and prioritize their efforts to address any gaps and achieve a successful transition to advanced technologies.

Table 10:

Degree of Readiness of each I4.0 Readiness Constructs

I4.0 Readiness Constructs	Sub-Dimensions	DR_{IRC}	Level of Readiness
Technology Enabler	IIOT(Industrial Internet of things)	37.5	Primary
	CPS(Cyber Physical System)		
	Big data collection and analysis		
	Additive manufacturing		
	Cloud computing technology		
	Collaborative / Autonomous Robots		
	Augmented/virtual Reality		
	Artificial intelligence		
Integrated Business Process	Technological Integration	73.3	Intermediate
	Data Driven services		
	Automated Workplace		
	Integrated Real-time Monitoring system		
	Modern ICT Availability		
Financial Support	Financial Resource investment	100.0	Ready
Logistic Support	Inventory Control	66.7	Intermediate
	Supply Chain		
	Real-time tracking		
	Warehouse and storage Automated monitoring		
	Transparency to Customer		
Management Support	Innovation strategy	66.7	Intermediate
	Monitoring new technology		
	Tracking Market change		
	Assessing Customer Trend		
	Creating healthy Work culture		
	Building people connection		
	Investment		
	Governance		
Skill Competencies	Training Program	55.6	Intermediate
	Removing Insecurity towards Technology		
	Embracing Innovative work model		

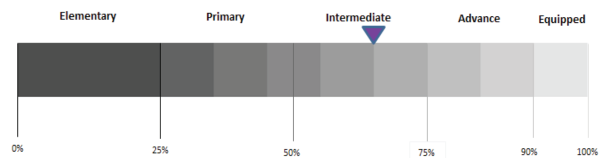
After the individual Digital readiness score are calculated (Table 7), then the average of these Digital readiness score of each I4.0 Readiness Constructs (IRC) will determine the degree of readiness to adapt I4.0 for the Organization.

$$DR = \frac{1}{6}\ 37.5+73.3+100.0+66.7+66.7+55.6$$

$$= 66.6$$

Figure 2:

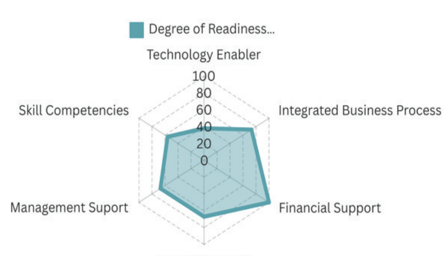
Degree of Readiness of the Organisation.



Based on the survey questionnaire for the SME considered in this case study, the SME has expressed that the necessary infrastructure and financial provisions are fully in place to support tool deployment. The corresponding readiness score for financial support is therefore calculated as 100%, reflecting that financial readiness in this context is primarily contingent upon a management decision rather than requiring additional operational actions. However, the organization's overall Degree of Readiness (Figure 2) is calculated as 66.6%, placing it squarely in the Intermediate stage (between 50% and 75%) for I4.0 implementation. While the company (case study) benefits from robust financial support, improvements are needed in other key areas such as technological enablement, integrated business processes logistic support, management support, and workforce skills.

Figure 3:

Radar chart visualizing I4.0 Degree of readiness in six RDs



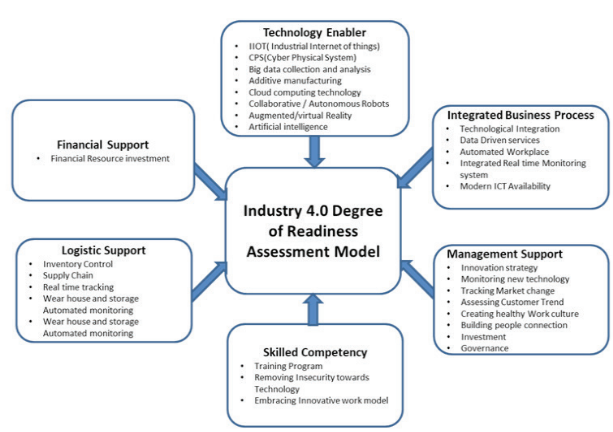
In summary, while the manufacturing industry demonstrates a moderate to promising degree of readiness for I4.0, targeted research and strategic investments in technology, workforce development, and process integration will be key to advancing its readiness.

This comprehensive approach will enable the company to optimize industrial processes through automation, real-time data analytics, monitoring, and efficiently manage the transformative effect of I4.0 technologies on its operational structures. Implementation of advanced technologies relies on a coordinated set of factors, including the following key factors.

- **Integrated Business Processes:** Seamless workflow and data exchange are crucial to supporting automation and real-time decision-making.
- **Skilled Workforce:** Investing in upskilling programs is essential. The organization should explore innovative training programs, revised educational curricula, and certification processes to equip employees with the necessary I4.0 competencies.
- **Management Support:** Effective leadership and change management are vital. Research should focus on optimizing management practices, developing frameworks for smoother transitions and adopting continuous improvement and innovation.

Figure 4:

Industry 4.0 Degree of Readiness Assessment Model



- **Logistic Support:** Enhancing logistics and supply chain management through research into real-time tracking, data sharing, and network integration can lead to improved transparency, efficiency, and responsiveness.
- **Financial Support:** Although already strong, further exploration of financial models, investment strategies, funding sources, and cost-benefit analyses will support I4.0 technologies.

4. Conclusion:

The main objective of this research paper is to design a readiness framework for implementing I4.0 within the industrial suburbs of Karnataka. To achieve this, the study first offers a detailed review of existing research articles and literature, identifying both the supporting technologies and current maturity models. Building on this foundation, the paper proposes a readiness model developed through the support of the AHP method to identify readiness factor weights. This model provides a conceptual approach in evaluating an organization's readiness for the adoption of I4.0 tools and technologies. The key outcomes of the research are described below.

- **Identification of I4.0 Readiness Constructs:** The study isolates six I4.0 readiness constructs that serve as core pillars for advanced technology integration. Integrated through AHP analysis, expert opinions were crucial in prioritizing these constructs. The analysis confirmed that all six constructs are both consistent and effective for assessing I4.0 readiness.
- **Questionnaire-Based Assessment Model:** A detailed questionnaire was developed, incorporating insights from manufacturing industry experts. This model evaluates each construct—and their sub-dimensions—using a systematic scoring system. The resulting scores provide the present preparedness level of the organization, pinpointing areas for improvement and highlighting opportunities for the effective application of I4.0 technologies.
- **Practical Implications for Industry Leaders:** The proposed readiness model is intended to help industrial personnel assess their present state of readiness for I4.0. Ultimately, it aims to support these organizations in their journey toward becoming global leaders by identifying critical gaps and paving the way for targeted technological and process advancement. This structured framework is not only limited to supporting better strategic decision-making but also positions organizations to embrace the transformative potential of I4.0, thereby driving continuous improvement and providing a competitive edge in a rapidly developing industrial landscape.

5. Scope of Future Study:

While this readiness assessment model effectively gauges the readiness level of manufacturing firms, it may not be entirely suitable for the service industry. The I4.0 Readiness Constructs (IRCs) are treated as independent factors in determining industrial readiness, but their interdependencies have not been evaluated in this study. Addressing these interdependencies can be considered for future research studies. This study emphasizes on the automotive part manufacturing SME in industrial suburb of Karnataka, However further research could explore other manufacturing industries (i.e Aircraft Components', 'Automobile Parts', 'Agricultural Machinery Components', 'Chemical Products', and 'Construction Machinery Components'.) across various suburbs of Karnataka. This additional research could support a more inclusive understanding of how I4.0 readiness varies across different contexts, leading to more tailored and effective implementation strategies. As the landscape of I4.0 continues to grow, it is crucial to explore these nuances to ensure that the readiness models are robust and adaptable to various industry needs.

References:

Çınar, Z. M., Zeeshan, Q., & Korhan, O. (3021). A Framework for I4.0 Readiness and Maturity of Smart Manufacturing Enterprises: A Case study. Sustainability, 13(12), 6659. https://doi.org/10.3390/su13126659

Genest, M. C., & Gamache, S. (2020). Prerequisites for the implementation of I4.0 in manufacturing SMEs. Procedia Manufacturing, 51, 1215–1220. https://doi.org/ 10.1016/j.promfg.2020.10.170

Pacchini, A. P. T., Lucato, W. C., Facchini, F., & Mummolo, G. (2019). The degree of readiness for the implementation of I4.0. Computers in Industry, 113, 103125. https://doi.org/10.1016/j.compind.2019.103125

Sony, M., & Naik, S. (2019). Key ingredients for evaluating Industry 4.0 readiness for organizations: a literature review. *Benchmarking an International Journal*, *27*(7), 2213–2232. https://doi.org/10.1108/bij-09-2018-0284

Ghadge, A., Kara, M. E., Moradlou, H., & Goswami, M. (2020). The impact of I4.0 implementation on supply chains. *Journal of Manufacturing Technology Management*, *31*(4), 669–686. https://doi.org/10.1108/jmtm-10-2019-0368

Axmann, B., & Harmoko, H. (2020). I4.0 readiness assessment: Comparison of tools and introduction of new tool for SME. Tehnički glasnik, 14(2), 212-217. https://doi.org/10.31803/tg-20200523195016

Stawiarska, E., Szwajca, D., Matusek, M., & Wolniak, R. (2021). Diagnosis of the maturity level of implementing I4.0 solutions in selected functional areas of management of automotive companies in Poland. *Sustainability*, *13*(9), 4867. https://doi.org/10.3390/su13094867

Rauch, E., Unterhofer, M., Rojas, R. A., Gualtieri, L., Woschank, M., & Matt, D. T. (2020). A Maturity Level-Based Assessment tool to enhance the implementation of I4.0 in Small and Medium-Sized Enterprises. *Sustainability*, *12*(9), 3559. https://doi.org/10.3390/su12093559

Govindan, K., & Arampatzis, G. (2023). A framework to measure readiness and barriers for the implementation of I4.0: A case approach. *Electronic Commerce Research and Applications*, *59*, 101249. https://doi.org/10.1016/j.elerap.2023.101249

Leyh, C., Bley, K., Schäffer, T., & Bay, L. (2017). The application of the maturity Model SIMMI 4.0 in selected enterprises. *Americas Conference on Information Systems*. http://dblp.uni-trier.de/db/conf/amcis/amcis2017.html#LeyhBSB17

Rajbhandari, S., Devkota, N., Khanal, G., Mahato, S., & Paudel, U. R. (2022). Assessing the industrial readiness for adoption of I4.0 in Nepal: A structural equation model analysis. *Heliyon*, *8*(2), e08919. https://doi.org/10.1016/j.heliyon.2022.e08919

Faisal, S. F., Banik, S. C., & Gupta, P. S. (2023). Development of a readiness model for I4.0 using Analytical Hierarchy process and fuzzy inference system: Bangladesh perspective. *Heliyon*, *10*(1), e23664. https://doi.org/10.1016/j.heliyon.2023.e23664

Shah, S., Madni, S. H. H., Hashim, S. Z. B. M., Ali, J., & Faheem, M. (2024). Factors influencing the adoption of industrial internet of things for the manufacturing and production small and medium enterprises in developing countries. IET Collaborative Intelligent Manufacturing, 6(1). https://doi.org/10.1049/cim2.12093

Kumar, V., Vrat, P., & Shankar, R. (2022). Factors influencing the implementation of I4.0 for sustainability in manufacturing. *Global Journal of Flexible Systems Management*, *23*(4), 453–478. https://doi.org/10.1007/s40171-022-00312-1

Schumacher, A., Erol, S., & Sihn, W. (2016). A maturity model for assessing I4.0 readiness and maturity of manufacturing enterprises. Procedia CIRP, 52, 161–166. https://doi.org/10.1016/j.procir.2016.07.040

Rylands, B., Böhme, T., Gorkin, R., Fan, J., & Birtchnell, T. (2016). The adoption process and impact of additive manufacturing on manufacturing systems. *Journal of Manufacturing Technology Management*, *27*(7), 969–989. https://doi.org/10.1108/jmtm-12-2015-0117

Raut, R. D., Yadav, V. S., Cheikhrouhou, N., Narwane, V. S., & Narkhede, B. E.(2020) . Big data analytics: Implementation challenges in Indian manufacturing supply chains. *Computers in Industry*, *125*, 103368. https://doi.org/10.1016/j.compind.2020. 103368

https://www.rockwellautomation.com/en-in/company/news/blogs/the-connected-enterprise-maturity-model--metrics-that-matter.html

https://www.acatech.de/wp-content/uploads/2020/04/aca_STU_MatInd_2020_en_Web. pdf

INLUMIA (2019): Project Website of the research project INLUMIA “A tool for improving business performance through I4.0”, funded by the

European Regional Development Fund NRW, Available at: https://inlumia.de/

Silva, I. A. D., Barbalho, S. C. M., Adam, T., Heine, I., & Schmitt, R. (2021). I4.0 Readiness: a new framework for maturity evaluation based on a bibliometric study of scientific articles from 2001 to 2020. Dyna, 88(218), 101-109.

Yang, C., Shen, W., & Wang, X. (2016). Applications of Internet of Things in manufacturing. *2022 IEEE 25th International Conference on Computer Supported Cooperative Work in Design (CSCWD)*. https://doi.org/10.1109/cscwd.2016.7566069

Hou, L., Zhao, S., Xiong, X., Zheng, K., Chatzimisios, P., Hossain, M. S., & Xiang, W. (2016). Internet of Things Cloud: Architecture and implementation. *IEEE.communications Magazine*, *54*(12), 32–39. https://doi.org/10.1109/mcom.2016.1600398cm

Zhang, Y., Ren, S., Liu, Y., & Si, S. (2016). A big data analytics architecture for cleaner manufacturing and maintenance processes of complex products. *Journal of Cleaner Production*, *142*, 626–641. https://doi.org/10.1016/j.jclepro.2016.07.123

Shao, X., Liu, W., Li, Y., Chaudhry, H. R., & Yue, X. (2020). Multistage implementation framework for smart supply chain management under I4.0. *Technological Forecasting and Social Change*, *162*, 120354. https://doi.org/10.1016/j.techfore.2020. 120354

Brozzi, R., D'Amico, R. D., Monizza, G. P., Marcher, C., Riedl, M., & Matt, D. T. (2018). Design of self-assessment tools to measure I4.0 readiness. A Methodological approach for craftsmanship SMEs. In *IFIP advances in information and communication technology* (pp. 566–578). https://doi.org/10.1007/978-3-030-01614-2_52

Castelo-Branco, I., Cruz-Jesus, F., & Oliveira, T. (2019). Assessing I4.0 readiness in manufacturing: Evidence for the European Union. *Computers in Industry*, *107*, 22–32. https://doi.org/10.1016/j.compind.2019.01.007

https://ec.europa.eu/futurium/en/system/files/ged/a2-schweichhart reference_ architectural _ model_industrie_4.0_rami_4.0.pdf

Sanghavi, D., Parikh, S., & Raj, S. A. (2019). I4.0: tools and implementation. *Management and Production Engineering Review*. https://doi.org/10.24425/mper.2019 .129593

Yang, H., Kumara, S., Bukkapatnam, S. T., & Tsung, F. (2019). The internet of things for smart manufacturing: A review. IISE transactions, 51(11), 1190-1216. https://doi.org/10.1080/24725854. 2018.1555383

Khin, S., & Kee, D. M. H. (2022). Factors influencing I4.0 adoption. Journal of Manufacturing Technology Management, 33(3), 448–467. https://doi.org/10.1108/jmtm-03-2021-0111

Vrchota, J., & Pech, M. (2019). Readiness of enterprises in Czech Republic to implement I4.0: Index of I4.0. *Applied Sciences*, *9*(24), 5405. https://doi.org/10.3390/app9245405

Yang, C., Shen, W., & Wang, X. (2016b). Applications of Internet of Things in manufacturing. *2022 IEEE 25th International Conference on Computer Supported Cooperative Work in Design (CSCWD)*. https://doi.org/10.1109/cscwd.2016.7566069

Bhatia, M. S., & Kumar, S. (2020). Critical success factors of I4.0 in automotive manufacturing industry. IEEE Transactions on Engineering Management, 69(5), 2439–2453. https://doi.org/10.1109/tem.2020.3017004

Ajayi, O., Bagula, A., & Maluleke, H. (2022). *The Fourth Industrial Revolution: A Technological Wave of Change*. In M. Gordan, K. Ghaedi, & V. Saleh (Eds.), *Industry 4.0 - Perspectives and Applications*. IntechOpen. https://doi.org/10.5772/intechopen.106209

Rupp, M., Schneckenburger, M., Merkel, M., Börret, R., & Harrison, D. K. (2021). Industry 4.0: A technological-oriented definition based on bibliometric analysis and literature review. *Journal of Open Innovation: Technology, Market, and Complexity*, *7*(1), 68. https://doi.org/10.3390/joitmc7010068

Schwab, K. (2017). *The Fourth Industrial Revolution*. Portfolio Penguin.