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ASSESSMENT OF THE READINESS AND MATURITY FOR INDUSTRY 4.0 ADOPTION IN INDIAN AUTOMOBILE INDUSTRIES

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Abstract: ***Purpose:*** *This paper addresses the urgent need to comprehensively assess the preparedness of the Indian automobile industry for adopting Industry 4.0 technologies, a critical imperative for sustaining global competitiveness in one of the world's largest and fastest-growing automotive sectors. The study introduces the Maturity Assessment and Readiness for Industry 4.0 in the Indian Automobile Industry (MARI-IA) Scale, offering a novel contribution to the scientific discourse on this vital issue.*

Literature Review: *The existing literature review underscores the scarcity of tailored tools specifically designed to evaluate Industry 4.0 readiness in the distinctive context of the Indian automotive industry.*

Methodology: *To bridge this gap, the paper employs a survey methodology involving 55 participants from 14 diverse organisations, spanning original equipment manufacturers (OEMs), supplier industries, and service centers. The chosen research object is these organisations, strategically selected to represent the spectrum of the industry. Utilising the MARI-IA Scale, the study systematically assesses maturity and readiness across five pivotal dimensions: Vision, Machines, Practices, Products, and People.*

Results: *The findings reveal discernible variations in readiness levels, with OEMs exhibiting the highest preparedness, followed by supplier and service industries. Large-scale industries consistently outperform their medium, small, and micro-scale counterparts, indicating a pronounced scale-dependent disparity. Notably, the 'People' dimension garnered the highest rating, suggesting an existing readiness for skill enhancement initiatives and heightened customer awareness initiatives. In contrast, the 'Vision' dimension is rated the lowest, signalling a pressing need for increased strategic commitment and top management involvement in implementing Industry 4.0 initiatives.*

Value: *The empirical analysis conducted substantiates the relevance and applicability of the MARI-IA Scale in effectively evaluating Industry 4.0 readiness in the unique context of the Indian automobile industry. Beyond a mere assessment tool, the results of this study carry significant practical implications for stakeholders, offering a roadmap for enhancing Industry 4.0 preparedness and maintaining a competitive edge in the global automotive landscape. This research is a foundational resource for scholars, industry practitioners, and policymakers navigating the dynamic landscape of Industry 4.0 adoption in the Indian automobile sector.*

Keywords: Index construction, MANOVA, MARI-IA scale, maturity, readiness, technology adoption.

JEL Classification: L2, L62, M11.

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Introduction

The Fourth Industrial Revolution, or Industry 4.0 (I4.0), has brought a transformative shift to the global manufacturing landscape (Brettel et al., 2014). Characterised by integrating advanced technologies and digitalisation, I4.0 marks a transformative era in manufacturing and production processes. It heralds the convergence of cutting-edge technologies, including artificial intelligence (AI), big data analytics, cloud computing, the Internet of Things (IoT), and robotics, to revolutionise industrial operations (Gilchrist, 2016). This wave of technological advancements can potentially revolutionise industries worldwide, including the Indian automobile sector.

The Indian automobile sector has contributed significantly to the country's economic growth and industrial development (Arya, 2019). Given its vast network of automotive manufacturers, suppliers, and service providers, the sector is pivotal in generating employment, driving innovation, and contributing to the nation's GDP. Furthermore, the Indian automobile sector has grown substantially, attracting domestic and foreign investment. Consequently, it has become a vital pillar of the country's manufacturing process and a significant player in the global automotive market (Department of Heavy Industries, 2015).

The Indian automobile sector must embrace the technologies of I4.0 to remain competitive and address the evolving dynamics of the global market. By adopting I4.0, Indian automotive companies can leverage advanced digital technologies to enhance productivity, optimise processes, and drive innovation across the supply chain. I4.0 offers opportunities for automation, predictive maintenance, real-time data analytics, and improved customer experiences, thereby enabling the industry to stay ahead in an increasingly digital and connected world (Adebanjo et al., 2021).

However, the successful implementation of I4.0 in the Indian automobile industries (IAI) require a thorough understanding of industry players' readiness levels and preparedness. It is essential to assess the existing state of readiness across different dimensions, including vision, technology infrastructure, organisational practices, product offerings, and workforce skills and capabilities (Pirola et al., 2019). This assessment may provide insights into the gaps, challenges, and potential areas for improvement in adopting I4.0 practices.

By utilising the Maturity Assessment of Readiness for I4.0 in the Indian Automobile Industry (MARI-IA) Scale, this study assesses the readiness levels of organisations operating in the automotive sector, including original equipment manufacturers (OEMs), supplier industries, and service centres. Additionally, the research categorises organisations based on their size, considering both the number of employees and turnover, to analyse the variations in readiness levels across different scales of operation.

Understanding the readiness of IAI to adopt I4.0 is crucial for driving informed decision-making, policy formulation, and strategic planning within the sector. The implications of this study, along with the results, may provide valuable insights for industry stakeholders, policymakers, and organisational leaders, enabling them to identify areas of improvement and develop targeted initiatives to enhance readiness.

The progress of the industrial age from Industry 1.0 to 4.0 has marked a significant revolution. Mechanical production facilities introduced machines powered by water and steam engines in the late eighteenth century (Sommer, 2015). The beginning of the 20th century saw a shift in power sources from mechanical to electrical. Electrical machines have increased efficiency and production scales. Industry 3.0 developed newly invented electronic devices, transistors, and integrated circuits. This eventually led to the introduction of automated technology and software systems, which increased the production speed and scale with greater accuracy and reduced human effort from several tasks. I4.0, driven by advancements in electronics and IT, has witnessed the continuous evolution of automation processes and software systems underpinned by the transformative power of the internet and telecommunications industry. Clive Humby coined the phrase "Data is the new oil" in 2006, highlighting the significance of data in driving nearly all functionalities of I4.0 (Humby, 2006). Examples include data-driven technologies such as smart manufacturing, cloud computing, cognitive computing, and AI.

I4.0 is a global movement transforming manufacturing, and India is actively embracing this trend. Developing countries worldwide are implementing substantial initiatives to enhance manufacturing capabilities by adopting advancements in technology-intensive business areas (Koibichuk et al., 2022). The "Make in India" initiative, launched by the Indian government, seeks to incentivise multinational and international corporations to establish manufacturing operations in India (Kamal, 2017). The Indian manufacturing sector has to show preparedness to take the lead in this competition to integrate the principles of I4.0 with the “Make in India” initiative. India has a unique opportunity to pave the way to the Smart Manufacturing domain by taking a jumpstart before other countries adopt this evolution from an agrarian society to an industrial one.

The automobile sector is a cornerstone of the Indian economy. It is among India's foremost contributors to manufacturing output and GDP (Krishnan et al., 2021). IAIs produce a variety of vehicles, such as passenger cars, commercial vehicles, three-wheelers, two-wheelers, and tractors. The Indian automobile industry has experienced consistent growth over the years and currently ranks fourth-largest globally. The sector accounts for approximately 7.1% of India’s GDP and employs over 35 million people (Department of Heavy Industries, 2015).

The automobile industry also significantly affects other sectors of the economy, such as steel, rubber, plastic, and electronics. This creates demand for various raw materials and components, which, in turn, supports the growth of other industries. The sector has also significantly contributed to India’s exports, accounting for approximately 4.7% of total exports (Ministry of Commerce and Industry (Government of India), 2023).

The automobile sector is pivotal in the Indian economy, driving the nation's growth and development. The government has proactively implemented various policies and initiatives to foster industry growth, and the sector is poised to remain a significant contributor to India's economic trajectory in the foreseeable future. The readiness of IAI for I4.0 is a substantial concern for the government, industries, and academia. The automobile industry is one of India's most significant and fastest-growing sectors. However, I4.0 in the adoption is still in its early stages (Iyer, 2018). A study by the Capgemini Research Institute (Winkler et al., 2020) revealed that the IAI plans to convert 44% of its factories into smart factories by 2019-23. The low adoption rate can be attributed to a lack of awareness, inadequate infrastructure, and limited access to advanced technologies (Jena & Patel, 2022).

This study presents a model to measure the readiness of Indian automobile companies to implement I4.0. The model introduced here is the Maturity Assessment and Readiness of I4.0 in the Indian Automobile Industry (MARI-IA) Scale. The proposed MARI-IA Scale aims to overcome the shortcomings of existing models of a generalised approach towards all industries, providing a tool for automobile industries to access their intelligent manufacturing level. The model focuses on five dimensions to measure maturity level and readiness index: vision, machines, processes, products, and people.

For the sake of the exploratory nature of this study, we probe the following research objectives:

- To assess the readiness of the Indian automobile industry for I4.0 adoption.
- To identify areas where the IAI needs to improve its readiness for I4.0.

Contribution of the Study

- This study is significant because it provides one of the first comprehensive frameworks to assess the IAI's readiness to adopt I4.0.
- The implications of this study may be valuable to organisations in the IAI, policymakers, and other stakeholders.
- The managerial implications of this study can help improve the readiness of the IAI for I4.0, thereby enabling it to enhance its competitiveness in the global market.

This paper is structured as follows. Section 2 reviews existing readiness and maturity assessment models, identifying key research gaps and laying the groundwork for developing the MARI-IA Scale. Section 3 explains the methodology employed and details the construction and validation of the model. Section 4 presents the results of the model's implementation in a comprehensive case study. Section 5 proposes a prioritised set of actions to expedite the transition to I4.0. Section 6 concludes the study, acknowledging its limitations and suggesting areas for future research.

Literature Review

The literature on maturity models and readiness indices for I4.0 adoption provides valuable insights into assessing organisations' preparedness across different industries and countries. This section reviews relevant past research and articles that have explored the application of maturity models and readiness indices in the context of I4.0.

Maturity models and readiness indices serve as essential tools for evaluating the readiness levels of organisations and industries for the adoption of technology and practices in I4.0. These frameworks provide a structured approach to assess an organisation's capabilities, identify gaps, and guide the implementation of I4.0 initiatives.

As shown in Table 1, numerous studies have focused on developing and applying maturity models and readiness indices to measure readiness for I4.0 (Pirola et al., 2019). For instance, Sheen and Yang (2018) proposed a maturity model to assess the readiness of the Korean manufacturing industries to implement I4.0. The model comprises six maturity levels and considers the following dimensions: "Automation"; "ICT System"; "System Integration"; "Remote control"; "Flexible Manufacturing"; "Organization/Strategy"; "Human Resources"; "Enterprise Culture".

Similarly, in the research conducted by Machado et al. (2019), a comprehensive maturity model was developed to evaluate the readiness of manufacturing companies for I4.0. The model comprises five levels, ranging from the initial level of automation to the advanced level of cyber-physical system integration. It considers various dimensions, such as "Strategy and organisation", "smart factory", "smart operations", "smart products", "data-driven services", and "employees".

Moreover, several studies have explored the readiness indices for I4.0 adoption at the country level. Research has examined the readiness levels of manufacturing, healthcare, and logistics sectors in specific industries. For example, (Çınar et al., 2021) developed a maturity model to assess manufacturing companies' readiness for I4.0. The model considered dimensions such as "Factory", "Logistics", "Operator", and "Management", providing insights into organisations' capabilities and areas for improvement.

Table 1. Literature Review of other maturity and readiness indices related to I4.0 implementation

S.No.	Name	Source	Target	Readiness/ Maturity	Empirical/ Theoretical	Dimensions
1.	"Maturity Model (MM)"	(Çınar et al., 2021)	Manufacturing industries (Case study: Turkish Automobile parts industry)	M	E	"Factory", "Logistics", "Operator", and "Management".
2.	"Global Readiness Assessment Model for Industry 4.0 (GRAMI 4.0)"	(Tripathi & Gupta, 2021)	Global Industries	R	E	"Enabling environment", "Human resources", "Infrastructure", "Ecological Sustainability", "Innovation Capability", "Cyber Security", "Consumer"
3.	"Maturity Level-Based Assessment Tool of Industry 4.0"	(Rauch et al., 2020)	SMEs	M	E	"Operational; "Organizational"; "Socio-Cultural"; "Technological" (Data-Driven); "Technological" (Process-Driven)
4.	"Industry 4.0 readiness model in Indian engineering industries"	(Sony & Aithal, 2020)	Indian engineering industries	R	T	"Organisational strategy", "digitisation level", "supply chain digitisation", "smart products", "employee adaptability", and "top management support".
5.	"FAHP-based Maturity Model"	(Wagire et al., 2020)	Indian Manufacturing industries	M	E	"People and Culture"; "Industry 4.0 Awareness"; "Organisational Strategy"; "Value Chain and Processes"; "Smart Manufacturing Technology"; "Product and Services oriented Technology"; "Industry 4.0 base Technology"

Table 1 (cont.). Literature Review of other maturity and readiness indices related to I4.0 implementation

S.No.	Name	Source	Target	Readiness/ Maturity	Empirical/ Theoretical	Dimensions
6.	"Metamodel of an enterprise's readiness for Industry 4.0"	(Basl & Doucek, 2019)	Generalised	R	T	"Technology"; "Strategy"; "Corporate Culture"; "Human Resources"
7.	"AHP-TOPSIS-based MCDM Model"	(Keskin et al., 2019)	Generalised	M	E	(Same as (Agca et al., 2017)) The paper employed the AHP method to assign weight to criteria and the TOPSIS method to rank dimensions per closeness to the ideal best maturity level.
8.	"Singapore Smart Industry Readiness Index (SIRI)"	(W. D. Lin et al., 2019)	Singaporean industries	R	T	Process: "Operations"; "Supply Chain"; "Product Lifecycle" Technology: "Automation"; "Connectivity"; "Intelligence" Organisation: "Talent Readiness"; "Structure and Management"
9.	"Industry 4.0 readiness"	(Machado et al., 2019)	Manufacturing Industries	R	E	"Strategy and organisation", "smart factory", "smart operations", "smart products", "data-driven services", and "employees"
10.	"Industry 4.0 readiness in Hungary: model."	(Nick et al., 2019)	Hungarian Firms	R	E	"Strategy and organisation", "Smart factory", "smart processes", "Smart products", "Services based on product data", "Employees", "Resolving territorial inequalities", "state involvement", "Energy and material-efficient tools and production methods", "Applying new and digital technologies"
11.	"SAE based Industry 4.0 Readiness Model"	(Pacchini et al., 2019)	Manufacturing Industries (Case: Brazilian auto-parts manufacturing company)	R	E	Enabling Technologies: "Internet of Things"; "Big Data"; "Cloud Computing"; "Cyber-Physical Systems"; "Collaborative Robots"; "Additive Manufacturing"; "Augmented Reality"; "Artificial Intelligence"
12.	"Digital readiness Level 4.0 (DRL 4.0)"	(Pirola et al., 2019)	Italian SMEs	R	E	"Strategy"; "People"; "Processes"; "Technology"; "Integration"
13.	"Industry 4.0 Maturity Model"	(Santos & Martinho, 2020)	Industrial Organizations	M	E	"Organisational Culture"; "Workforce"; "Smart Factory"; "Smart Processes"; "Smart Products" and "Services".
14.	"Identification of factors through Systematic Literature Review"	(Sony & Naik, 2019)	Generalised	R	T	"Organisational Strategy"; "Level of digitisation"; "Extent of digitisation of supply chain"; "Smart products and services"; "Employee Adaptability"; and "Top management involvement and commitment".
15.	"Maturity and Readiness Model for Industry 4.0"	(Akdil et al., 2018)	Generalised	M and R	E	"Products and Services"; "Processes"; "Strategy"; and "Organization".
16.	"Industry 4.0 Maturity Assessment"	(Bibby & Dehe, 2018)	Defence manufacturing firms	M	E	"Factory of the Future"; "People and Culture"; "Strategy"

Table 1 (cont.). Literature Review of other maturity and readiness indices related to I4.0 implementation

S.No.	Name	Source	Target	Readiness/ Maturity	Empirical/ Theoretical	Dimensions
17.	"SME craftsmanship self-assessment tool"	(Brozzi et al., 2018)	Craftsmanship SMEs	R	E	"Production and Operations"; "Digitalisation"; "Ecosystem"
18.	"IMPULS"	(Hamidi et al., 2018)	Malaysian SMEs	M and R	E	"Strategy and Organisation"; "Smart Factory"; "Smart Products"; "Data-Driven Services"; "Smart Operations"; "Employees"
19.	"Smart Manufacturing Maturity Model for SMEs (SM3E)"	(Mittal et al., 2018)	SMEs	M	T	"Finance"; "People"; "Strategy"; "Process"; "Product"
20.	"Industry 4.0 maturity model of Munich University of Applied Sciences (I4-MMM)"	(Puchan et al., 2018)	SMEs	M	E	"Key factors"; "Employees"; "Organization"; "Product"; "Production"
21.	"Smart Manufacturing and Innovation Assessment Model (Korea)"	(Sheen & Yang, 2018)	Korean manufacturing industries	R	E	Smart Factory Facilities: "Automation"; "ICT System"; "System Integration"; "Remote control"; "Flexible Manufacturing" Strategy and Culture: "Organization/Strategy"; "Human Resources"; "Enterprise Culture"
22.	"Industry 4.0 Readiness Self-Assessment"	(Agca et al., 2017)	Generalised global approach	R	E	"Products and Services"; "Manufacturing and Operations"; "Strategy and Organization"; "Supply Chain"; "Business model"; "Legal consideration"
23.	"Digital Readiness Assessment Maturity Model (DREAMY)"	(De Carolis et al., 2017)	Manufacturing companies	M	T	"Process"; "Monitoring and Control"; "Technology"; "Organization"
24.	"Industry 4.0 Maturity Model"	(Gökalp et al., 2017)	Generalised	M	T	"Asset Management"; "Application Management"; "Data Governance"; "Process Transformation"; "Organizational Alignment"
25.	"Technological Readiness"	(Samaranayake et al., 2017)	Generalised	R	E	"Internet System"; "Workforce Competency"; "M2M Communication"; "Big Data Management"; "Data Sharing"; "Data Security"
26.	"The acatech Industrie 4.0 Maturity Index"	(Schuh et al., 2017)	General industries	M	E	"Organisational Structure"; "Culture"; "Information Systems"; "Resources"
27.	"PwC Maturity Model"	(Geissbauer et al., 2016)	General industries	M	E	"Business models and customer access"; "Product and services"; "Vertical and horizontal integration of value chains"; "Data & Analytics as core capability"; "Agile IT architecture"; "Compliance, security, legal & tax"; "Organisation, employees and digital culture"

Table 1 (cont.). Literature Review of other maturity and readiness indices related to I4.0 implementation

S.No.	Name	Source	Target	Readiness/ Maturity	Empirical/ Theoretical	Dimensions
28.	"Smart Manufacturing System Readiness Level (SMSRL)"	(Jung et al., 2016)	Manufacturing industries	R	E	"Organisational"; "IT"; "Performance management"; and "Information connectivity"
	"System Integration Maturity Model Industry 4.0 (SIMMI 4.0)"	(Leyh et al., 2016)	Generalised (Only focuses on IT Classification)	M	T	"Vertical Integration"; "Horizontal Integration"; "Digital Product Development"; "Cross-sectional Technology Criteria"
29.	"Industry 4.0 maturity assessment procedure"	(Schumacher et al., 2016)	Manufacturing industries	M	E	"Technology"; "Products"; "Customers and Partners"; "Value Creation Processes"; "Data and Information"; "Corporate standards"; "Employees"; "Strategy and Leadership"
30.	"IMPULS"	(Lichtblau et al., 2015)	German Manufacturing industries	R	E	"Strategy and Organisation"; "Smart Factory"; "Smart Products"; "Data-Driven Services"; "Smart Operations"; "Employees"
31.	"Rockwell Automation Connected Enterprise Maturity Model"	(Rockwell Automation & Allen-Bradley, 2014)	Generalised	M	T	"Organization"; "Infrastructure"; "Strategy"; "Resources"

Source: compiled by authors.

Furthermore, studies have explored the readiness levels and challenges different countries face in adopting I4.0. For instance, Hamidi et al. (2018) research examined the readiness of SMEs in Malaysia for I4.0 adoption. The study highlights the importance of government support, funding, and technology infrastructure to facilitate SMEs' adoption of I4.0.

In summary, the literature on maturity models and readiness indices for I4.0 adoption showcases the significance of assessing organisations' readiness levels across various industries and countries. These models and indices provide structured frameworks to evaluate different dimensions, including strategy, technology, organisation, and culture, guiding organisations in their I4.0 transformation journey. This review highlights the need to customise these models and indices to suit the specific context of the IAI, emphasising the importance of evaluating readiness levels and identifying areas for improvement to foster successful I4.0 adoption within the sector.

This literature review aims to analyse the existing research and literature on measuring the readiness of industries for I4.0. Various studies have proposed frameworks and models to calculate enterprises' readiness for I4.0.

Readiness Assessment and Maturity Models

Trends and technology around I4.0 are converging and promising for transforming the manufacturing process. However, most people find these ideas pretty far from reality today since many factories have not yet fully embraced the automation technology of Industry 3.0 (Jennings, 2015). The automotive industry is one of the early adopters of I4.0 (Baur & Wee, 2015). The industry relies on supply chains for timely raw material procurement and scheduled batch delivery. I4.0 technologies like IoT and cloud computing make supply chain processes more agile and transparent. I4.0 technologies support wise decision-making and offer enhanced warehouse management and real-time asset tracking features. Above all, it makes it possible to automate the entire process, which lowers operational complexity and overhead expenses.

The term “readiness” encompasses psychological and behavioural preparedness for taking action, signifying a state of willingness and capability (Weiner, 2009). A readiness assessment identifies potential challenges while implementing new procedures, structures, and processes within the existing organisational framework. By pinpointing these gaps within the current organisation, readiness assessment facilitates the timely remediation of these deficiencies either prior to or as an integral component of the implementation plan (Pirola et al., 2019).

The term "maturity" denotes a state of advancement or completion, suggesting progress in the development of a system (Wibowo & Waluyo, 2015). As systems mature, whether biological, organisational, or technological, they exhibit enhanced capabilities over time, enabling them to strive towards a desired future state (Teichert, 2019). The Readiness Assessment and Maturity Model provide a foundational tool that organisations can leverage to assess their current capability state and facilitate evolution toward desired capabilities.

The maturity of an industrial company is determined by its level of progress in both internal and external factors that support the implementation of I4.0 concepts. These concepts encompass the integration of manufacturing systems and enterprises along vertical and horizontal dimensions and the digital integration of engineering processes throughout the entire value chain (Schumacher et al., 2016).

The existing models target a broad range of industries in various dimensions. While previous research has made significant contributions to understanding maturity models and readiness indices for I4.0 adoption, there are still notable research gaps that the current study aims to address. These gaps include:

i. Need for focus on the IAI: Existing literature on maturity models and readiness indices for I4.0 adoption has primarily focused on general assessments or specific industries in other countries. There was a need for research explicitly examining the readiness of the IAI to adopt I4.0. Therefore, this study aims to fill this gap by comprehensively assessing readiness levels in the Indian automobile sector.

ii. Lack of industry-specific dimensions: Many maturity models and readiness indices are generic and may not capture specific industries' unique characteristics and requirements. The current research addresses this gap by utilising the MARI-IA Scale, which incorporates industry-specific dimensions, such as Vision, Machines, Practices, Products, and People. This tailored approach enables a more accurate and industry-focused evaluation of readiness levels.

iii. Limited categorisation of organisations based on size: Prior research often overlooks the impact of organisational size on readiness for I4.0 adoption. This study addresses this gap by categorising organisations in the IAI into different scales based on both the number of employees and turnover. This categorisation allows for a comparative analysis of readiness levels among large-scale, medium-scale, small-scale, and micro-scale industries, providing a nuanced understanding of the variations and specific challenges faced by organisations of different sizes.

iv. Insufficient consideration of service centres: Previous research has focused on manufacturing-oriented organisations, neglecting the role of service centres within the broader ecosystem of the automobile industry. Including service centres in the current study enables a comprehensive evaluation of readiness levels across the entire value chain, providing insights into the preparedness of these entities for I4.0 adoption.

v. Emphasis on the People’s dimension: While previous research has acknowledged the significance of human capital in I4.0 adoption, there is a need for a more in-depth exploration of the People’s dimension. The current research places particular emphasis on assessing the readiness levels of employees, training programs, customer involvement, and utilisation of customer feedback. This focus on the People's dimension offers valuable insights into the workforce's capabilities and the extent to which organisations foster a culture conducive to I4.0 adoption.

By addressing these research gaps, the current study enhances the understanding of readiness for I4.0 adoption in the IAI. The findings contribute to the existing literature by providing industry-specific insights, considering organisational size, including service centres, and emphasising the importance of the people dimension. These contributions not only fill gaps in the literature but also offer practical implications for decision-makers, policymakers, and industry stakeholders aiming to foster successful I4.0 implementation within the Indian automobile sector.

Methodology

This section presents the methodology employed to measure the readiness of IAI for I4.0. The research design, questionnaire preparation, data collection, and data analysis were discussed in detail.

Research Design

A cross-sectional design was adopted in this study. The cross-sectional design allows for data collection at a specific point in time, providing a snapshot of the readiness levels of the IAI for I4.0 adoption. The research design used the MARI-IA Scale to facilitate readiness assessment across different dimensions, as shown in Figure 1: Vision (VIS), Machines (MAC), Practices (PRT), Products (PDT), and People (PPL). The individual dimensional scores were calculated by rounding the scores to a scale of 10 per the following formulae:

$$VIS_i = \frac{\sum vis_{ij}}{\sum \max(vis)} \times 10 \quad (1)$$

$$MAC_i = \frac{\sum mac_{ij}}{\sum \max(mac)} \times 10 \quad (2)$$

$$PRT_i = \frac{\sum prt_{ij}}{\sum \max(prt)} \times 10 \quad (3)$$

$$PDT_i = \frac{\sum pdt_{ij}}{\sum \max(pdt)} \times 10 \quad (4)$$

$$PPL_i = \frac{\sum ppl_{ij}}{\sum \max(ppl)} \times 10 \quad (5)$$

Consequently, the MARI-IA Score was calculated as per the following formula:

$$MARI\_IA\ Score = \frac{VIS_i + MAC_i + PRT_i + PDT_i + PPL_i}{5} \quad (6)$$

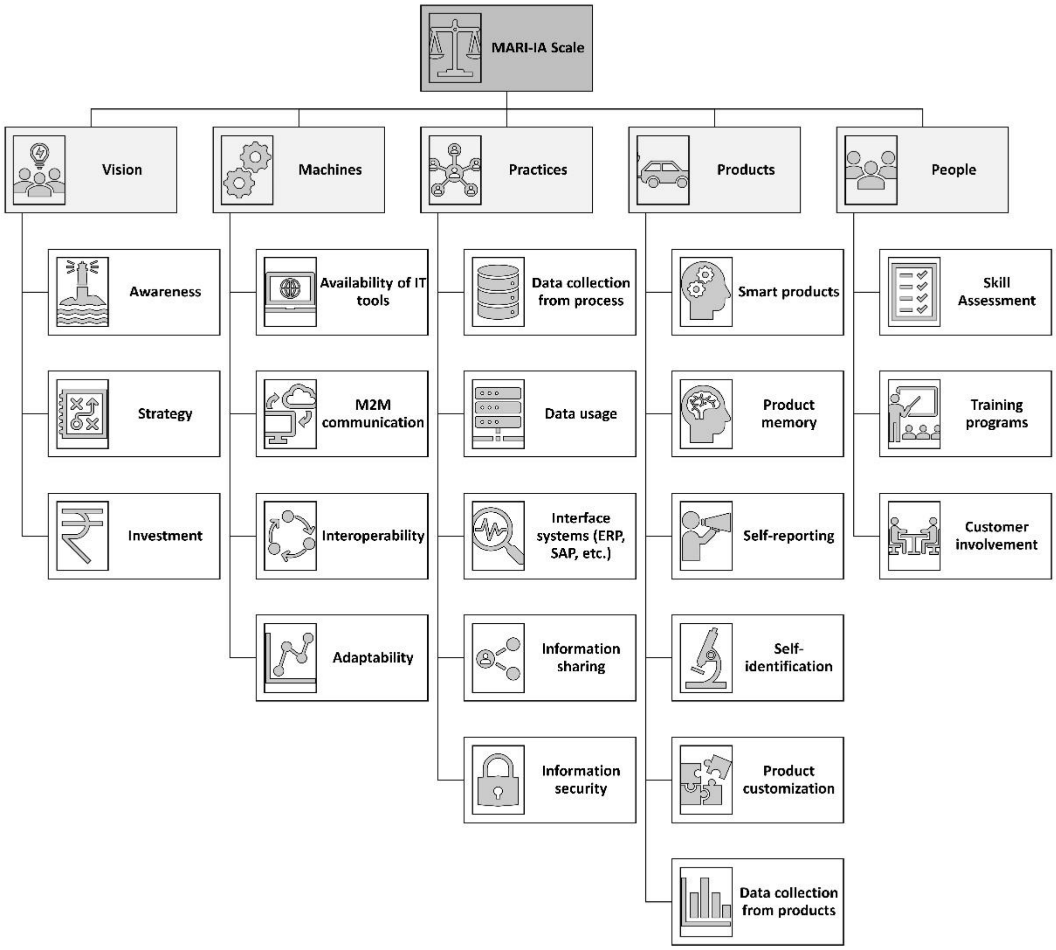

Figure 1. Framework of MARI-IA Scale with dimensions and sub-dimensions

Source: compiled by authors.

Preparation of Questionnaire:

A questionnaire was developed based on the dimensions of the MARI-IA Scale. Each dimension consisted of multiple items aimed at capturing the readiness levels of organisations. The questions were carefully designed to align with the IAI's specific context and the respective dimensions' requirements. The questionnaire underwent rigorous review, including expert feedback and pilot testing, to ensure reliability and validity.

Data Collection:

The target population for this research comprised organisations operating in the IAI. Three categories of organisations were considered: original equipment manufacturers (OEMs), supplier industries, and service centres. A stratified random sampling technique was used to select participants for this study. A total of 9 organisations were sampled, including 2 OEMs, 6 suppliers, and one service provider.

The organisations were further categorised based on the number of employees and turnover to ensure representativeness. Four categories were created for each criterion: large-scale, medium-scale, small-scale, and microscale. This categorisation allowed for analysing readiness levels across different scales of operations within the IAI.

Data were collected through a combination of online and personal interviews. The questionnaire was administered to the selected organisations, and responses were collected. In-person interviews were conducted to gather additional insights and to clarify any ambiguities in the questionnaire responses.

Data Analysis:

The collected data were analysed using descriptive and inferential statistical techniques. Descriptive statistics was used to summarise and present responses to each item in the questionnaire. The scores were calculated to assess the overall readiness levels within each dimension and across different categories of organisations.

In addition to descriptive analysis, inferential statistical methods such as multivariate analysis of variance (MANOVA) were employed to examine any significant differences in readiness levels among the different categories of organisations based on size and type. The data analysis aimed to uncover patterns, trends, and significant findings that would contribute to understanding the readiness of Indian automobile industries to adopt I4.0.

Overall, the research methodology employed in this study enables a comprehensive assessment of readiness levels in the IAI. Adopting the MARI-IA Scale, along with careful data collection and analysis procedures, facilitated an in-depth exploration of the dimensions of readiness for I4.0 adoption. The findings obtained through this methodology may provide valuable insights for decision-makers, industry stakeholders, and policymakers, enabling them to develop targeted strategies and interventions to enhance readiness levels and drive successful I4.0 implementation within the Indian automobile sector.

Result and Discussion

Reliability Test

Internal consistency refers to the degree to which all items within a test assess the same concept or construct, reflecting the interconnectedness of the items within the test. The reliability test results of this study provide valuable insights into the consistency and trustworthiness of the collected data. The Cronbach’s alpha value (α) was calculated as per the following formula (Şimşek & Noyan, 2013):

$$\alpha = \frac{n}{n-1}\left(\frac{\sum_{i\neq j} Cov(X_i, X_j)}{Var(\sum_{i=1}^{n} X_i)}\right) \tag{7}$$

where n is the number of observations (participants), $Cov(X_i, X_j)$ is covariance in scores by participants i and j, respectively, and Var() gives variance in the summation of all scores.

The McDonald’s omega value (ω) was calculated as per the following formula (Şimşek & Noyan, 2013):

$$\omega = 1 - \left(\frac{\sum_{i=1}^{n} u_i^2}{Var(\sum_{i=1}^{n} x_i)}\right) \tag{8}$$

where u_i^2 is the uniqueness factor from factor analysis.

The Cronbach's alpha value of 0.895 and McDonald's omega value of 0.921, as shown in Table , indicate a high level of internal consistency among the items used in the questionnaire. Different reports about the acceptable alpha values range from 0.70 to 0.95 (Tavakol & Dennick, 2011). Generally, a Cronbach's alpha above 0.7 is considered acceptable for reliability, and your result comfortably surpasses this threshold. The high reliability of the collected data indicates that the survey items consistently measure the intended constructs (vision, machine, practices, product, and people) and yield dependable results.

Additionally, the item-wise reliability test, as shown in Source: compiled by authors.

Table , assessed the impact of removing specific items on the overall reliability. Notably, even after removing individual items related to 'vision,' 'machine,' 'practices,' 'product,' and 'people,' the Cronbach's alpha values remained above 0.8, suggesting that no single item disproportionately influenced the overall reliability. The McDonald's omega values further supported this conclusion, showing a similar pattern of high reliability even when individual items were dropped.

Table 2. Reliability Scale

Scale	Cronbach's α	McDonald's ω
Reliability	0.895	0.921

Source: compiled by authors.

Table 3. Item-wise Reliability Scale

	If item dropped	
	Cronbach's α	McDonald's ω
Vision	0.852	0.878
Machine	0.848	0.890
Practices	0.837	0.877
Product	0.926	0.936
People	0.897	0.928

Source: compiled by authors.

Normality Test

The study's Shapiro-Wilk Multivariate Normality Test results, indicate a departure from multivariate normality in the data. The W value of 0.810 and a p-value of <0.001 signifies a statistically significant deviation from the normality assumption. The low W value suggests that the data does not perfectly conform to a normal distribution. The associated p-value of less than 0.001 indicates that this deviation is statistically significant. The same is also shown in Figure . This shows that the data was free from any manipulation to achieve normality.

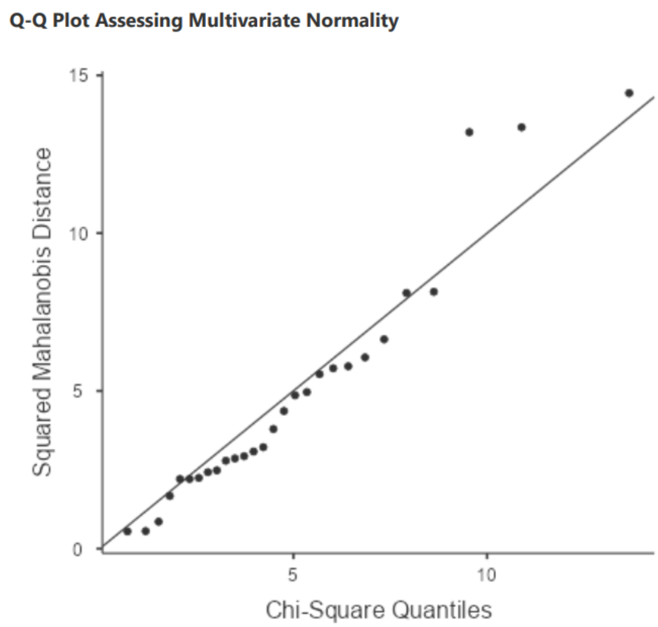

Figure 2. Q-Q Plot assessing normality

Source: compiled by authors.

Criteria Correlation

The degree and direction of the relationship between two variables recorded on at least an interval scale are expressed as Pearson's Correlation coefficient (Obilor & Amadi, 2018). The Pearson's Correlation Coefficient, r, between two variables, x and y, is calculated using the formula:

$$r = \frac{C_{x,y}}{S_x S_y} \tag{9}$$

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where $C_{x,y}$ is the covariance between x and y, and S_x and S_y are the standard deviation in x and y respectively.

The Pearson correlation heatmap, shown in Figure , reveals noteworthy patterns of association among the dimensions assessed by the MARI-IA scale. Strong positive correlations are observed between Vision and Practices (r = 0.93), Vision and Machine (r = 0.87), and Machine and Practices (r = 0.86), indicating a high degree of interdependence between these dimensions. Similarly, the positive correlations between Vision and People (r = 0.69), Machine and People (r = 0.66), Practices and Product (r = 0.67), and Practices and People (r = 0.64) suggest a cohesive relationship among these aspects of I4.0 readiness. However, it is noteworthy that the correlation between People and Product is comparatively lower (r = 0.33), suggesting a weaker association between workforce-related factors and product-related readiness. The correlation of Vision with Product (r = 0.58) and Machine with Product (r = 0.56) reveals moderate associations. These findings imply that while specific dimensions exhibit strong interrelations, others may demonstrate more nuanced connections. Discerning these correlation patterns contributes to a nuanced understanding of the multidimensional nature of I4.0 readiness, offering insights that can inform targeted interventions and strategic initiatives to bolster organisational preparedness. The strong positive correlation between the Vision, Machine, and Practices dimensions of the MARI-IA Scale highlights the interconnectedness of these factors in adopting I4.0. A clear vision drives the adoption of advanced machinery and the implementation of innovative practices, creating a synergistic relationship that fosters I4.0 transformation.

Pearson Correlation Heatmap

	Vision	Machine	Practices	Product	People
Vision	1	0.87	0.93	0.58	0.69
Machine		1	0.86	0.56	0.66
Practices			1	0.67	0.64
Product				1	0.33
People					1

Figure 3. Pearson Correlation Value between five dimensions

Source: compiled by authors.

MARI-IA Score

The MARI-IA Score for OEMs, Supplier industries, and Service centres and the individual dimensional scores, shown in Figure , reveal a clear readiness hierarchy for I4.0 adoption. OEMs consistently demonstrate the highest readiness levels across all dimensions, with an average MARI-IA Score of 7.78. This suggests that OEMs have a well-defined vision for I4.0, have invested in advanced machinery, have adopted innovative practices, are committed to employee upskilling, and are actively enhancing customer awareness. Supplier industries, with an average MARI-IA Score of 6.61, exhibit moderate readiness levels. While they have made progress in adopting advanced machinery and implementing innovative practices, their vision, product development, and employee upskilling initiatives lag behind those of OEMs. This highlights the need for supplier industries to strengthen their I4.0 strategies to remain competitive in the global automotive supply chain. With an average MARI-IA Score of 5.32, service centres display the lowest readiness levels for I4.0 adoption. Their vision, machinery, practices, and product development efforts are still in their early stages, and their employee upskilling initiatives are limited. This suggests that service centres must prioritise developing a clear vision for I4.0, investing in advanced technologies, adopting innovative practices, and enhancing employee skills to remain relevant in the I4.0 era.

The vision was the dimension with the lowest score among all industry types, showing a lack of managerial vision and strategy to adopt I4.0 across the Indian automobile sector. However, the People dimension got the highest score in all surveyed organisations, signifying that the stakeholders, i.e., the employees, customers, etc., are comparatively readiest for the changes I4.0 adoption will bring.

When studied, a similar pattern was observed in the scores regarding employee size and turnover. Large-scale industries scored highest, followed by medium-scale and small-scale industries. Micro-scale industries scored significantly low. Industries with a medium number of employees scored closer to small enterprises. In contrast, industries with medium-scale turnover scored closer to companies with significant turnover in vision, machine and practices. This shows that turnover is a significant factor that enables companies to invest in technology adoption. This is further validated in the next section.

The MARI-IA score of OEMs, supplier industries, and service centres portrayed a similar result, with various organisations scoring similar to their competitors. A significant difference in the two service centres is observed due to the different scale of operations of the two enterprises.

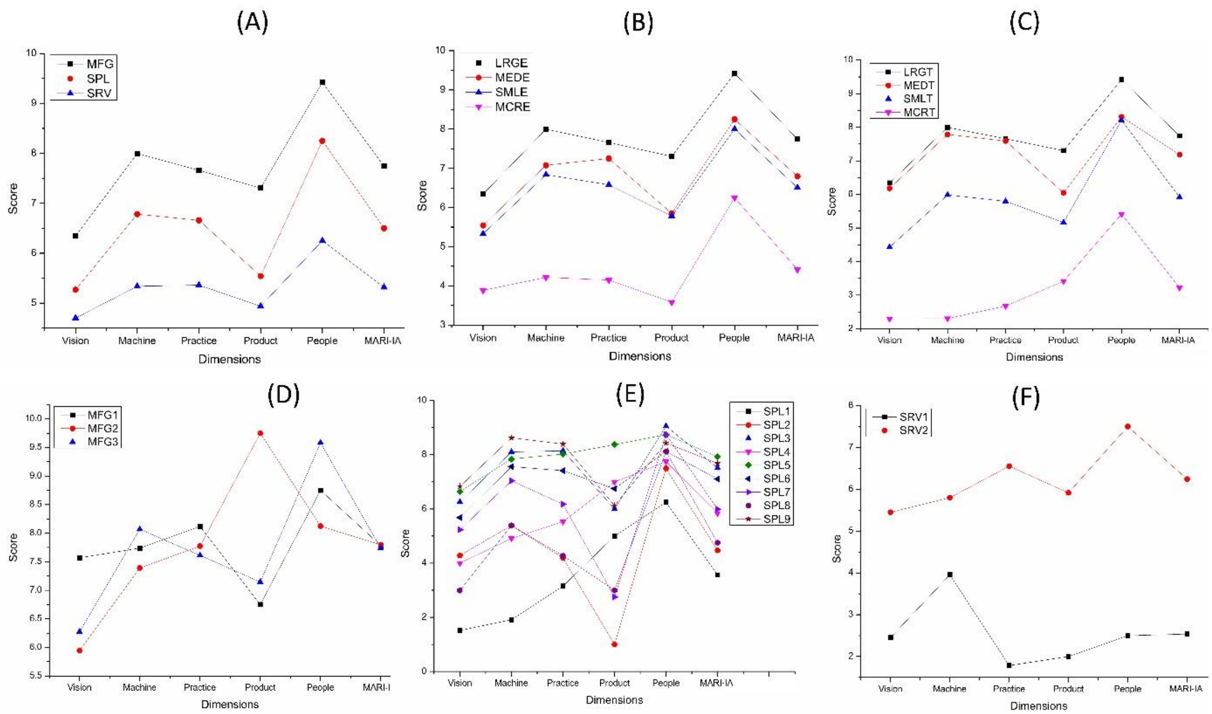

Figure 4. MARI-IA Score: (A) by industry type, (B) by employee size, (C) by turnover size, (D) by OEMs, (E) of supplier industries, and (F) by service centres

Source: compiled by authors.

Multiple Factor Analysis of Variance (MANOVA)

The MANOVA analysis was performed to analyse the effect of turnover (TRNOSZE) and employee size (EMPLSZE) on the overall score. Table shows that turnover size significantly influenced the overall score, while the number of employees had no significant effect on the overall score. This can be validated by Lin et al. (2017), who highlighted that larger companies are more inclined to adopt new technologies, driven by their access to ample resources, technical expertise, and accumulated experience.

Table 4. Multi-Factor Analysis of Variance on MARI-IA Score by Turnover and Employee Size

		value	F	df1	df2	p
TRNOSZE	Pillai's Trace	1.284	1.70	20	72	0.053
	Wilks' Lambda	0.0815	2.86	20	51	0.001
	Hotelling's Trace	7.128	4.81	20	54	< .001
	Roy's Largest Root	6.557	23.60	5	18	< .001
EMPLSZE	Pillai's Trace	0.877	1.41	15	51	0.181
	Wilks' Lambda	0.3276	1.39	15	42	0.198
	Hotelling's Trace	1.471	1.34	15	41	0.224
	Roy's Largest Root	0.955	3.25	5	17	0.031

Source: compiled by authors.

The Univariate Test was performed to analyse the influence of turnover size (TRNOSZE) and employee size (EMPLSZE) on the individual dimensions. As shown in Table , the turnover size significantly influenced all dimensions (all p values <0.05). In contrast, the number of employees significantly influenced the Practices dimension (p-value: 0.049). It is easier for OEMs and large firms to invest in training and adopt recent advanced practices in their operations than small firms (Arvanitis & Hollenstein, 2001).

Table 5. Univariate Multi-Factor Analysis of Variance on individual dimensions of MARI-IA Score by Turnover and Employee Size

		Sum of Squares	df	Mean Square	F	p
TRNOSZE	VISION	50.2529	4	12.5632	15.6314	< .001
	MACHINE	93.6486	4	23.4122	15.8652	< .001
	PRACTICES	73.4546	4	18.3637	13.2011	< .001
	PRODUCT	66.8330	4	16.7083	3.1674	0.037
	PEOPLE	81.1223	4	20.2806	9.8623	< .001
EMPLSZE	VISION	11.6085	3	3.8695	4.8145	0.012
	MACHINE	6.6274	3	2.2091	1.4970	0.247
	PRACTICES	13.1181	3	4.3727	3.1434	0.049
	PRODUCT	34.1260	3	11.3753	2.1564	0.127
	PEOPLE	0.6594	3	0.2198	0.1069	0.955

Source: compiled by authors.

Implications

Managerial Implications

The IAI can ready itself and mature in I4.0 adoption in several ways. Some of the methods include:

i. Adopt a holistic approach to I4.0 adoption: Organizations should prioritise developing a clear vision for I4.0 implementation, investing in advanced machinery and technologies, adopting innovative practices, focusing on employee upskilling and training (Faller & Feldmúller, 2015), and enhancing customer awareness.
ii. Strengthen I4.0 strategies: Supplier industries should strengthen their I4.0 strategies to remain competitive in the global automotive supply chain by enhancing their vision, product development, and employee upskilling initiatives.
iii. Prioritize I4.0 readiness: Service centres must prioritise developing a clear vision for I4.0, investing in advanced technologies, adopting innovative practices, and enhancing employee skills to remain relevant in the I4.0 era.
iv. Investing in new technologies: The industry can invest in new technologies, such as cyber-physical systems, the IoT, cloud computing, and AI. These technologies can help the industry improve efficiency, productivity, and quality (Chakravarthy et al., 2023).
v. Reorganizing production processes: The industry can use I4.0 technologies to reorganise its operations. For example, the industry can use 3D printing to create customised products or robots to automate production lines.

vi. Developing new business models: The industry can create new business models to exploit I4.0 technologies. For example, the industry can offer new services like predictive maintenance or remote monitoring.

Theoretical implications

The areas where the industry needs to improve include:

vii. Interconnectedness of I4.0 dimensions: The strong positive correlation between Vision, Machine, and Practices highlights the interconnectedness of these factors, suggesting a synergistic relationship that fosters I4.0 transformation.

viii. Hierarchy of I4.0 readiness: The varying MARI-IA Scores across OEMs, supplier industries, and service centres reveal a hierarchy of I4.0 readiness, emphasising the need for targeted interventions to enhance preparedness levels.

ix. Impact of turnover and employee size on I4.0 adoption: The significant influence of turnover on the overall score and individual dimensions suggests that larger companies with higher turnover are more likely to adopt I4.0 technologies and practices due to increased resources and favourable risk attitudes.

x. Relationship between the Dimensions: The industry needs to develop a clear vision for I4.0 adoption, must invest in new machines compatible with I4.0 technologies, develop new approaches (practices) and products that align with I4.0 principles, and train its employees on I4.0 technologies.

Conclusion

This research has successfully developed and validated the MARI-IA Scale to assess the readiness for I4.0 adoption in the IAI. The scale has been demonstrated to have high internal consistency and reliability, making it a valuable tool for evaluating organisational preparedness for I4.0. The application of the MARI-IA Scale has revealed a hierarchy of I4.0 readiness among OEMs, supplier industries, and service centres, with OEMs exhibiting the highest levels of readiness, followed by supplier industries and service centres. These findings highlight the need for targeted interventions and initiatives to accelerate I4.0 adoption across the different sectors of the IAI.

Despite its contributions, this research has certain limitations. Firstly, the study focused on the IAI, and the findings may not be directly transferable to other industries or geographical contexts. Secondly, the study relied on self-reported data from survey respondents, which may be subject to biases and inaccuracies. Thirdly, the study did not investigate the causal relationships between the dimensions of the MARI-IA Scale and I4.0 adoption outcomes.

Building on this research, future studies can explore the following directions:

- Cross-industry comparison: Investigate the applicability and generalizability of the MARI-IA Scale to other industries, such as manufacturing, healthcare, and services, to identify commonalities and differences in I4.0 readiness across diverse sectors.
- Longitudinal analysis: Conduct longitudinal studies to examine the changes in I4.0 readiness over time and assess the impact of interventions and initiatives to enhance I4.0 adoption.
- Causal relationships: Employ causal research methods, such as experimental or quasi-experimental designs, to investigate the causal relationships between the dimensions of the MARI-IA Scale and I4.0 adoption outcomes, such as productivity, efficiency, and innovation.
- Contextual factors: Explore the influence of contextual factors, such as government policies, regulatory frameworks, and cultural norms, on I4.0 adoption across different regions and countries.
- Employee perspectives: Gather insights from employees at different levels of the organisation to understand their perceptions of I4.0 readiness and the challenges and opportunities associated with I4.0 adoption.

Adopting I4.0 is crucial for the growth and sustainability of the IAI. The readiness of Indian automobile industries for I4.0 is influenced by various factors such as organisational, technological, and environmental readiness. Several frameworks and models have been proposed to measure the readiness of Indian automobile industries for I4.0, which can guide industries and policymakers in implementing I4.0 technologies effectively.

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