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ORIGINAL RESEARCH

Developing a maturity model for Industry 4.0 practices in manufacturing SMEs

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Abstract
Disruptive technologies like IoT, cyber-physical systems, blockchain, additive manufacturing, simulation, and robotics are transforming traditional factories into smart factories, considered an 'Industry 4.0' revolution. Industry 4.0 (I4.0) technologies positively impact the organizations at different level of sustainability. Organizations must understand I4.0 technologies and be prepared to adopt physical and digital technologies to make appropriate decisions to improve their market competitiveness. In this regard, I4.0 readiness and maturity models can support organizations to assess their current maturity status and set up a roadmap for further actions for digital transformation. Integrating sustainability principles with I4.0 can enable socially responsible and environmentally conscious manufacturing in organizations. Also, leveraging I4.0 technologies can optimize resource consumption and reduce waste, which helps manufacturing organizations to achieve market competitiveness and sustainable innovation. In the literature, most of maturity models are developed for or by large enterprises with limited applicability in small and medium enterprises (SMEs). Also, maturity items considered in these models are not empirically validated. To fill this research gap, this study proposes a maturity model for SMEs, which is empirically tested in Indian manufacturing organizations and includes 40 maturity items in eight major dimensions that impact sustainability and can help to transform the manufacturing sector towards more resource-efficient and sustainable. A large survey is conducted in the Indian manufacturing organizations to validate these maturity items in the Indian context. Then, a model based on Exploratory factor analysis is proposed in 8 dimensions. The proposed model is validated in four case organizations from pharmaceutical and automobile sectors. The results indicated that base technologies and legal maturity items have higher maturity scores. Based on the study's findings, implications for practitioners and policymakers are provided to improve maturity levels in manufacturing organizations. The study's contribution is important and unique for manufacturing organizations as validation of maturity items and maturity model for SMEs with sustainability benefits is non-existent.

Keywords Industry 4.0 · Digitalization · Maturity model · Exploratory factor analysis · Decision making · Maturity index · Sustainability

1 Introduction

Industry 4.0 (I4.0) technologies, including physical and digital technologies, have proposed a new industrial maturity stage which influences the sustainability of manufacturing activities throughout the process, product and system level (Enyoghasi & Badurdeen 2021; Machado et al. 2020; Schumacher et al. 2016). I4.0 can be considered as new industrial revolution that integrates information and communication technologies (ICTs) with manufacturing activities through the Internet of Things (IoT), thereby forming Cyber-Physical systems (CPS). Also, the technologies under the I4.0 umbrella, i.e., Artificial intelligence (AI), machine learning (ML), additive manufacturing (AM), cloud computing (CC), Blockchain technology (BC), augmented reality (AR), virtual reality (VR) and automation can help manufacturing sector to address dynamic market demands, mass customization and sustainability issues (Bai et al. 2020; Beier et al. 2020; Cimini et al. 2023). These technologies

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transform traditional factories into smart ones (Beier et al. 2020; Calabrese et al. 2021; Kim 2017). The benefits for the manufacturing sector are shorter lead times, lower costs, and operational efficiency (Frank et al. 2019). From the market perspective, I4.0 technologies offer a better product life cycle and smart products to customers (Dalenogare et al. 2018). Existing studies have discussed the benefits of I4.0 practices in terms of sustainability, such as less carbon emissions, optimal resource consumption and inventory management (Bai et al. 2020; Enyoghasi & Badurdeen 2021; Machado et al. 2020).

Due to these benefits and global market competition, several countries are adopting I4.0 practices in their business models as local programs, such as Germany's "High-Tech Strategy 2020", the U.S as "Smart Manufacturing", India as "Make in India", Brazil as "Towards Industry 4.0" and China as "China 2025" but with a common objective of developing smart factories (Machado et al. 2020). Nevertheless, these initiatives are relatively novel and challenging for emerging economies due to a lack of knowledge and technological infrastructure (Chauhan et al. 2021; Raj et al. 2020). Emerging economies have less developed markets and face barriers to managerial capabilities, human capital and weaker government regulations (de Sousa Jabbour et al. 2018; Luthra et al. 2020). This affects the adoption of new technologies in emerging economies compared to developed countries (Yadav et al. 2020). Other factors, such as more robust technological infrastructure, ICT infrastructure, level of education, and political and economic stability, are more decisive in developed countries than in emerging economies (Bag et al. 2021; Kumar et al. 2020). I4.0 practices play a vital role in developing the SME sector due to their product specialization knowledge and limited financial resources (Mittal et al. 2018). The past studies also discussed the importance of I4.0 tools and technologies for SMEs (Chauhan et al. 2021; Kamble et al. 2019; Kumar et al. 2020; Mittal et al. 2018; Raj et al. 2020). Other studies also discussed the opportunities and challenges related to I4.0 practices in SMEs (Kumar et al. 2020; Luthra & Mangla 2018; Masood & Sonntag 2020). Despite the importance of I4.0 practices in SMEs, emerging economies still struggle with I4.0 practices due to a lack of technological maturity, reference architecture and technical infrastructure (Jamwal et al. 2021; Yadav et al. 2020).

In this context, Mittal et al., (2018) argued that there is limited research related to I4.0 definitions and constructs such as readiness assessment and maturity. Approaches such as maturity assessment can help manufacturing organizations build a roadmap for digitalization and provide guidelines to improve their progress (Caiado et al. 2021; Santos & Martinho 2019; Schumacher et al. 2016; Wagire et al. 2020). This also helps to assess the current level of organization in digital transformation (Elibal & Özceylan 2020; Ganzarain & Errasti 2016). Prior research has focused on large enterprises' I4.0 maturity and readiness assessment (Caiado et al. 2021; Mittal et al. 2018). There is still a significant research gap related to the maturity assessment of SMEs, and its impact on sustainability is not explored. Recent literature on I4.0 shows SMEs have many opportunities for I4.0 practices (Kumar et al. 2020; Yadav et al. 2020). MNCs (Multinational companies) are also investing in the SMEs of emerging economies due to lower manufacturing and labour costs (Yadav et al. 2020). However, the maturity and readiness assessment in the SMEs of emerging economies has not yet been addressed in developing markets like India. Moreover, due to the complexity of the business models of I4.0, it is crucial to identify the relevant maturity items in SMEs and their impact on sustainability.

Based on the existing literature gaps and previous studies: Mittal et al., (2018); Wagire et al., (2020), we propose that consideration of legal maturity items is important for SMEs because of intellectual property, labour laws and data protection issues, which affects the growth of industries. Therefore, legal items need to be considered in the maturity assessment. It is also important to analyze maturity models from the triple-bottom-line perspective and investigate the impact of maturity items on sustainability (Correia et al. 2017). It helps to develop a roadmap for the technology adoption and upgradation and assess its long-term impact on sustainability. The sustainability assessment, along with the maturity models, is adopted in various sectors such as new product development (Hynds et al. 2014), supply chain (de Almeida Santos et al. 2020), Green-IT (Patón-Romero & Piattini 2017), Sustainable Business (Cagnin et al. 2005) but limited attention have been observed in the maturity models for the manufacturing sector. Addressing this issue in the manufacturing sector is important to ensure sustainability practices are considered during the digital transformation. To address this research gap, the study addresses the following research questions:

RQ1: What are the different maturity and readiness items and their impact on sustainability to assess the current I4.0 adoption level in emerging economies?
RQ2: What is the priority order of these items in emerging economies in the manufacturing sector?
RQ3: What is the current maturity level of industries in emerging economies?

To answer the above-discussed research questions, a systematic literature review approach has been followed on the I4.0-related documents since the evolution of the I4.0 concept in literature. A list of the critical maturity items was found after a systematic literature review, and a survey was done with these maturity items in the Indian manufacturing sector. The exploratory factor analysis (EFA) approach categorises the various maturity items into major dimensions. The fuzzy-analytical hierarchy (F-AHP) approach is used for weight prioritization in the major maturity dimensions. A maturity model is proposed after identifying relevant maturity items for SMEs. Four case studies in different manufacturing organizations have been conducted to investigate the applicability of the maturity model.

The remaining paper has seven sections. Section 2 discusses about the review protocol; Section 3 discusses about research gaps; Section 4 discusses about research framework and data collection; Section 5 discusses about the maturity model development and results of case studies; Section 6 discusses about theoretical and managerial implications; Section 7 discusses about the conclusion and future scopes of study.

2 Systematic literature review—methodology

In the initial phase of the study, a systematic literature review (SLR) approach by Tranfield et al., (2003) is followed using a search string shown in Fig. 1 on three major digital scientific literature databases, i.e., "IEEE Xplore", "Web of Science" and "Scopus". Various inclusion and exclusion criteria were considered for article filtration based on the subject area, article type, and language. A total of 83 articles were included in the final study for the maturity models. These articles were used to find the relevant maturity items and research opportunities in this area. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) diagram for the SLR is presented in the Fig. 1.

The articles included in PRISMA diagram were used to identify the maturity items. Other than these articles we

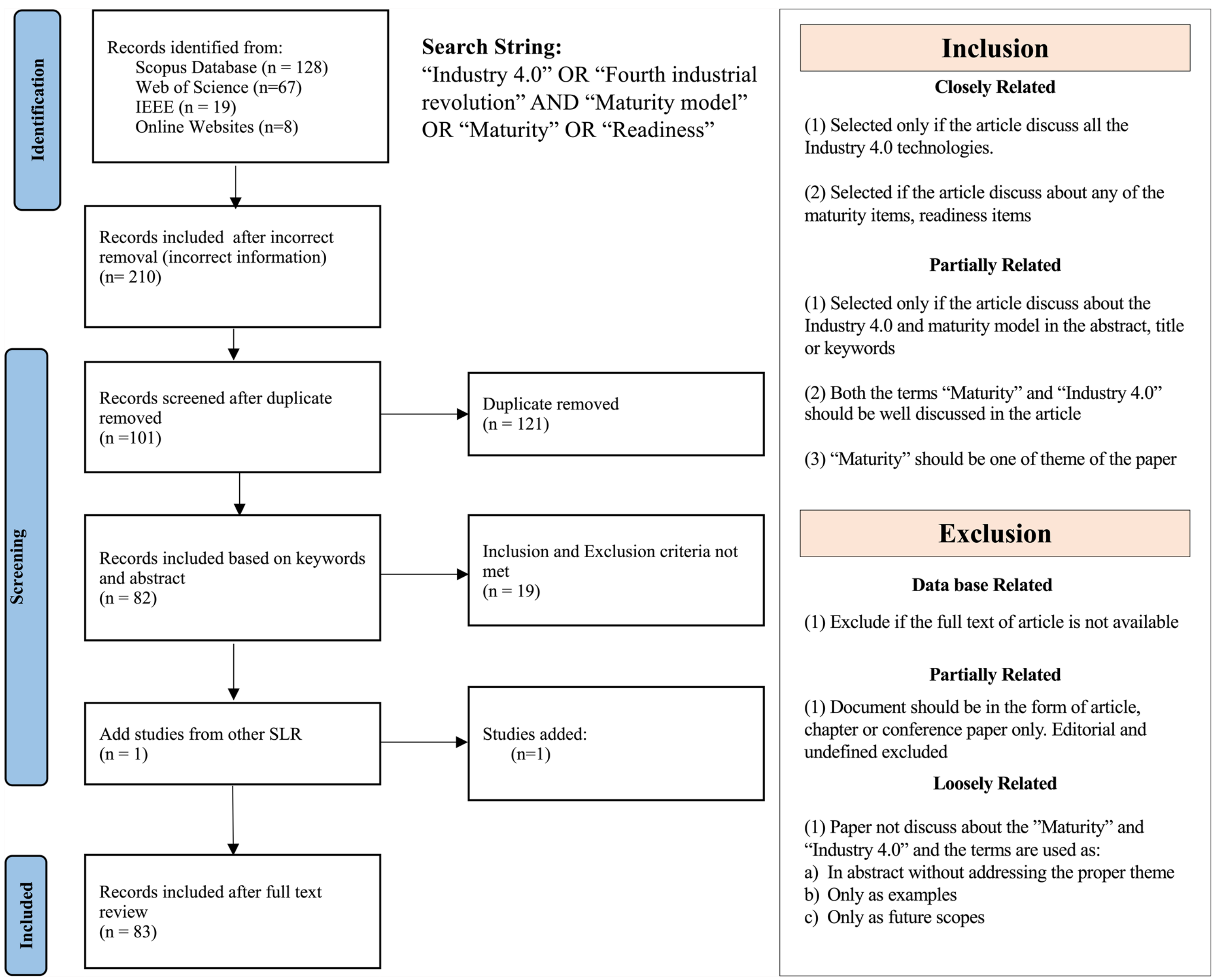


Fig. 1 PRISMA diagram for SLR conducted in the study with inclusion and exclusion criteria

used the literature available on the I4.0 and sustainability to identify the impact of maturity items on the sustainability i.e., (Bai et al. 2020; Enyoghasi & Badurdeen 2021; Machado et al. 2020) discussed how I4.0 technologies such as: machine learning, artificial intelligence and IoT impact sustianability. This approach was used to identify the sustianability impact of each item.

2.1 Industry 4.0 opportunities for SMEs

SMEs are the major contributors to the manufacturing sector, which completes customers' dynamic and complex demands. The existing literature on I4.0 discussed the opportunities for SMEs related to new business models (Bag et al. 2021; Luthra & Mangla 2018; Mittal et al. 2018; Raj et al. 2020; Yadav et al. 2020). Digitalization in SMEs can help in mass customization at lower costs with better quality (Masood & Sonntag 2020; Mittal et al. 2018). The initial attempt to discuss literature on the smart factory was made by Würtz & Kölmel (2012), which highlights opportunities for SMEs. Before 2016, the manufacturing industry used some of the same technologies, i.e., IoT, additive manufacturing and cloud computing, that are now part of I4.0. Nevertheless, "Industry 4.0" was not popular until 2016. So, before 2016, there was less focus on the I4.0 literature in this period (Masood & Sonntag 2020; Zheng et al. 2021). In the past six years, literature discussed the role and benefits of I4.0 for manufacturing SMEs in terms of real time process monitoring (Dutta et al. 2020; Kumar et al. 2020; Masood & Sonntag 2020; Mittal et al. 2018). I4.0 technologies are shaping manufacturing industries to increase productivity and sustainability in SMEs. In addition, emerging manufacturing hubs, i.e., India, actively support I4.0 initiatives in SMEs by providing direct and indirect financial support to improve SMEs' level of I4.0 maturity. Thus underpinning the "SAMARTH Udyog Bharat 4.0" initiative by the Government of India (GOI) for smart and sustainable growth. GOI supports innovation and research projects intending to create a favourable ecosystem for I4.0 practices in SMEs (*BRICS* Council 2017). SMEs are innovative and adaptive not only in terms of products but also in terms of manufacturing practices (Mittal et al. 2018). Due to increased global market competition, SMEs are also improving their business models by adopting I4.0 technologies. Few studies have pointed out the potential and changes required for I4.0 adoption in SMEs (Dutta et al. 2020; Masood & Sonntag 2020; Mittal et al. 2018; Trotta & Garengo 2019). I4.0-enabled business models offer SMEs a wide range of opportunities by enhancing their competitiveness (Cimini et al. 2017; Luthra & Mangla 2018).

2.2 Industry 4.0 maturity and readiness models in the manufacturing sector

Maturity and readiness assessment is important for a manufacturing sector to understand the organization's preparedness and capability levels for adopting technology and implementing I4.0 practices (Pirola et al. 2020). Due to dynamic market changes, manufacturing organizations are adopting I4.0 practices to enhance operational efficiency and leverage advanced technologies to improve market competitiveness and productivity (Cimini et al. 2020).

However, the adoption level is low due to immature technologies and a lack of a roadmap to guide these organizations to adopt I4.0 practices (Elibal & Özceylan 2020; Mittal et al. 2018; Wagire et al. 2020). In this context, the literature suggests using maturity models to develop their digitalization roadmap by knowing their current status and readiness (Rafael et al. 2020). Also, understanding the appropriate maturity item will help to improve their I4.0 progress and sustainability performance (Dikhanbayeva et al. 2020).

Therefore, assessing the maturity and readiness of I4.0 practices is a topic of interest in the I4.0 research domain (Mittal et al. 2018; Rafael et al. 2020; Santos & Martinho 2019; Wagire et al. 2020). Manufacturing organizations are adopting I4.0 practices to create a sustainable value chain and increase flexibility and productivity in production systems (Bag et al. 2021; Kumar et al. 2020). Few studies (Dalenogare et al. 2018; El Baz et al. 2022; Frank et al. 2019) highlighted the evolution of new business models in manufacturing organizations due to the digital transformation of industrial activities. However, due to technological infrastructure limitations and skills gaps in the manufacturing sector, it is important to assess the current maturity of technologies and develop a strategic plan with I4.0 standards. Also, maturity and readiness assessment helps to guide the industry's stakeholders and management through a roadmap for digital transformation (Caiado et al. 2021; Elibal & Özceylan 2020; Rafael et al. 2020). Developed and developing economies are working on the I4.0 maturity models but have disparities due to the varying economic conditions and infrastructure facilities. There is a lack of advanced infrastructure in developing countries and skill gaps, which impact their progress and opportunities in I4.0 implementation. In this context, studies by Caiado et al., (2021); Rafael et al., (2020); Schumacher et al., (2016) highlighted the I4.0 maturity model development for developed nations. Similarly, Wagire et al., (2020) developed a maturity assessment model in the developing nation context.

However, these models are for MNEs or large enterprises and have limited empirical evidence in the case of SMEs. Also, the available literature on the maturity model (MM) has considered only several dimensions and has limited applicability to the SME context. In our case, these models provide an initial foundation to build a new I4.0 MM for SMEs, including new dimensions in MM, which were not considered in previous models. Most models offer a self-assessment measurement tool that can be applied to industries, but few do not show the measurement results. There is less evidence regarding the reliability and validity of the maturity items used in these MMs. A few MM discussed the validation through the case studies, but it was not reported in SMEs. A detailed comparison of previously developed maturity models is discussed in Table 1. Table 2 shows the list of identified maturity items.

As discussed in the Introduction section, it is important to identify the relevant maturity and readiness items related to the I4.0. The assessment of I4.0 practices in any organization involves the evaluation of various readiness or maturity items. These items may include organization, infrastructure, skill, or technology-related items, which are well discussed in the existing literature on maturity models. Sustainability can be seen as the long-term impact of the I4.0 adoption in organizations. In manufacturing enterprises, the impact of sustainability is significant, as a well-prepared or matured technology enhances the overall sustainability performance in terms of social, economic, and environmental perspectives. It involves the impact of technologies or practices to improve innovation, resource utilization and identify areas for continuous improvement. Evaluation of such factors is important as it provides insights into the level of preparedness of I4.0 practices and potential challenges to embrace I4.0 technologies in business models.

3 Research gaps in the previous work

Rapid industrialization and dynamic global market changes have forced manufacturing organizations to address sustainability issues in their business practices, such as resource efficiency, inventory management, carbon emission, lead time, mass customization, and customer satisfaction (Machado et al. 2020). All these issues can be addressed with the adoption of I4.0 technologies. However, the practices are at the initial level in the emerging economies. There is a need to assess the current maturity status of industries before developing the roadmap for digitalization. There is also a need to address the sustainability issues at the product, process, and system level with I4.0 technologies. The previous literature discussed the maturity and readiness models to assess the current status of practices and developed a roadmap by providing guidelines. However, the previously published studies lack the statistical validation of maturity items. Moreover, these studies have limited discussion for SMEs' opportunities and model validation.

As discussed by Mittal et al., (2018), most models are either developed for or developed by large enterprises and MNEs, which cannot be generalized for SMEs because of different starting points and opportunities. The present study acknowledges the initial efforts in the maturity model development for I4.0 practices (Akdil et al. 2017; Dikhanbayeva et al. 2020; Rong & Automation 2014; Santos & Martinho 2019; Schumacher et al. 2016, 2019; Sternad et al. 2018), which provides an initial foundation for the model development. Similarly, the model developed by Wagire et al., (2020) discussed the opportunities in emerging economies. In the literature, significantly less attention has been observed toward the model developed for SMEs (Rafael et al. 2020). Few review studies discussed how opportunities for SMEs and Large enterprises are different but can have similar maturity and readiness items (Angreani et al. 2020; Elibal & Özceylan 2020; Mittal et al. 2018). Apart from the maturity items, a few studies discussed that there is an impact of physical and digital technologies of I4.0 on the sustainability performance of organizations and can address the sustainability issues in manufacturing (Enyoghasi & Badurdeen 2021; Machado et al. 2020).

There is a lack of studies and a maturity model that provides a holistic approach to maturity assessment for SMEs in emerging economies. Further, there is less evidence of statistical validation of maturity items based on the extensive survey. To address these research gaps, the present study focused on the maturity model development for SMEs of emerging economies to achieve sustainability in manufacturing organizations.

4 Research design for the development of the Industry 4.0 maturity model

The maturity model development began in 2020 with a systematic literature review approach. Initially, the relevant maturity items were identified, focusing on their impact on sustainability. After extensive literature analysis, 40 maturity items were finalized. The literature review ensured that all the maturity items were applicable in SMEs. Also, the literature review helped to identify new research opportunities within I4.0 and sustainability.

The next phase involved expert consultation to finalize these items. SME managers, I4.0 consultants, and academicians working on I4.0 adoption or digital transformation reviewed and confirmed the items. Subsequently, a questionnaire was prepared, comprising three sections: (1) General information and consent form, (2) Main questions on maturity items, and (3) Demographic details (See Appendix 2).

The survey was distributed to 1,147 companies in the Indian manufacturing sector from December 2021 to March 2022, achieving a 21.2% response rate. Eleven invalid responses were excluded from the final analysis. The survey, which also included questions on enablers and challenges,

Table 1 Comparison of different I4.0 maturity models

Author	ND	NM	ST	LD	CS	PR	OP	CL	PL	GR	TG	LG	SMEs	Case Study	Discussion on emerging economies	Statistical validation/Case study	Maturity item prioritization	Discussion on sustainability
(Schumacher et al. 2016)	9	62	✓	✓	✓	✓	✓	✓	✓	✓	✓	–	–	✓	–	✓	–	–
(Santos & Martinho 2019)	5	41	✓	–	✓	✓	✓	✓	✓	–	✓	–	–	✓	✓	✓	–	Economic perspective
(Ganzarain & Errasti 2016)	–	–	–	–	–	–	–	–	–	–	–	–	✓	–	–	–	–	✓
(Rafael et al. 2020)	5	24	✓			✓	✓	–	–	–	✓	–	✓	✓	–	✓	–	✓
(Schumacher et al. 2019)	8	65	✓	✓	✓	✓	✓	–	✓	–	✓	–	–	✓	–	✓	–	Economic perspective
(Caiado et al. 2021)	7	15	–	–	✓	–	–	–	–	–	–	–	✓	✓	✓	✓	–	–
(Wagire et al. 2020)	7	38	✓	✓	✓	✓	✓	✓	✓	✓	✓	–	–	✓	✓	✓	✓	Economic perspective
(Gökalp et al. 2017)	5	–	–	–	–	–	✓	–	✓	✓	✓	–	–	–	–	–	–	–
(Rajnai & Kocsis 2018)	6	18	✓	✓		✓	✓	–	✓	–	✓	–	–	–	–	–	–	–
(Rong & Automation 2014)	4	–	–	–	–	–	–	–	–	✓	✓	–	–	✓	–	–	–	–
(Lichtblau 2015)	6	18	✓	–	–	–	✓	✓	✓	–	✓	–	–	✓	–	–	–	–
(Bibby & Dehe 2018)	3	23	✓	–	–	–	✓	✓	✓	–	✓	–	–	✓	–	✓	–	✓
(Keskin et al. 2018)	6	43	✓	✓	✓	✓	✓	✓	✓	–	✓	✓	–	✓	✓	✓	✓	–

ND; No. of dimensions, *NM;* No. of maturity items, *ST;* Strategy, *LD;* Leadership, CS; Customer; *PR;* Products, *OP;* Operations, *CL;* Culture, *PL;* People, *GR;* Governance, *TG;* Technology, *LG;* Legal

Table 2 Maturity items, description and their impact on sustainability

Item code	Maturity item name	Description	Impact on sustainability			Reference
			Product level	System-level	Process level	
M_1	Qualification and digital skills	It refers to the digital expertise and literacy of employees. It also focused on the ability of employees to work with digital technologies and make decisions based on data. In terms of sustainability, a higher maturity level will help to reduce waste and monitor environmental impact	✓	✓	✓	(Lichtblau et al. 2015; Santos & Martinho 2019; Sharma et al. 2022; Wagire et al. 2020)
M_2	Dedicated teams	Availability of dedicated departments and teams for I4.0 practices in the organization. In terms of sustainability, higher maturity will help to implement sustainable business practices by reducing waste and optimizing resources	✓	✓	✓	(Akdil et al. 2017; Jamwal et al. 2021; Marnewick & Marnewick 2019; Wagire et al. 2020)
M_3	Management support	Awareness in top-level management regarding I4.0 practices. A higher maturity level will help to support the sustainability initiatives, which include funding, training programs	✓	✓	✓	(Rafael et al. 2020; Santos & Martinho 2019; Schumacher et al. 2016; Yadav et al. 2020)
M_4	Continuous improvement	It refers to a continuous improvement culture in the organization in their manufacturing practices. Higher maturity will help to identify the opportunities for areas of improvement to reduce emissions and wastes	✓	✓	✓	(Santos & Martinho 2019; Vinodh et al. 2020; Wagire et al. 2020)
M_5	Knowledge and familiarity	Understanding I4.0 practices, tools, and technologies and familiarity with these to execute pilot and main projects. Higher maturity will help to implement technologies which can contribute to sustainability	✓	✓	✓	(Akdil et al. 2017; Luthra & Mangla 2018; Santos & Martinho 2019; Wagire et al. 2020)
M_6	Economic and sustainability benefits	Knowledge and awareness about the economic and sustainability benefits of I4.0 practices. Higher maturity will help in smart budget allocation for renewable energy sources	✓	✓	✓	(Luthra & Mangla 2018; Mittal et al. 2018; Santos & Martinho 2019; Wagire et al. 2020)
M_7	Industry 4.0 preparedness	Organization preparedness for I4.0 tools and technologies adoption. A higher maturity level will help to increase the automation level and improve functional safety	✓	✓	✓	(Rajnai & Kocsis 2018; Singhal 2021; Tripathi & Gupta 2021; Wagire et al. 2020)

Table 2 (continued)

Item code	Maturity item name	Description	Impact on sustainability			Reference
			Product level	System-level	Process level	
M_8	Digital culture	Digital culture in an organization on its shop floor and supply chain activities. Higher maturity levels help to enable digital technologies, which improves real-time supply monitoring	✓	✓	✓	(Luthra & Mangla 2018; Schumacher et al. 2016, 2019; Trotta & Garengo 2019; Wagire et al. 2020)
M_9	Customer integration	Customer involvement in the new product development processes is necessary to understand customer requirements. Higher maturity will help to improve innovation by enhancing product development time	✓	✓	✓	(Javaid et al. 2022; Kim 2017; Schumacher et al. 2016, 2019)
M_{10}	Zero paper strategy	Use of digital platforms to share information, i.e., spreadsheets, email, and servers, rather than using papers. Higher maturity will help reduce costs associated with paper use and carbon emissions through its usage	✓	✓	✓	(Mittal et al. 2018; Wagire et al. 2020)
M_{11}	Collaboration	Collaboration with OEM, consultants, academia, and other organizations for I4.0 solutions. Higher maturity will help to share knowledge and resources and help in better decision-making	✓	✓	✓	(Akdil et al. 2017; Ghobakhloo 2020; Lichtblau et al. 2015; Mittal et al. 2018)
M_{12}	Financial investments	Availability of financial resources for the I4.0 pilot and other projects in an organization. Higher maturity will help by smart budget allocations for renewable infrastructure	✓	✓	✓	(Bai et al. 2020; Keskin et al. 2018; Mittal et al. 2018; Schumacher et al. 2016)
M_{13}	Vertical value chain digitalization	It helps in the digitalization of product development to the manufacturing phase of the product. Higher maturity will help to improve quality and innovation	✓	✓	✓	(Castelo-Branco et al. 2019; Keskin et al. 2018; Mittal et al. 2018; Toktaş-Palut 2022)
M_{14}	Real-time process monitoring and control	Real-time process monitoring and control practices for sales forecasting, logistics and warehouse management. Higher maturity will help optimize efficiency and reduce waste	✓	✓	✓	(Gray-Hawkins et al. 2019; Lichtblau et al. 2015; Mittal et al. 2018; Wagire et al. 2020)
M_{15}	End to End IT-enabled planning	IT-enabled process planning and scheduling to address dynamic market changes. Higher maturity will help in logistic planning, respond quickly to dynamic market changes	✓	✓	✓	(Jamwal et al. 2021; Schumacher et al. 2016; Trstenjak & Cosic 2017)

Table 2 (continued)

Item code	Maturity item name	Description	Impact on sustainability			Reference
			Product level	System-level	Process level	
M_{16}	Shop floor digitalization	Shop floor digitalization using a wide area network facility and IoT-enabled platforms to transfer data from machines to the cloud. Higher maturity will help to reduce downtime and wastes	✓	✓	✓	(Akdil et al. 2017; Javaid et al. 2022; Schumacher et al. 2019)
M_{17}	Horizontal value chain digitalization	Digital integration of horizontal value chain across the suppliers, OEM, and other organizations. Higher maturity will help in visibility and collaboration in the value chain	✓	✓	✓	(Ghobakhloo 2020; Kim 2017; Mittal et al. 2018; Sternad et al. 2018)
M_{18}	Industrial robots	Using industrial robots, such as collaborative and autonomous robots on the shop floor helps to minimize accidents. Higher maturity will help to improve quality and functional safety	✓	✓	✓	(Akdil et al. 2017; Bai et al. 2020; Chiarini 2021)
M_{19}	Advanced software systems	Use of software systems in an organization, such as PLM, PDM, MDC, SCM, etc., to share information and receive feedback, manage the inventory level and manufacturing data. Higher maturity will help in better resource management, energy consumption monitoring and control	✓	✓	✓	(Akdil et al. 2017; Ferrari et al. 2021; Rakic et al. 2021; Schumacher et al. 2019)
M_{20}	Use of identifiers	Use of identifiers to locate tools and machines on the system, product level, and warehouse management. Higher maturity will help to improve efficiency in real-time inventory management	✓	✓	✓	(Kamble et al. 2018; Rafael et al. 2020; Schumacher et al. 2019; Sternad et al. 2018)
M_{21}	Use of intelligent sensors	Use of sensors to capture valuable machine data, which helps to optimize manufacturing activities. Higher maturity will help to detect inefficiencies and suggest areas of improvement for waste reduction	✓	✓	✓	(Bai et al. 2020; Mittal et al. 2018; Schumacher et al. 2019)
M_{22}	Machine-to-machine and human-to-machine communications	It refers to information exchange on the shop floor with networked machines and humans. Higher maturity will help to minimize errors and increase productivity	✓	✓	✓	(Kim 2017; Schumacher et al. 2016, 2019; Yadav et al. 2020)

Table 2 (continued)

Item code	Maturity item name	Description	Impact on sustainability			Reference
			Product level	System-level	Process level	
M_{23}	Use of digital platforms for supplier integration	Use of digital platforms in an organization to integrate a group of suppliers, manage supply levels and warehouse management. Higher maturity will help to improve supply chain transparency, reduce transportation cost	✓	✓	✓	(Akdil et al. 2017; Kamble et al. 2018; Kim 2017; Mittal et al. 2018; Wagire et al. 2020)
M_{24}	Use of digital platforms for customer integration	Use of digital platform to integrate the customer in the product design and development process for customization. Higher maturity will help to develop a platform where customers can design what they need, which can reduce waste and minimize inventory	✓	✓	✓	(Akdil et al. 2017; Mittal et al. 2018; Toktaş-Palut 2022; Wagire et al. 2020)
M_{25}	Use of AR and VR technologies	Use of AR and VR technologies for training, simulation and remote assistance purposes. Higher maturity will help in faster response time to market and reduce carbon footprint by reducing the need for physical prototypes	✓	✓	✓	(Akdil et al. 2017; Enyoghasi & Badurdeen 2021; Schumacher et al. 2019)
M_{26}	Additive manufacturing	Use of additive manufacturing to reduce waste, lead time, carbon emission and mass customization demands. Higher maturity will help to reduce fatigue, waste and energy consumption	✓	✓	✓	(Enyoghasi & Badurdeen 2021; Mittal et al. 2018; Rafael et al. 2020)
M_{27}	Use of mobile devices and wearables-based solutions	Use of mobile devices and wearables in an organization to integrate employees with the digital platform. Higher maturity will help in remote monitoring, control of equipment and reduce on-site staff requirement	✓	✓	✓	(Bai et al. 2020; Lichtblau et al. 2015; Rafael et al. 2020)
M_{28}	Blockchain technology	Use of blockchain technology for supply chain activities. Higher maturity will help to build digital trust, enhance transparency, improve environmental and ethical practices	✓	✓	✓	(Akdil et al. 2017; Leng et al. 2020; Lichtblau et al. 2015; Sternad et al. 2018)
M_{29}	Smart products	Use of smart products for better integration, product identification and product monitoring. Higher maturity level helps to adopt circular economy business models	✓	✓	✓	(Akdil et al. 2017; Kamble et al. 2018; Lichtblau et al. 2015; Mittal et al. 2018)

Table 2 (continued)

Item code	Maturity item name	Description	Impact on sustainability			Reference
			Product level	System-level	Process level	
M_{30}	Use of cloud technology for resource sharing and data storage	Use of cloud technology for data storage, resource and information sharing. Higher maturity will reduce the need for on-premise hardware	✓	✓	✓	(Enyoghasi & Badurdeen 2021; Kim 2017; Mittal et al. 2018)
M_{31}	Use of cloud technology for data analysis	Use of cloud technology for the data analysis for process optimization. Higher maturity will help in energy optimization through server virtualization	✓	✓	✓	(Enyoghasi & Badurdeen 2021; Kim 2017; Mittal et al. 2018)
M_{32}	Internet of Things (IoT)	Use of IoT platforms for resource optimization and managing inventory levels. Higher maturity will help to reduce waste and emissions by optimizing resource usage	✓	✓	✓	(Enyoghasi & Badurdeen 2021; Lichtblau et al. 2015; Sternad et al. 2018)
M_{33}	Internet of Services (IoS)	Use of the IoS platform to support IT infrastructure in an organization. Higher maturity will help to improve customer experiences and operational efficiency	✓	✓	✓	(Akdil et al. 2017; Ghobakhloo et al. 2021; Schumacher et al. 2016)
M_{34}	Big data analytics	Use of big data tools to store a large volume of manufacturing data and evaluate real-time data. Higher maturity will help to improve decision-making and identify new areas for improvements	✓	✓	✓	(Akdil et al. 2017; Castelo-Branco et al. 2019; Enyoghasi & Badurdeen 2021; Kim 2017)
M_{35}	Simulation tools	Use of simulation tools for better production planning and process control activities. Higher maturity will help to predict outcomes and optimize production processes	✓	✓	✓	(Akdil et al. 2017; Gunal2019; Kamble et al.2018;Lichtblau et al.2015; Sternad et al. 2018)
M_{36}	Artificial Intelligence	Use of Artificial intelligence and machine learning to extract useful information from manufacturing data. Higher maturity will help in quality control and supply chain optimization	✓	✓	✓	(Enyoghasi & Badurdeen 2021; Mittal et al. 2018; Wagire et al. 2020)
M_{37}	Cyber security	It refers to data security which includes internal data security, cloud data security, in-house data, supplier and business partner data security. Higher maturity will help to reduce the risks of cyber threats and resilience of I4.0 systems	✓	✓	✓	(Culot et al. 2019; Keskin et al. 2018; Kim 2017; Luthra & Mangla 2018; Mittal et al. 2018)

Table 2 (continued)

Item code	Maturity item name	Description	Impact on sustainability			Reference
			Product level	System-level	Process level	
M_{38}	Data protection	It refers to data protection laws and policies an organization adopts to ensure its data protection. Higher maturity will help to improve legal liabilities, the privacy of stakeholder information	✓	✓	✓	(Alcácer et al. 2021; Culot et al. 2019; Kamble et al. 2018; Keskin et al. 2018)
M_{39}	Labour protection laws	It refers to labour protection policies and laws adopted by an organization. Higher maturity will help to safeguard the personal information and privacy of workers	✓	✓	✓	(Harikannan et al. 2023; Keskin et al. 2018; Kovacs 2018; Mittal et al. 2018; Oláh et al. 2020)
M_{40}	Intellectual property laws	It refers to intellectual property laws policies adopted by an organization. Higher maturity will help to drive innovation, more sustainable products and processes	✓	✓	✓	(Eppinger et al. 2021; Keskin et al. 2018; Ziebermayr 2021)

had consistent demographics across studies (Jamwal et al. 2023). However, due to the scope of this study, only maturity items results have been presented in this study. A mixed-method research approach was employed, integrating extensive surveys, reliability and validity tests, exploratory factor analysis (EFA), and the Fuzzy-AHP (F-AHP) method to prioritize maturity items. The model was tested in four manufacturing firms. The approach aligns with established guidelines for maturity model development Marx et al., (2012), combining theoretical foundations with empirical validation. The research design for the present study is presented in Fig. 2.

The EFA categorized maturity items into relevant dimensions, and reliability and validity tests confirmed the model's robustness. The F-AHP method prioritized these items, and case studies validated the model's applicability in real-world scenarios. The maximum response rate received from the automobile sector, indicates awareness of I4.0 practices among these organizations. Organizations were further classified based on industry type, automation status, annual turnover, and respondent experience. Detailed demographic information is presented in Fig. 3.

It is found that the maximum response rate received from the automobile sector shows that automobile organizations are more aware of I4.0 practices. Further, organizations were classified based on industry, type, automation status, annual turnover, respondent experience, and their profiles. The detailed demographic details are shown in Fig. 3.

4.1 Overview and description of the four cases

4.1.1 Case organization A

Case Organization A has been an original equipment manufacturer (OEM) in the automobile sector in India for the last 75 years and holds excellence awards in manufacturing. The organization is working on a continuous improvement concept. The organization started its I4.0 journey four years back and formulated a dedicated team in its R&D department. The organization has already adopted energy management strategies, GHG emission metrics, environmentally friendly buildings, and waste management strategies in its business practices. Two plant visits were conducted from January 2022 to March 2022, which included semi-structured interviews and discussion sessions with the I4.0 team. After the discussion with the I4.0 expert, eight experts agreed to participate in the study and were involved in the I4.0-related projects. The detailed information of experts is presented in Table 3.

Five of the experts have the expertise to work on Internationally collaborative projects related to digitalization. The case organization first digitalized its critical areas during the digitalization of manufacturing activities.

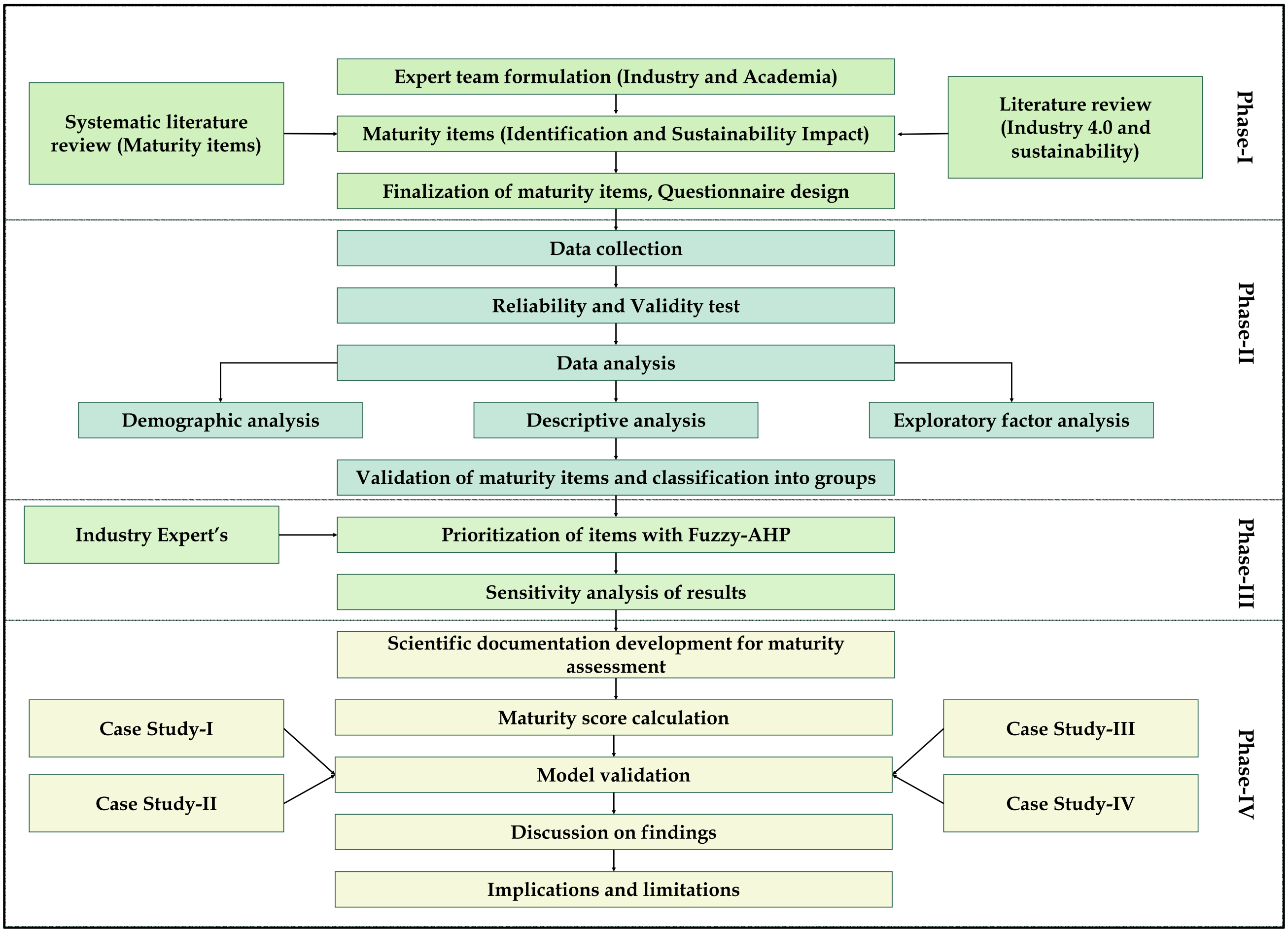


Fig. 2 Research design for the study

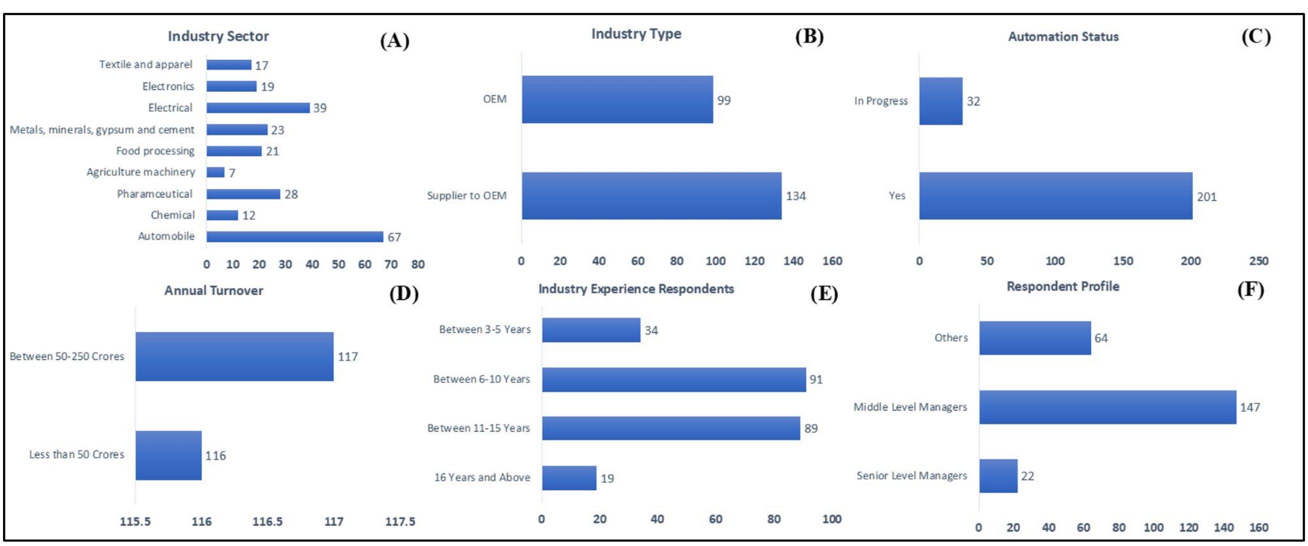


Fig. 3 Demographic analysis of responses (Jamwal et al. 2023)

Table 3 Experts involved in Case-A

Expert	Expert position	Experience (In years)	Responsibilities
Expert 1	Digital officer	13	Managing digital technologies
Expert 2	R&D Head	22	Research and development
Expert 3	Manager Supply Chain	7	Supply chain strategies, managing supplier relationship
Expert 4	Manager Product design	8	Market research, new product development
Expert 5	Digital project management officer	12	Managing digital projects
Expert 6	Data scientist	6	Data analysis and interpretation for continuous improvement
Expert 7	Associate Manager	6	Inventory management
Expert 8	Assistant Manager	5	Production monitoring

4.1.2 Case organization B

Case Organization B is from the automobile SME sector in India and has been operational for the last 25 years. The organization is a leading automotive components supplier. Case Organization B started its I4.0 journey with IoT implementation two years before and was a Tier 1 supplier of Case Organization A. The organization has also supported its critical pilot projects related to I4.0 by providing some financial investments. The organization continuously works on minimizing fluids, single-use plastics, and environment-conscious manufacturing initiatives in sustainability. Two plant visits, which included interaction and semi-structured interviews with the expert team, were done in Case Organization B in February 2022 to understand its shop floor activities and I4.0 practices. Five experts from the case organization participated in the study (See Table 4). All these experts have more than ten years of industry experience and are responsible for I4.0 projects in the organization.

4.1.3 Case organization C

Case organization C is from the pharmaceutical sector. The case organization is located in India in the northern region, a major pharmaceutical product hub due to its favourable climate conditions. The organization is one of the significant contributors to pharmaceutical products in India and has a good reputation in the global market share in the pharma sector. The industry was founded 38 years ago in North India. More than 20 R&D employees drive innovation and technology in the organization. The organization has optimized its operational cost and vertical integration for six years. The organization has a dedicated team for planning and inventory management, procurement, and logistics to maintain supply chain sustainability. The organization has also defined its KPIs (Key performance indicators) to manage its overall business sustainability. Three plant visits included the general discussion and semi-structured interviews with the expert's team organization. The organization includes nine members: Three managers, two senior managers, one assistant manager, one supply chain manager, one digital leader, and a digital consultant, as presented in Table 5.

4.1.4 Case organization D

Case Organization D has been operating in the pharmaceutical SME sector in India for the last 30 years and is a Tier 1 supplier of Case Organization C. The organization holds around 150 full-time and contractual employees. The organization has the emerging SME award in the pharmaceutical industry. Also, the organization holds quality control and total quality management awards. The organization is ISO 14000 certified and working on efficient resource utilization. Also, the organization has fully automated and remote-controlled IT systems. Two plant visits were conducted within the organization to understand the production activities and I4.0-related initiatives. An expert team of five members (See

Table 4 Experts involved in Case-B

Expert	Expert Position	Experience (In years)	Responsibilities
Expert 1	Director	14	Stakeholder relationships
Expert 2	Digital consultant	13	Digital strategies development
Expert 3	Plant Manager	13	Production, maintenance, quality control
Expert 4	Production Manager	11	Scheduling and resource allocation
Expert 5	Assistant Manager	10	Quality control

Table 5 Experts involved in Case-C

Expert	Expert position	Experience (In years)	Responsibilities
Expert 1	IT Project Manager	7	Software development and IT project implementation
Expert 2	Production Manager	15	Lean Six Sigma projects, Strategic planning
Expert 3	Supply Chain Manager	9	Warehouse management
Expert 4	Senior Manager Packaging Development	11	Packaging line troubleshooting, cost reduction
Expert 5	Senior Manager Quality assurance	14	Quality control, Managing quality issues
Expert 6	Assistant Manager Maintenance	6	Equipment, utilities management
Expert 7	Operations Manager	10	Continuous improvement, forecasting, and capacity planning
Expert 8	Digital Leader	12	Digital transformation, developing data analytics strategies
Expert 9	Digital Consultant	8	Developing digital strategies

Table 6), including one executive member, two managers, one assistant manager and one digital consultant, is asked to provide their inputs and insights into the case study. The sample question asked from the case organization is shown in Appendix 1 (Fig. 8).

5 Results

5.1 Data reliability, validity, and exploratory factor analysis

Mean and reported Deviation value for each maturity item discussed in Table 2 is presented in Table 7, which shows that each item has a mean value of more than 2. It shows that all the maturity items found through SLR are significant for the maturity model development. The Cronbach Alpha coefficient is used in the study to measure the data consistency. The literature suggests that if the Cronbach Alpha's value is greater than 0.6, it shows the data reliability. In the present study, Cronbach Alpha's value obtained is 0.858. Also, the factor loading of each construct was more than 0.5, which proves the convergent validity (Bhatia & Kumar 2022; Field 2013). The study uses EFA to categorize the various maturity items presented in Table 2 into different dimensions. The KMO value was higher than the minimum suggested value of 0.6 in the literature (Fernando et al. 2022; Field 2013). The degree of freedom, chi-square value and significance level are also reported in Table 7. The EFA results of the study are presented in Table 7.

In manufacturing enterprises from emerging economies, investigating priority order of maturity is important to identify the importance of each item. Due to resource and time constraints, it is not possible in the case of SMEs to develop strategies for all maturity items at the same time. Therefore, the identification of priority order of maturity items can help manufacturing organizations to allocate their resources efficiently, ensure a strategic approach to implement I4.0 practices and address critical challenges systematically. Therefore, the priority order of identified maturity items is calculated in Sect. 5.2.

5.2 Weight prioritization of maturity items using Fuzzy-AHP

Decision-making models play a vital role in weight prioritization and strategy selection. In the literature, decision-making models have many applications, including process planning and scheduling, supplier selection, technology selection and energy management (Kumar et al. 2017). Generally, the choice of decision-making models for a decision-making problem depends on the nature of the problem (Govindan

Table 6 Experts involved in Case-D

Expert	Expert position	Experience (In years)	Responsibilities
Expert 1	Director	14	Developing departmental strategies, Ensuring regulatory compliance
Expert 2	Supply chain Manager	8	Managing inventory levels, monitoring supply chain performance metrics
Expert 3	R&D Manager	10	Optimizing drug development processes, Managing R&D budget allocation
Expert 4	Assistant Manager IT project management	7	System implementations and upgrades
Expert 5	Digital Consultant	8	Developing digital strategies and initiatives

Table 7 Reliability and EFA results for maturity items

Dimension	Maturity item	Mean	Std. deviation	Item loading	Eigen value	Construct Cronbach Alpha	Cumulative percentage
Employees and Industry culture	M_1	2.5236	0.9916	0.888	5.956	0.908	14.889
	M_2	2.4206	0.98432	0.857			
	M_3	2.2961	0.92047	0.874			
	M_4	2.3391	0.95641	0.873			
Awareness about Industry 4.0 practices	M_5	3.2103	1.18666	0.871	5.461	0.811	28.542
	M_6	3.6223	1.16479	0.820			
	M_7	2.4506	1.07415	0.834			
Organization and Strategy	M_8	2.9356	0.8561	0.826	3.621	0.891	37.595
	M_9	2.8369	0.89972	0.777			
	M_{10}	2.7253	0.86707	0.745			
	M_{11}	3.1116	0.88351	0.772			
	M_{12}	2.8584	0.83647	0.850			
Value chain-related processes	M_{13}	3.5966	0.76021	0.735	3.325	0.837	45.907
	M_{14}	3.7682	0.63479	0.621			
	M_{15}	3.8197	0.68992	0.844			
	M_{16}	3.6309	0.72593	0.610			
	M_{17}	3.7983	0.53947	0.871			
Smart technologies to facilitate Industry 4.0 practices	M_{18}	3.4893	0.86658	0.807	3.223	0.950	53.965
	M_{19}	3.3948	0.91838	0.834			
	M_{20}	3.4678	0.83565	0.798			
	M_{21}	3.6567	0.837	0.848			
	M_{22}	3.4077	0.93833	0.827			
	M_{23}	3.5279	0.83063	0.846			
	M_{24}	3.6695	0.78662	0.852			
Service or Product based technologies to facilitate Industry 4.0 practices	M_{25}	3.9571	0.68093	0.611	3.215	0.834	62.009
	M_{26}	3.8927	0.65757	0.875			
	M_{27}	3.8369	0.7065	0.809			
	M_{28}	3.9056	0.63627	0.587			
	M_{29}	3.8627	0.7358	0.839			

Table 7 (continued)

Dimension	Maturity item	Mean	Std. deviation	Item loading	Eigen value	Construct Cronbach Alpha	Cumulative percentage
Base technologies to facilitate Industry 4.0 practices	M_{30}	3.97	0.61163	0.758	2.234	0.942	67.587
	M_{31}	3.9528	0.60344	0.823			
	M_{32}	3.9742	0.60117	0.826			
	M_{33}	3.97	0.63242	0.861			
	M_{34}	4.0172	0.6226	0.886			
	M_{35}	3.9914	0.66948	0.857			
	M_{36}	3.9485	0.68033	0.717			
	M_{37}	3.9528	0.63137	0.821			
Legal-related factors to facilitate Industry 4.0 practices	M_{38}	3.1073	1.1528	0.827	2.127	0.759	72.904
	M_{39}	3.5021	1.1749	0.809			
	M_{40}	2.8627	1.14019	0.793			

Global Cronbach Alpha: 0.858

KMO measure of sample adequacy: 0.812

Bartlett's test: (1) Approx. Chi-Square: 7957.315 (2) df: 780 (3) Sig.: 0.000

Rotation method: Varimax with Kaiser Normalization

Extraction method: Principal component analysis et al. 2015). In literature, many decision-making models have been used, such as the Analytical hierarchy process (AHP), Analytical network process (ANP), Best and Worst method (BWM), Decision-making trial and evaluation laboratory (DEMATEL) etc. (Jamwal et al. 2020).

AHP is a multi-criteria decision-making method based on a numerical approach proposed by Saaty (2008). In decision-making, AHP can be considered the versatile and effective method that allows managers to set goals and make the right decisions. Presently, AHP is more popular in business decision-making than other methods such as DEMATEL, BWM and ANP. AHP-based models have been used in various I4.0-related decision-making problems (Luthra & Mangla 2018).

The traditional AHP approach limits vagueness and uncertainty, which can be handled using the Fuzzy set theory. In the past few years, the integration of Fuzzy set theory with the traditional AHP approach has been used to address the uncertainty issues. In the present study, the Fuzzy AHP steps discussed by Chang (1996); Singh et al. (2019) are followed for the decision-making. For the pairwise comparison, eight industry experts: (1) Three I4.0 consultants, (2) Two R&D Heads, and (3) Three managers were selected based on their rich experience and involvement in I4.0-related projects and initiatives. All the experts have more than ten years of industry experience and are responsible for digitalization-related initiatives in their organizations.

In the study, the Fuzzy-AHP method is used to find the global weight of each maturity item using the pair-wise comparison based on experts' judgements. The consistency of pairwise comparison done by experts was checked as follows:

1. The calculation for λ_{max} (Maximum eigenvalue)
2. $CR \leq 0.1$, where CR can be computed as:

$$CR = \frac{CI}{RI} \tag{1}$$

CI can be computed as:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2}$$

where n is the matrix size.

Crisp inputs given by the decision makers are converted into a triangular fuzzy number (v) as follows:

$$\mu v(x) \begin{cases} \frac{x-l}{m-l}, l \leq x \leq m \\ \frac{u-x}{u-m}, m \leq x \leq u \\ 0, otherwise \end{cases} \tag{3}$$

where l, m, u represents the number's lower, middle, and upper bound.

Crisp's number is converted into fuzzy numbers as follows:

$$L = \left(x - \frac{1}{2}, x, x + \frac{1}{2}\right) \tag{4}$$

The weights of the matrix can be calculated as follows:

$$\alpha_j = \left[\prod_{j=1}^{n} l_{ij}\right]^{1/n}, \beta_j = \left[\prod_{j=1}^{n} m_{ij}\right]^{1/n}, \gamma_j = \left[\prod_{j=1}^{n} n_{ij}\right]^{1/n} \tag{5}$$

and

$$\alpha = \sum_{j=1}^{n} \alpha_j, \beta = \sum_{j=1}^{n} \beta_j, \gamma = \sum_{j=1}^{n} \gamma_j \tag{6}$$

The fuzzy weight vector can be calculated as:

$$\hat{\omega} = \left(\alpha_j \gamma^{-1}, \beta_j \beta^{-1}, \gamma_j \alpha^{-1}\right) \tag{7}$$

Further, Table 8 shows each maturity item's priority weight and rank.

The analysis shows that "Knowledge and familiarity with I4.0 tools and technologies" have maximum weight in all maturity items. The initial studies Chauhan et al. (2021); Kamble et al. (2019); Luthra & Mangla (2018) also argued that the concept of I4.0 in India is novel and requires a more in-depth understanding. Prior literature (Kumar et al. 2020; Luthra et al. 2020) highlighted that there is a need to align "Make in India" and "Digital India" concepts with I4.0, which will help SMEs to create sustainable value creation in business models. Dimension 2 maturity item "Dedicated teams for I4.0 practices" has maximum importance. Marnewick & Marnewick (2019) discussed the importance of project teams for I4.0 practices and argued that there would be an increased demand for project teams for I4.0 in the upcoming years. Bag et al. (2021) suggested that there is a need for project teams in an organization to execute I4.0 practices in a better way. The study aligned with the findings of Lasi et al. (2014), who stated that successful I4.0 projects are based on I4.0 teams, which are experienced manager heads. In Dimension 3, the maturity item "Digital culture in the industry" has maximum importance. Raj et al. (2020) also argued that digital culture is essential to I4.0 practices. There is a need for knowledge and strong internal capabilities of project teams to enhance an organization's digitalization level.

In Dimension 4, the "Vertical value chain integration" maturity item has maximum importance. Bag et al. (2018); Qin et al. (2016); Stock & Seliger (2016) argued that vertical integration is essential to drive I4.0 practices. However, this is also important for supply chain and manufacturing

Table 8 Priority weight and ranks of maturity items

Dimension	Dimension rank	Maturity item	Relative weight	Relative rank	Global weight	Global rank
D1		M_1	0.348	2	0.0927	3
	1	M_2	0.410	1	0.1092	2
		M_3	0.162	3	0.0432	7
		M_4	0.078	4	0.0209	16
D2		M_5	0.226	2	0.054	4
	2	M_6	0.672	1	0.1607	1
		M_7	0.101	3	0.0242	14
D3		M_8	0.420	1	0.0472	5
		M_9	0.046	4	0.0052	30
	3	M_{10}	0.047	5	0.0052	29
		M_{11}	0.342	2	0.0384	11
		M_{12}	0.143	3	0.0161	17
D4		M_{13}	0.637	1	0.0395	10
	5	M_{14}	0.072	4	0.0044	32
		M_{15}	0.085	3	0.0053	28
		M_{16}	0.021	5	0.0013	39
		M_{17}	0.183	2	0.0113	20
D5		M_{18}	0.021	7	0.004	33
	4	M_{19}	0.226	3	0.0422	9
		M_{20}	0.252	1	0.047	6
		M_{21}	0.231	2	0.0432	8
		M_{22}	0.142	4	0.0265	13
		M_{23}	0.057	6	0.0106	22
		M_{24}	0.068	5	0.0127	19
D6		M_{25}	0.284	2	0.0125	14
		M_{26}	0.439	1	0.01515	18
	6	M_{27}	0.115	3	0.00398	34
		M_{28}	0.050	5	0.00175	37
		M_{29}	0.110	4	0.00381	35
D7		M_{30}	0.028	8	0.00134	40
		M_{31}	0.029	7	0.00138	38
	7	M_{32}	0.495	1	0.02329	15
		M_{33}	0.048	6	0.00226	36
		M_{34}	0.185	2	0.0087	24
		M_{35}	0.114	4	0.00537	27
		M_{36}	0.099	5	0.00469	31
		M_{37}	0.161	3	0.00761	25
D8		M_{38}	0.622	1	0.028	12
	8	M_{39}	0.239	2	0.01077	21
		M_{40}	0.138	3	0.00623	26

sustainability (Cimini et al. 2019). Focusing on Vertical integration will help managers to improve digitalization-related projects in industries. In Dimension 5, the maturity item "Use of identifiers" has maximum importance. Similarly, Luthra & Mangla (2018) also highlighted the importance of digital culture in I4.0 and stated that there is a need to develop the research facilities and provide training for the skill development of employees, which will help to improve the digital culture. In Dimension 6, the maturity item "Use of additive manufacturing" has maximum importance. Khorasani et al. (2022) also highlighted the role of additive manufacturing (AM) in I4.0 and stated that AM could address mass customization demands from customers and reduce lead times. In Dimension 7, the maturity item "Use of IoT platform" has maximum importance. Chae & Olson (2021) discussed that IoT platforms are essential in manufacturing organizations and have changed the traditional way of collecting and sharing information, which has data accuracy and latency limitations. In Dimension 8, the maturity item "Data protection policies" has maximum importance. Majumdar et al. (2021) stated that the cybersecurity of cyber-physical systems is crucial in I4.0. Formulation of data protection policies for cybersecurity-related risks, data privacy and access are necessary.

5.3 Sensitivity analysis of Fuzzy-AHP results

The sensitivity analysis is performed on the results of maturity items to check how the priority order of items is changed when assigning the different weights to items. In decision-making, an expert's responses may be biased due to differences in knowledge and industry experience. Sensitivity analysis also investigates the robustness of the framework. The Fuzzy-AHP methodology includes the linguistics responses from the experts to compute the priority of the factors. Therefore, it is important to check the final rank of each factor by a slight variation in the most important factor (Govindan et al. 2014; Kumar 2020). It is important to note that a slight variation in the weight of any factor may lead to a significant variation in the final rank of factors. To check the robustness of the results, we used the sensitivity analysis in which we varied the weight of the most important factor from 0.1 to 0.9 with a small increment of 0.1. The graphical representation of the final rank after the analysis is shown in Fig. 4. It can be seen that there is less variation in the priority of ranks when assigning the different weights, which proves the robustness of the framework.

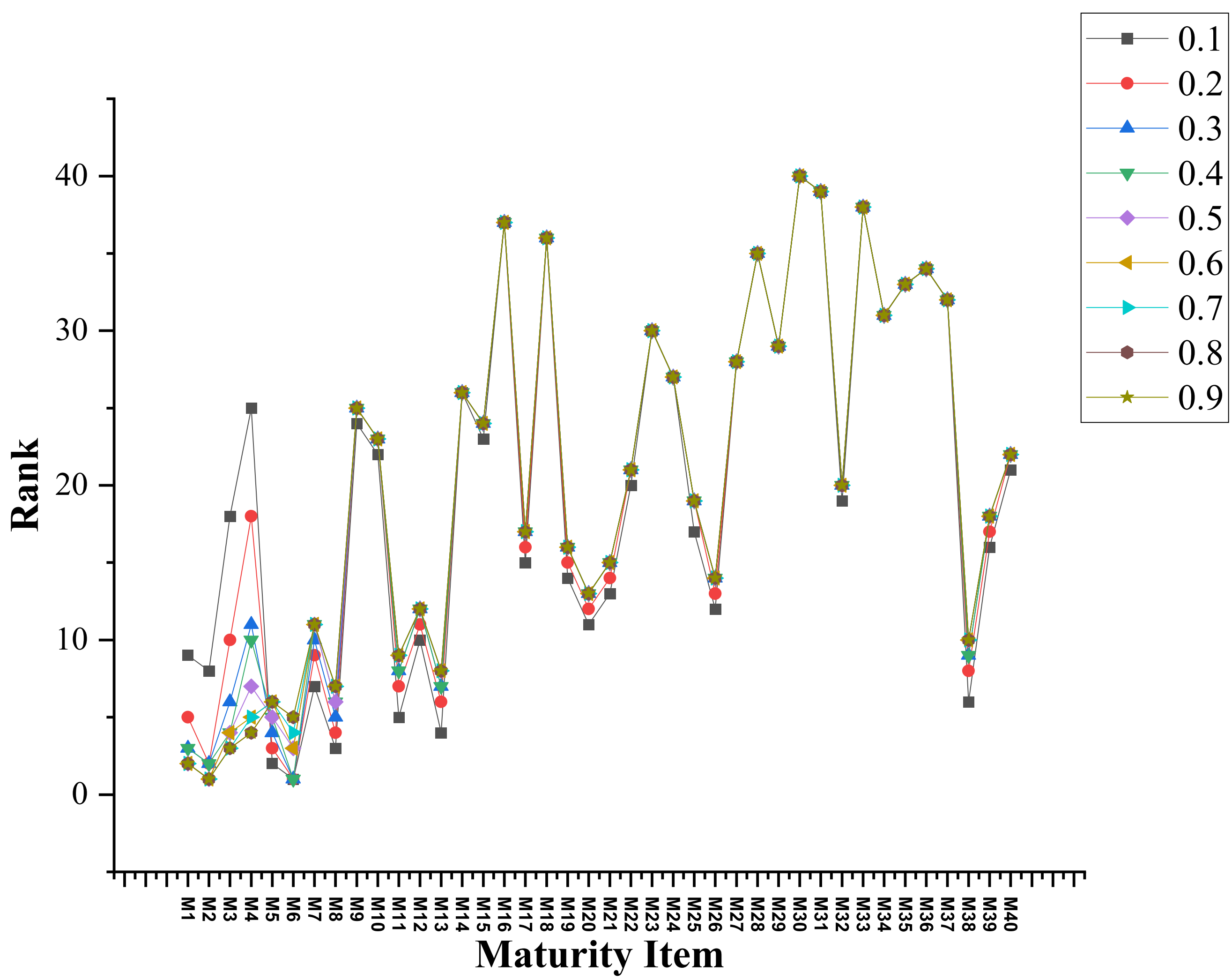


Fig. 4 Sensitivity analysis of results

6 Structure of I4.0 maturity assessment model

The proposed maturity model for I4.0 practices includes 40 items categorized into eight major dimensions using EFA. The priority of each maturity item is calculated using F-AHP. The EFA provides a theoretical foundation for the maturity model. The maturity model developed after EFA is shown in Fig. 5. Further, Fig. 6 shows the I4.0 maturity level based on maturity scores. This maturity score range with its maturity level is selected based on the existing literature on I4.0 maturity models (Mittal et al. 2018; Wagire et al. 2020). The following equations have been used to determine the item maturity score, dimension score and overall industry maturity level.

The item maturity score can be calculated as follows:

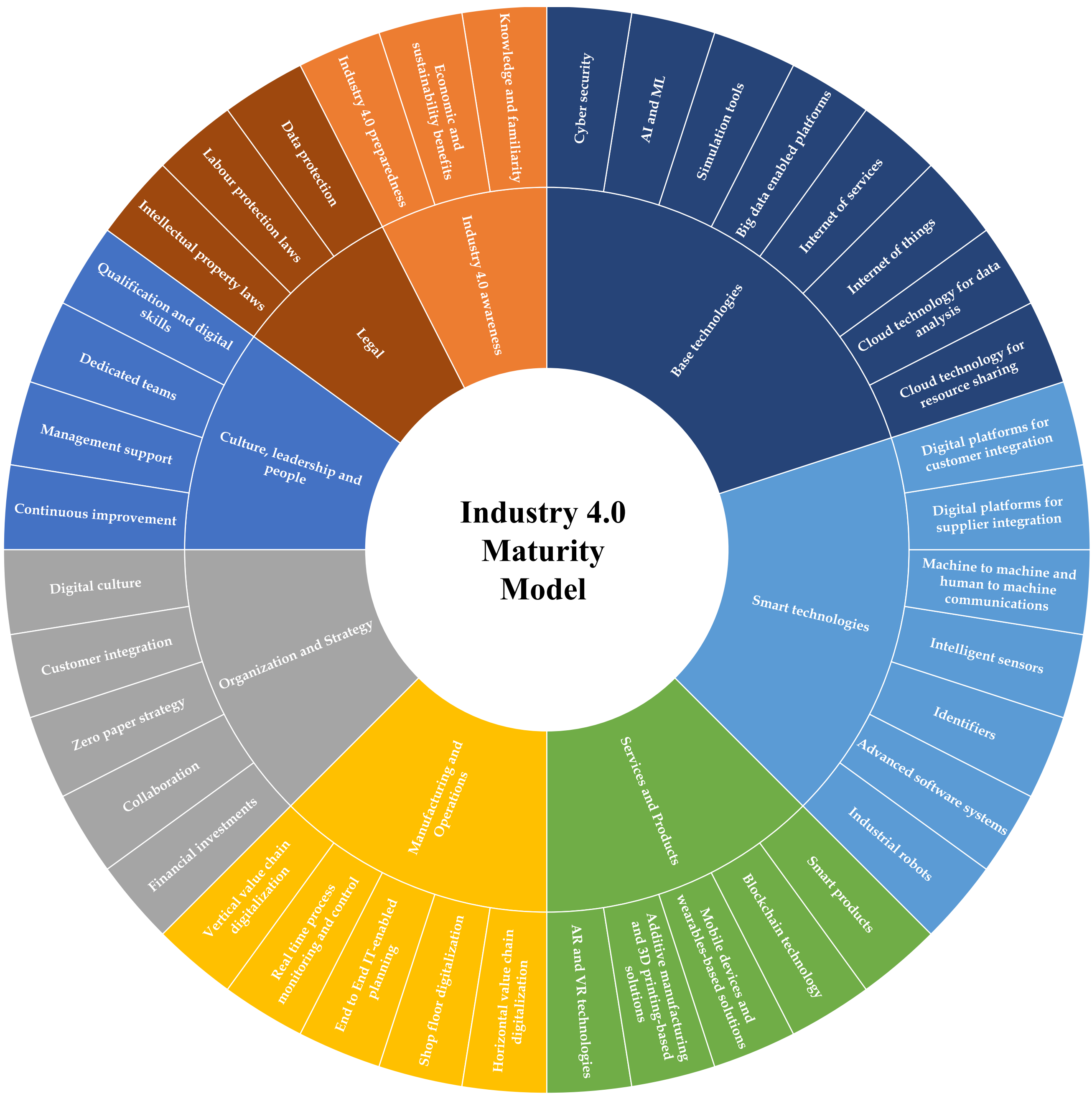


Fig. 5 Proposed Industry 4.0 maturity model for SMEs

Maturity Score	Maturity Level
$4.00 \le M_o \le 5.00$	Level 4: Expert
$3.00 \le M_o \le 4.00$	Level 3: Experienced
$2.00 \le M_o \le 3.00$	Level 2: Learner
$1.00 \le M_o \le 2.00$	Level 1: Newcomer

Fig. 6 I4.0 maturity level based on maturity score

$$M_I = \frac{1}{n}\sum_{i=1}^{n} WR_i i \in 1,2,\ldots\ldots n \tag{8}$$

Here, M_I represents the Maturity of an item and WR_i represents the weight given by the respondent.

The maturity score of dimension can be calculated as:

$$M_D = \frac{1}{J}\sum_{j=1}^{J} M_{Ij} j \in 1,2,\ldots\ldots.J \tag{9}$$

Here, M_D represents the dimension maturity score.

The overall industry maturity score can be calculated as:

$$O_M = \frac{1}{K}\sum_{k=1}^{K} M_D k \in 1,2,\ldots\ldots.K \tag{10}$$

Here, O_M represents the overall maturity score.

Understanding the maturity levels in manufacturing organizations for I4.0 adoption in emerging economies provides a holistic view of organizational preparedness for I4.0 practices. It involves the skills, organizational and legal items adoption in the organization. This assessment goes beyond the prioritization of each item and offers a nuanced perspective on the specific strengths and weaknesses of the item for individual organizations. For instance, if the priority is the qualification and digital skills of the employees, the maturity assessment for the organization helps in tailoring the training program to address the skill gap. In the context of sustainability, if the maturity level of qualification and digital skills is higher in an organization, that indicates its capabilities to work on digital technologies such as artificial intelligence and simulation technologies, contributing to sustainability. In this context, we investigated the maturity assessment of four cases in the Indian manufacturing sector to investigate their current maturity level, which is presented in the next sections.

6.1 Case study results of four cases

In the present study, a total of four case organizations have been considered, which are: (A) Automobile OEM, (B) Automobile component supplier to OEM, (C) Pharmaceutical OEM, and (D) Pharmaceutical supplier to OEM. This section presents a synthesized view of maturity scores of each item across eight dimensions of maturity model. Each dimension highlights the critical aspect of I4.0 adoption and provide a comprehensive view of each of organizational progress and challenges in I4.0 journey. The maturity scores of each maturity item in each dimension is presented in Fig. 7.

Dimension 1: employees and industry culture Organizations considered in the case study represent the varied maturity levels in terms of employees and industry culture, with scores ranging from 1.7 to 3.5. Organization C leads with the highest maturity score of 3.5, showcasing robust digital capabilities which are also important to achieve sustainability through I4.0. Organizations A and C have higher digital skills, while Organization B, despite active participation in I4.0 programs, needs to improve its digital capabilities. Organizations B and D, relatively new to I4.0 concept, face challenges in focusing on sustainability. A notable difference is observed in organizational approaches: Organizations A and C have already established dedicated teams and pilot projects supported by top management, whereas Organizations B and D are still relying on external collaborations and are still developing their continuous improvement strategies.

Dimension 2: awareness about industry 4.0 practices The awareness dimension reveals a range of maturity, with scores between 1.7 and 3.3. Organizations A and C have successfully completed pilot projects and are advancing towards end-to-end digitalization, leveraging technologies like Cloud computing and IoT. In contrast, Organizations B and D are still in the early stages, with plans to adopt AR and VR technologies in upcoming years. The strategic use of technologies by A and C has significantly improved their I4.0 capabilities.

Dimension 3: organization and strategy Scores in this dimension range from 1.6 to 3.3, indicates varying levels of digital integration and strategy. Organizations A and C have integrated digital culture into major departments, although Organization A has yet to fully adopt digital practices in its packaging department. Organization A also utilizes digital platforms for customer integration, a practice not yet adopted by Organizations B and D. While A and C have adopted zero paper strategies, B and D are still in the planning phase.

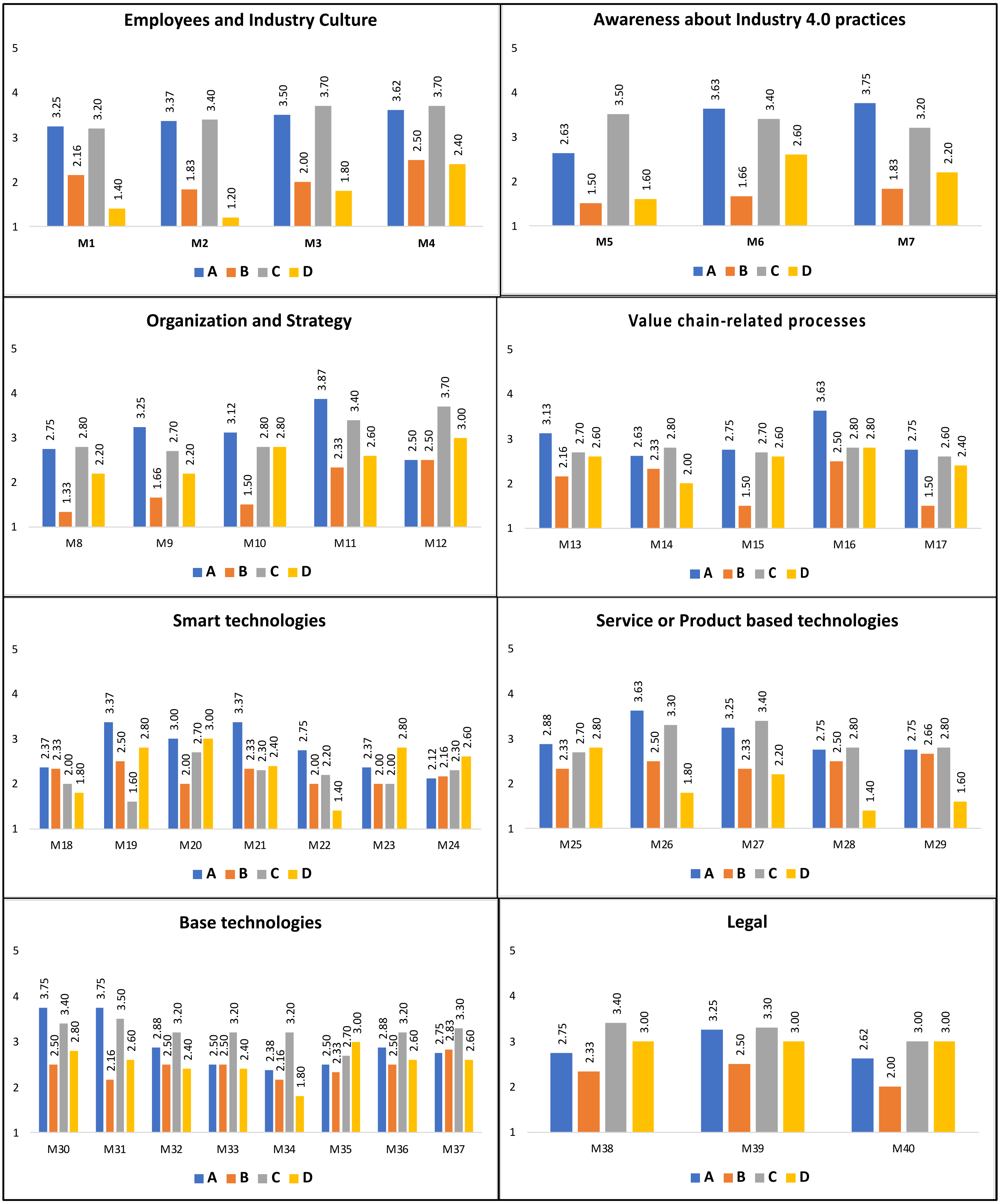


Fig. 7 Maturity item wise scores for case studies

This dimension highlights the importance of organizational strategy and customer integration in driving I4.0 success.

Dimension 4: value chain-related processes The maturity of value chain processes varies across organizations, ranging from 1.5 to 3.6 on the maturity scale. Organizations A and C maturity scores a clear commitment to digitalizing their vertical value chains. This is due to their management support and the allocation of sufficient financial resources. The advanced capabilities in real-time process monitoring and control help to achieve operational excellence in these organizations. Furthermore, these organizations have also implemented IT-enabled process planning and integrating IoT solutions into their operations. In contrast, Organizations B and D are far behind and primarily rely on traditional methods for process planning and management. This gap highlights the role of strong leadership and resource investment to drive digital transformation within the value chain. The findings emphasizes that without a proactive approach from management and adequate financial investment, organizations may struggle to achieve the technological advancements which are necessary for market competitiveness in present market.

Dimension 5: smart technologies Maturity scores for smart technologies range from 2.1 to 2.7, reflecting limited adoption across the organizations. Organization A has implemented industrial robots in critical departments as pilot projects, while Organization C plans future use. Despite having knowledge of industrial robots, Organizations B and D have yet to deploy them. Organizations A and C also use advanced software systems and digital platforms to enhance their operations, whereas B and C have limited adoption. This dimension emphasizes the need for broader implementation of smart technologies to boost I4.0 maturity.

Maturity scores for smart technologies reveal a limited level of adoption across the organizations, ranging between 2.1 and 2.7. Organization A has taken a proactive step by deploying industrial robots as pilot projects in major departments, showcasing their effort to integrate advanced technologies into their operations. Similarly, Organization C is planning to implement this in future, indicating a strategic approach toward adopting smart technologies.

In contrast, Organizations B and D, despite having knowledge about industrial robots, have not yet initiated their deployment or have not done any pilot projects. Organizations A and C leverage these technologies to enhance operational efficiency, Organizations B and D have less focus on these technologies, highlighting a significant gap in their technological advancements.

These observations highlighting the need for implementation of smart technologies across all organizations. Such advancements are important to enhance Industry 4.0 maturity.

Dimension 6: service or product-based technologies The maturity scores in this dimension range from 1.9 to 2.4. Organizations A and C have high awareness and adoption of AR and VR technologies, utilizing them for training and remote assistance. Both also employ additive manufacturing to improve supply chain performance. In contrast, Organizations B and C have yet to invest significantly in these technologies. The limited adoption of blockchain is due to high energy consumption and lack of reference architecture. This dimension reflects the varied adoption levels of emerging technologies and their impact on operational efficiency.

Dimension 7: base technologies The maturity scores for base technologies range from 2.1 to 2.6, reflecting varying levels of adoption among the organizations. Cloud technology have highest maturity in Organization C and using it for data analysis related projects and Organization A successfully integrating it into specific projects. All four organizations have embraced IoT and IoS-based platforms as a pilot project or in its majority of departments which shows their commitment towards digital transformation.

However, the adoption of simulation tools remains limited to Organizations A and C, highlighting a gap in leveraging these technologies for process optimization. Similarly, AI and ML-based approaches for predictive maintenance are using by Organization A and C. These advancements highlight the critical role of technologies like AI, ML, and simulation tools in driving operational efficiency and improving decision-making in I4.0. But still, improving the adoption level and maturity of these base technologies across all organizations is essential to improve the overall maturity score.

Dimension 8: legal-related factors Legal maturity scores range from 2.2 to 3.3, with pharmaceutical organizations shows the highest maturity. These organizations are more focused towards the data protection and labor laws, as compared to automotive organizations. While all organizations have adopted intellectual property laws, progress remains limited in automotive organizations. Higher maturity of data protection policies are observed in Organizations C and D, reflecting their commitment to securing intellectual property and enhancing process optimization.

The findings across all eight dimensions reveal a dynamic landscape of I4.0 adoption, with leading organizations like A and C demonstrating advanced capabilities and strategic integration. The varied maturity levels highlights the need for new strategies to address specific challenges and explore opportunities for improvement. Further, Fig. 7 represent the maturity item wise scores for case studies.

6.2 Overall maturity levels

The overall maturity scores of each organization are calculated, and results for each case are presented in Table 9. Case Organization C has the highest maturity score, followed by Case Organization A. Both organizations are at an experienced level in the I4.0 journey. Case organizations B and D are still at the learner stage. From the above discussion, it can be concluded that Case organizations B and D have to work on their smart technologies. The adoption level of smart technologies is lower than that of A and C. Also, organizations B and D have still explored the I4.0 technologies for their organizations. In such cases, collaboration with external agencies and research institutes can help them to provide solutions and consultants for I4.0 practices. All the organizations have adopted legal measures in their organizations. However, organizations must work on their data protection and cybersecurity-related measures after their horizontal value chain integration. In each case, we represented how the proposed model helped the organizations to identify their overall maturity and dimension-wise maturity level. In addition, we also provided guidance based on existing literature on how organizations can reach a higher level of maturity. Based on the above discussion, the overall maturity level of four cases with an overall maturity score and maturity level is reported in Table 9.

Table 9 shows that all the OEMs who started their digital journey earlier have a maturity level of 3, which shows that these organizations are experienced. Both organizations B and D are at the learner level. The maturity level of organization D is higher as compared to organization B due to a more focus on the legal-related maturity items. For each organization, reasons for lower maturities have been discussed in next sections. Potential solutions proposed for the organizations have also been discussed based on the reasons for lower maturities. Once the organization has successfully developed the strategy to address these solutions and start working, it can expect potential sustainability benefits in the long term.

Table 9 Overall maturity score of case organizations

Organization	Overall maturity score	Maturity level
Case Organization A	3.05	Experienced
Case Organization B	2.12	Learner
Case Organization C	3.03	Experienced
Case Organization D	2.13	Learner

6.2.1 Maturity gaps and strategies to improve maturity levels across case organizations

The case results across four organizations revealed that the digital transformation towards I4.0 adoption is hindered by various challenges faced by these organization. The analysis of each organization's lower maturity levels reveals key areas needing improvement, along with pathways to enhance their digital capabilities. The journey for each organization highlights specific actions that can be strategically planned to improve their I4.0 practices and overall maturity.

For **Case A**, the main challenges are limited financial investments, less focus on real-time process monitoring, limited adoption of digital platforms, lack of knowledge about big data analytics and simulation tools. These are main challenges in Case A, which are responsible for lower maturity scores across different dimensions. To address this, a strategic plan aligning the financial investments with long-term goals is important for the organization. By conducting a comprehensive return on investment assessment, exploring new funding opportunities, and fostering partnerships, organization can address the challenges. Implementing advanced monitoring systems, centralized control platforms, and IoT-based predictive maintenance will be helpful to improve their operational efficiency. Additionally, the organization A can invest in simulation tools for virtual prototyping and production planning will be helpful to drive their progress.

In **Case B**, the main challenges are lack of dedicated teams, digital culture, and awareness about sustainability. To address these challenges, the organization can develop training programs, foster collaboration, and seek guidance from external experts which can help them to build the necessary knowledge base. A culture of innovation and adaptability should be promoted through employee recognition and reward systems in organization. Implementing digital document management, encouraging electronic communication, and working with partners on digital value chain integration are essential next steps for organization to improve their maturity scores. Awareness programs focusing on the economic and sustainability benefits of I4.0 can motivate a culture shift toward continuous learning and improvement in organization.

In **Case C**, the main challenges are lack in adoption of collaborative robots, advanced software, intelligent sensors, and digital platforms. Therefore, the first step for the organization is to identify key processes where cobots can improve efficiency. Then, pilot projects can be implemented in controlled environments. Investing in advanced software systems and sensor technologies, along with comprehensive training programs for their employees, can streamline operations. Improvement in human–machine interaction with user-friendly interfaces and cloud-based communication platforms will be helpful for the organization to ensure seamless integration. The focus should be on building a balanced digital ecosystem that supports value chain digitalization.

For **Case D**, the main challenges are limited digital skills, dedicated teams, and adoption of advanced tools like cobots, additive manufacturing, blockchain, and big data platforms. The organization need to improve their digital skills through training and fostering a learning culture in organization. Establishing specialized teams across multiple department and promotion of cross-functional collaboration will be helpful in the integration of new technologies. Collaborating with partners to adopt blockchain and big data solutions, with effective employee training, will be helpful to improve the maturity score in digital transformation.

These possible paths provide a clear roadmap for each the organization, to improve their maturity levels and successful transformation towards I4.0 business models. By addressing their specific gaps and strategically implementing targeted improvements, these organizations can unlock the full potential of digitalization and drive sustainable growth.

6.2.2 Impact on organizational sustainability in long term by moving towards next levels

By addressing the maturity gaps, organizations can unlock the benefits of I4.0 practices for sustainability which will not only contribute to environment stewardship but also to ensure long term operational efficiency.

Case A By investing in sustainable technologies and improving digital platforms, the organization can significantly enhance resource usage. Implementing predictive maintenance and simulation tools will be helpful to reduce errors, minimize waste, and lead to better product lifecycle management. The optimization of supply chain practices can result in lower energy consumption and operational costs and to driving higher customer satisfaction loyalty.

Case B Strengthening digital culture and introducing advanced tools will be helpful for the organization to make progress in environmental and social responsibility. Implementing a zero-paper strategy will be helpful to reduce waste while enhancing efficiency across the value chain through digital connectivity. As transparency increases, the organization can improve both its environmental impact and operational agility which will be helpful for responsible growth.

Case C Enhancing the adoption of smart technologies and digital platforms can be helpful for the organization to optimize its manufacturing processes, reducing energy consumption and waste. By implementing advanced software and collaborative tools, the organization can improve decision-making and reduce errors. As the organization will embrace the data-driven strategies and resource management practices, both operational efficiency and resource sustainability will improve.

Case D Addressing gaps in digital skills and technology integration can pave the way for more sustainable practices. By leveraging advanced tools like blockchain and big data platforms, the organization can achieve greater transparency and accountability in its operations. Optimizing resource use and reducing waste will enable organization to better align its operations with sustainability goals.

The maturity improvements in each organization will not only address current maturity gaps but also set the foundation for long-term sustainability. By embracing these strategic changes, the organizations can move beyond mere compliance and actively contribute to environmental stewardship and operational excellence. These strategies will be helpful to position them as forward-thinking leaders in global competition in sustainable practices.

7 Implications of study

7.1 Theoretical implication of the study

The present study contributes to both the academic community and practitioners. Based on the present study, the few theoretical implications are proposed. The study contributes to the theoretical literature on maturity models by proposing a maturity model for I4.0 practices for SMEs. Most proposed models are tailored for large enterprises and not empirically validated (Mittal et al. 2018). The present study addresses this research gap by focusing on the limitations of existing studies such as (Santos & Martinho 2019; Wagire et al. 2020) in terms of addressing the sustainability aspects. The 40 maturity items identified from the literature are empirically validated in the Indian manufacturing sector in SMEs. This provides a solid foundation of maturity items and significance in the maturity models for SMEs in emerging economies like India. The proposed model is validated through four case studies in the pharmaceutical and automobile sector organizations. These case studies strengthen the applicability and generalizability of the model in specific industry contexts. The case studies conducted in the specific industry sectors shows the dimension wise and maturity item wise score obtained by specific organization. It helps the organization to assess their current level and recognize their current capabilities in Industry 4.0. Further, the results of the cases provide the roadmap and strategies which can be adopted by organizations to improve their maturity levels. The existing studies on maturity models have not discussed the benefits and opportunities for organizations in terms of sustainability by improving their maturity scores. This study fills this gap by integrating the concepts of sustainability and I4.0 maturity models based on the existing literature (Enyoghasi & Badurdeen 2021; Machado et al. 2020).

7.2 Managerial implications of the study

The model uses the mixed-method research approach in which verification is done at each stage, which is rare in the previously published literature on maturity models. Based on the study, few managerial implications are proposed. The proposed maturity model for SMEs provides a strategic roadmap for digital transformation and sustainability as a long-term goal. SME managers can use this model to assess their current maturity, identify areas for improvement, and develop targeted action plans to improve their maturity, competitiveness and sustainability. Managers from SMEs can use this model to identify improvement areas in the organization. By understanding that dimensions and maturity items have lower scores, decision-makers can prioritize investments and resource allocation to contribute more towards digital transformation and sustainability. The model provides opportunities to improve sustainability based on the maturity items. This will help the manufacturing organization make informed decisions and align its strategies with sustainability practices. By improving digital and physical technologies maturity levels, the organization can optimize their resource consumption, reduce energy consumption, wastes and improve their market competitiveness. The study's findings provide valuable guidance for policymakers regarding I4.0 practices in SMEs. The empirical evidence of this study can be used by policymakers to tailor support initiatives and programs to address specific challenges and opportunities faced by SMEs in the manufacturing sector. Managers can use the maturity model to foster knowledge sharing and collaboration within and across external organizations. Knowledge sharing is important in I4.0, where collaboration with R&D institutions and universities can be done (Luthra & Mangla 2018; Mittal et al. 2018). The findings of pilot implementation can be shared in the form of best practices and lessons learned in I4.0 adoption, which can contribute to the manufacturing sector.

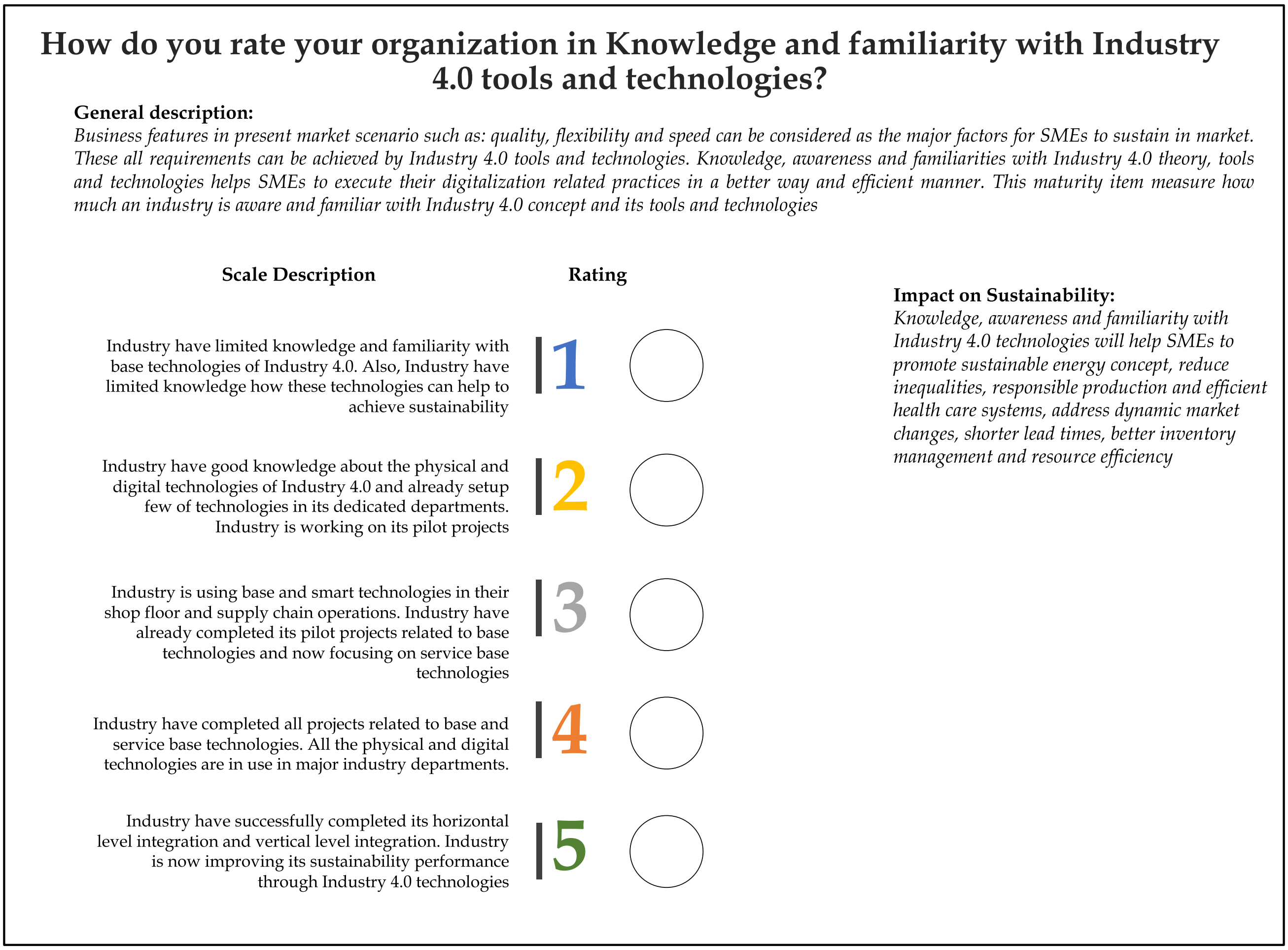
8 Conclusion

The study proposes a maturity model for SMEs to assess their current status and level in the I4.0 journey. The study also addresses the impact of maturity items on the different levels of sustainability. The present study fills the research gaps addressed in previously published studies by providing a theoretical foundation for the maturity items and validation of these with an extensive survey. In the initial step, maturity items were identified through SLR. Then, maturity items were finalized with a discussion with industry experts. Two hundred thirty-three valid responses were received from a questionnaire survey from Indian manufacturing organizations. The reliability and validity tests were performed, and the EFA approach was used to categorize the maturity items into the different major dimensions. An expert team of six members were formulated, which helped in pairwise comparison. The priority of maturity items was calculated with F-AHP, and then sensitivity analysis was performed to check the framework's robustness. The maturity scores of each item and dimension were calculated. The case studies were performed in the four organizations, which shows that OEMs have higher maturity and are at the "experienced" stage, while both the SMEs are at the "learner level".

The research also helps develop a scientific document and self-assessment tool for maturity assessment for SMEs by providing the list and priority of maturity items. From an industrial perspective, the present study provides guidelines and a self-assessment tool for SMEs to assess their current level in the I4.0 journey. Another practical contribution of this study is the conceptual maturity model formulated after an extensive survey. In general, industries struggle to identify relevant maturity items, and it is unclear what further steps must be taken after assessing their current level. Level 2 can be considered the transition point for the industries to transform them into an I4.0 environment and work on their vertical value chain digitalization at the initial level.

Moreover, the managers can use other approaches based on Fuzzy set theory for better decision-making models. Like every study, the present study has limitations that can be used as the scope of future research. In the future, evaluation of maturity levels at different times can be done with the organization's periodic goals. Although the maturity model is supported by SLR, extensive surveys and case studies, expert opinions are involved, which contain a certain level of subjectivity. The model is tested in the pharmaceutical and automobile sectors and can be further tested in the textile, steel, food, and cement sectors. The importance of each maturity item is calculated based on the opinion of a limited number of experts. In the future, many experts and other decision-making approaches can be applied, and results can be compared. The maturity model may have domain applicability as it represents the manufacturing context, and the survey is based on the specific industry sectors, which may have some limitations in other domains. However, the limitations can be addressed in future research. Future research can address these limitations by considering a wider range of industry sectors in the survey to enhance the model's applicability. Comparative studies across domains, other developing countries can further validate and adapt the model for broader use.

Appendix 1



How do you rate your organization in Knowledge and familiarity with Industry 4.0 tools and technologies?

General description:
Business features in present market scenario such as: quality, flexibility and speed can be considered as the major factors for SMEs to sustain in market. These all requirements can be achieved by Industry 4.0 tools and technologies. Knowledge, awareness and familiarities with Industry 4.0 theory, tools and technologies helps SMEs to execute their digitalization related practices in a better way and efficient manner. This maturity item measure how much an industry is aware and familiar with Industry 4.0 concept and its tools and technologies

Scale Description	Rating
Industry have limited knowledge and familiarity with base technologies of Industry 4.0. Also, Industry have limited knowledge how these technologies can help to achieve sustainability	1
Industry have good knowledge about the physical and digital technologies of Industry 4.0 and already setup few of technologies in its dedicated departments. Industry is working on its pilot projects	2
Industry is using base and smart technologies in their shop floor and supply chain operations. Industry have already completed its pilot projects related to base technologies and now focusing on service base technologies	3
Industry have completed all projects related to base and service base technologies. All the physical and digital technologies are in use in major industry departments.	4
Industry have successfully completed its horizontal level integration and vertical level integration. Industry is now improving its sustainability performance through Industry 4.0 technologies	5

Impact on Sustainability:
Knowledge, awareness and familiarity with Industry 4.0 technologies will help SMEs to promote sustainable energy concept, reduce inequalities, responsible production and efficient health care systems, address dynamic market changes, shorter lead times, better inventory management and resource efficiency

Fig. 8 Sample question and description of maturity item asked from respondents to measure maturity score

Appendix 2: Survey questionnaire on Industry 4.0 maturity items for manufacturing organizations

Section A: General information

The questionnaire survey for the Industry 4.0 maturity model for the Indian industries is designed to assess the significance of Industry 4.0 maturity items for manufacturing firms. The questionnaire is designed to assess the current maturity level of manufacturing firms. Through the literature, we have identified 40 relevant maturity items that can be used to evaluate the readiness and maturity score of the Industry 4.0 practices in India.

The questionnaire survey is divided into three sections. In section A, we discussed the general information. Section B represents the list of 40 maturity items in which the significance of each maturity item can assessed on the Likert Scale of 1–5, in which 1 represents the No Significance and 5 represents the Extremely Significant.

We request that you participate in the survey by taking the time to answer the questions in the questionnaire. You can also refer it to the relevant person. Your responses will remain confidential, and no personal information will be shared with anyone. Your responses to the maturity scores will only be used for research purposes.

Section B: Significance of the maturity items to Industry 4.0 practices in the manufacturing sector

Rate the following maturity items to Industry 4.0 in the manufacturing sector on the 5-point Likert scale (1- not significant, 2-somewhat significant, 3-significant, 4-very significant and 5-extremely significant) (Please tick only ONE in each row).

S. No	Maturity items to Industry 4.0 in the manufacturing sector	Rating				
		1	2	3	4	5
1	Qualification and digital skills					
2	Dedicated teams					
3	Management support					
4	Continuous improvement					
5	Knowledge and familiarity					
6	Economic and sustainability benefits					
7	Industry 4.0 preparedness					
8	Digital culture					
9	Customer integration					
10	Zero paper strategy					
11	Collaboration					
12	Financial investments					
13	Vertical value chain digitalization					
14	Real-time process monitoring and control					
15	End to End IT-enabled planning					
16	Shop floor digitalization					
17	Horizontal value chain digitalization					
18	Industrial robots					
19	Advanced software systems					
20	Use of identifiers					
21	Use of intelligent sensors					
22	Machine-to-machine and human-to-machine communications					
23	Use of digital platforms for supplier integration					
24	Use of digital platforms for customer integration					
25	Use of AR and VR technologies					
26	Additive manufacturing					
27	Use of mobile devices and wearables-based solutions					
28	Blockchain technology					
29	Smart products					
30	Use of cloud technology for resource sharing and data storage					
31	Use of cloud technology for data analysis					
32	Internet of Things (IoT)					
33	Internet of services (IoS)					
34	Big data analytics					
35	Simulation tools					
36	Artificial Intelligence					
37	Cyber security					
38	Data protection					
39	Labour protection laws					
40	Intellectual property laws					

Section C

Respondent Information

1. Name of Respondent……………………………………………
2. Industry/Organization Name…………………………………….
3. Position…………………………………………………………….
4. Experience (In Years)…………………………………………….

Please tick (✓) only one choice in each question as follows:

5. Is there currently any kind of manufacturing automation in your organization?
- ☐ **Yes**
- ☐ **No**
- ☐ **In Progress**

6. Are you familiar with the concept of Industry 4.0 and related technologies
- ☐ **Yes**
- ☐ **No**

7. Does your organization participate in environmental initiatives, certification programs?
- ☐ **Yes**
- ☐ **No**

8. Does your organization follow Sustainable/Green strategies?
- ☐ **Yes**
- ☐ **No**

9. What type of organization you have ?
- ☐ **OEM**
- ☐ **Supplier to OEM**

10. What is your annual turnover?
- ☐ **Less than 50 crores**
- ☐ **Between 50-250 crores**

11. Indicate your education level
- ☐ **Post-Graduation**
- ☐ **Undergraduate/Graduation**

12. In which department do you work?
- ☐ **Finance and HR**
- ☐ **Information Technology**
- ☐ **R&D**
- ☐ **Shop floor**
- ☐ **Supply chain and logistics**

13. What is the type of organization you are employed in?
- ☐ **Automobile**
- ☐ **Drugs and Pharmaceuticals**
- ☐ **Food Processing**
- ☐ **Electrical**
- ☐ **Mineral, Cement, Gypsum**
- ☐ **Textile**
- ☐ **Electronics**
- ☐ **Chemical**
- ☐ **Agriculture**

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Data availability The data to support the findings of the study is available from the Corresponding author upon reasonable request.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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