Evaluation of key factors for industry 4.0 technologies adoption in small and medium enterprises (SMEs): an emerging economy context

Koppiahraj Karuppiah, Bathrinath Sankaranarayanan, Idiano D'Adamo and Syed Mithun Ali

Abstract

Purpose – *Industry 4.0 (I4.0) not only turns traditional industrial activities upside down but also demonstrates its potential to enhance industrial competitiveness and productivity. In this context, technological advancement and I4.0 is a strategy to be pursued. This study aims to consider different I4.0 technologies by analysing Indian small and medium enterprises (SMEs).*

Design/methodology/approach – *Key factors and promising I4.0 technologies were selected using literature analysis and experts' panel. The appropriate I4.0 technology for Indian SMEs is recommended using the fuzzy complex proportional assessment (COPRAS) method.*

Findings – *Results reveal that ability to expand IT infrastructure, change in the organization's structure and the capacity to analyse key performance indicators as three crucial key factors in I4.0 implementation. In particular, the smart factory is identified as a better I4.0 for Indian SMEs.*

Originality/value – *This work has analysed Indian SMEs, but it is appropriate for other developing economies with limited technical resources, financial resources and inadequate skill sets. This work identifies a gap in the current literature, and the findings proposed by this work are oriented to assist decision makers, industrial managers and practitioners in selecting I4.0 technology and enhancing the industrial infrastructure. At the same time, cooperation between the government and industrial community is required to develop programmes for imparting the knowledge of I4.0 among SMEs. The framework used in this study will arm the industrial management in adopting I4.0.*

Keywords *Industry 4.0, Fuzzy COPRAS, Smart factory, Small and medium enterprises (SMEs)*

Paper type *Research paper*

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1. Introduction

Digitalization and technological leaps are expected to assist industrial sectors in creating sustainable business models (Del Giudice *et al.*, 2021). One such technological evolution is Industry 4.0 (I4.0). I4.0 is a technological advancement in which traditional manufacturing and industrial practices are automated using modern smart technologies. Using I4.0, it is possible to improve productivity, efficiency, flexibility and agility. The dawn of I4.0 technologies has changed many manufacturing processes (Stock and Seliger, 2016). Progress towards I4.0 gives immense opportunities for an industrial organization to realize various sustainable manufacturing processes. From the operational perspective, digital technology, using cyber-physical system (CPS), is expected to reduce set-up time and production time, resulting in increased productivity (Dalenogare *et al.*, 2018; D'Adamo *et al.*, 2021). Although I4.0 offers immense benefits to the industrial community, the adoption of I4.0 needs organizational restructuring and improved technological capability.

Such transformation towards I4.0 is difficult for small and medium enterprises (SMEs), especially for SMEs in developing countries. According to Nair *et al.* (2019), SMEs are industries that act as suppliers to large organizations. Depending on the requirements of large organizations, SMEs need to update technologically; it becomes imperative for SMEs to embrace technology swiftly. However, as SMEs are characterized by their limited financial assistance, number of workers (less than 250), rigid organization structure, limited technological advancement and reluctance of industrial management, technological upgrades remain a challenge for SMEs (Yüksel, 2020). Because SMEs are primarily confined to developing countries, technological updating is a major problem for industrial communities in developing countries.

Several developed countries have started enhancing technological capability through various programmes because they realize the potential impact of I4.0 in industrial performance. For instance, in Germany, where the I4.0 concept was born, this programme was called "High-tech strategy 2020". Similarly, in the USA, it is "Advanced Manufacturing Partnership", in China, "Made in China 2025", and in Brazil, "Towards Industry 4.0". The programmes of these countries were developed to familiarize local industrial community members with I4.0 concepts (Ciffolilli and Muscio, 2018). With the vision of increasing production capacity and stimulating the manufacturing sector, India's Government has developed the "Make in India" programme. However, India's industrial community suffers from technological gaps; hence, they still reside at the level of Industry 2.0 (Chan *et al.*, 2021). To keep pace with the exponential technological development and enhance the workforce's technical knowledge, the Government of India has created initiatives such as "Digital India" and "Skill India" (De, 2019).

The government's initiatives are helpful, but knowledge and awareness resources on the significance of I4.0 are scant among the industrial practitioners; hence, most SMEs have not upgraded to I4.0. A study by Kamble *et al.* (2018) indicates that a lack of clear understanding of I4.0 is the major hindrance in embracing I4.0 by industries in the Indian context. Further, the absence of standard government regulations for industries using I4.0 increases the security breach (Raj *et al.*, 2020). Such barriers raise concerns about data ownership and cybersecurity. Regardless of the barriers, the growing level of competition and the need for reduced time-to-market requires industries to adopt I4.0 (Oomen *et al.*, 2019). Transformation towards I4.0 is also forced by decreased product lifecycles and heterogeneous market trends (Horváth and Szabó, 2019). Hence, the adoption of I4.0 has become mandatory for the industrial community of both developed and developing countries. Various concepts in I4.0, such as CPS, Big Data (BD), Internet of Things (IoT) and visual computing, have been studied and discussed by Lu (2017) and Muhuri *et al.* (2019). Most works focus only on the identification of the barriers in the adoption of such technology. However, earlier studies fail to explore the possibility of adopting any such technologies.

From the above information, it is evident that the industrial community worldwide is primed to accept I4.0. However, compared with developed economies, reliable knowledge and awareness of I4.0 principles are scant in developing economies (Popkova and Zmiyak, 2019; Ś lusarczyk, 2018). Hence, there is a need to impart knowledge on the significance of I4.0 and its role in value creation to industrial performance in the developing country context.

Because of I4.0's relevance, this study fills a key gap in the literature. To begin, it creates a framework for identifying the 10 most important factors of I4.0 adoption. Next, considering the industrial community's ability in the Indian context, the research suggests the ideal choice of I4.0 technology. A study from an Indian backdrop will reliably represent the scenario of developing countries despite the socio-economic and financial differences that exist among developing countries. Future studies can validate the findings by taking data from other emerging countries like Bangladesh, Thailand, Vietnam, etc. According to Yüksel (2020), most industries located in India, Bangladesh, Thailand and Vietnam are SMEs. In addition, the findings of this study will serve as a guide for SMEs interested in adopting I4.0 by highlighting the specific elements that SMEs should consider. It is estimated that India will be one of the fastest-growing economies in the world in the following years and the manufacturing sector will yield US$1m in 2025 (Safar *et al.*, 2020). Like India, most Asian countries also serve as production hubs to meet global demand. As a result, Asian countries urgently require a transition to I4.0 and an investigation into the problems that SMEs have in implementing I4.0 (Amaral and Peças, 2021; Ricci *et al.*, 2021). Here, the focus has been given to SMEs as they are more prevalent in developing economies. With consideration of the present technological capability of Indian SMEs, this research raises some questions for analysis as follows:

Q1. Which technologies are currently connected with I4.0 in the manufacturing industry?

Q2. What are the key factors to be considered for the successful adoption of I4.0?

Compared with developed countries, the developing countries still lag behind in terms of technological advancements. Being recognized as a manufacturing hub by global nations, developing countries like India, Bangladesh and Thailand are in a position to meet the global demand. Hence, being proficient with technological advancement is necessary for developing countries. This study uses a framework for answering the previously listed research questions by meeting the following objectives:

- to identify the latest I4.0 technologies to enhance the production capacity of the industrial community in developing countries;
- to rank the I4.0 technologies based on the possibility of their embrace by the developing countries;
- to recognize the key factors that must be considered in adopting I4.0; and
- to prioritize the key factors based on their influence in I4.0 adoption.

The goal of this study is to assess the essential factors required for I4.0 adoption. For this, the multi-criteria decision-making (MCDM) approach, combining fuzzy set theory and complex proportional assessment (COPRAS), has been used. Using fuzzy-COPRAS, the weight of the factors is calculated and the suitable technology in I4.0 is selected. Fuzzy COPRAS may assist the industrial practitioners and policymakers in the selection of appropriate I4.0 technology. Fuzzy COPRAS has also been used in some earlier studies on various fields (Bathrinath *et al.*, 2022; Subba and Shabbiruddin, 2022).

The paper is organized as follows: the concept of I4.0, some of the most popular I4.0 technologies, the technique for selecting the optimal technology and the research gap are all summarised in Section 2. The steps involved in fuzzy COPRAS are outlined in Section 3. Section 4 contains an application of the research methodology. The outcomes of the proposed methodology are examined in Section 5. The study's contribution, limitations, implications and future scope are all discussed in Section 6.

2. Literature review

2.1 Fourth industrial revolution

The paradigm of industrial activities constantly changes with technological advancements. For instance, the model of industrial activities changed from steam-powered (first industrial revolution) to electric power (second industrial revolution) to electronic and information stage (third industrial revolution) to automated production (fourth industrial revolution) (Vaidya *et al.*, 2018). In 2011, the phrase "Industry 4.0" was coined at the Hanover Fair. When the term "Industry 4.0" was originally coined, there was some discussion about whether it was a hit or merely hype. Despite differing viewpoints, the notion of I4.0 has gained traction in a wide range of industrial activities, including manufacturing, inventory management and supply chain management. Researchers (Oesterreich and Teuteberg, 2016) defined I4.0 as a confluence of various technological features connected with internet technologies. The current technologies that are associated with I4.0 are CPS, BD, Smart factories, IoT and interoperability (Haseeb *et al.*, 2019). Table 1 provides a brief overview of the most extensively adopted I4.0 technologies. All these technologies make a substantial contribution to industry output capacity. Realizing the potential impact of I4.0 on industrial growth, in 2013, Germany became the first country to adopt I4.0 with the intention to provide a cutting edge and competitive manufacturing practice (Raj *et al.*, 2020; Roblek *et al.*, 2016). Following Germany, other countries also formulated similar strategies, such as Advanced Manufacturing Partnership by the USA (Chen, 2017), Productivity 4.0 by Taiwan (Chen and Chen, 2019) and strategy for innovation in the manufacturing industry by the Republic of Korea (Lee *et al.*, 2019). I4.0 technologies can be separated into two categories: front-end technologies and base technologies. Smart working, smart manufacturing, smart supply chain and smart products are examples of front-end technologies, whereas base technologies are those that offer connectivity for the front-end technologies (Frank *et al.*, 2019). This type of technology boosts productivity, flexibility and quality. I4.0's main goal is to create an intelligent manufacturing process. Furthermore, I4.0 is predicted to be a significant driver of employment creation (Kamble *et al.*, 2018). Therefore, the industrial communities around the globe are in a situation to embrace I4.0. Further, from the above information, it can be stated that I4.0 has immense potential in

Table 1 Preferred industry 4.0 technologies

S. No.	*Name of the technology*	*Explanation*	*References*
1	Big data	A word that denotes a significant amount of complex data with a high volume, velocity and diversity that requires advanced technology to gather, store, manage, disseminate and analyse it	(Bydon *et al.*, 2020; Favaretto *et al.*, 2020)
2	Internet of Things (IoTs)	A network connects a collection of physical and virtual items for communication and interaction with the internal and external environment	(Abdel-Basset *et al.*, 2018; Hassan, 2019; Wortmann and Flüchter, 2015)
3	Cyber-physical systems	A game-changing technique for managing physical assets and computing capabilities that is interconnected	(Lee *et al.*, 2015; Roehm *et al.*, 2019; Sanislav and Miclea, 2012; Sony and Naik, 2020)
4	Interoperability	The ability of two or more systems to interact and execute programmes to function properly	(Enos and Nilchiani, 2019; Motta *et al.*, 2019; Wegner, 1996)
5	Smart factory	An integrated manufacturing system that gathers real-time data on the manufacturing environment and makes autonomous modifications to manufacturing procedures and raw materials	(Hozdić, 2015; Lucke *et al.*, 2008; Shi *et al.*, 2020)
6	RFID	A wireless communication system that allows an object and an interrogating device to track each other automatically	(Bai *et al.*, 2020; Mondal *et al.*, 2019)
7	Blockchain	A distributed database that uses a consensus process to maintain a distributed list of records	(Bai *et al.*, 2020; Frank *et al.*, 2019)
8	Global positioning system (GPS)	A technique that uses a constellation of satellites in Earth's orbit that broadcast exact signals, determining the precise position and relaying information to users	(Bai *et al.*, 2020; Osterrieder *et al.*, 2020; Rajput and Singh, 2020)
9	Artificial intelligence	A branch of computer science that focuses on the creation of intelligent machines that behaves like humans	(Bai *et al.*, 2020; Brahma *et al.*, 2020)
10	Augmented reality	An interactive environment that uses computer-generated graphics and sound to simulate a real-world situation	(Ardito *et al.*, 2019; Bai *et al.*, 2020; D'Adamo and Rosa, 2019)

Note: RFID – Radio frequency identification enhancing industrial productivity and in changing the paradigms of various industries. However, the embrace of I4.0 demands some prerequisites which appear to be challenges for industries. The next section explains these prerequisite factors.

2.2 Prerequisite factors for industry 4.0

While I4.0 is expected to bring revolution in industrial activities, adoption of I4.0 remains an uphill task for many SMEs owing to the high-end technological requirements (Bartodziej, 2017). This struggle remains more prevalent in emerging economies because they are not technologically well-established. A study by Raj *et al.* (2020) reports that a vast difference prevails in the adoption of I4.0 between developed and developing countries, and the lag in technology is cited as the major reason. Hence, it is essential for developing countries to strengthen their technological capability. To enhance the technological capability, a knowledge-based community must be established. According to Olsen and Tomlin (2020), trade-offs among cost, speed, flexibility and quality restrict SMEs from preferring I4.0. Further, limited financial resources, technological access and other market issues hinder SMEs from adopting I4.0 technologies. However, by citing these factors, the SMEs cannot escape from adopting I4.0, as I4.0 adoption becomes mandatory for myriad reasons (Gutiérrez and Ezponda, 2019; Xu *et al.*, 2018). Further, the industry needs to have strong human, technological and organizational integration for seamless utilization of I4.0 (Havle and Ucler, 2018). A study by Bag *et al.* (2021) regarding the adoption of I4.0 by South Africa lists 35 resources as the key factors and emphasizes knowledge-based environment and top management involvement as critical resources. In addition to having a knowledge-based working environment, it is also mandatory to have a flexible organizational structure. Compared to SMEs, many large-scale companies are witnessing success in I4.0 adoption because of the following characteristics: flexibility, decentralized decision-making and enhancement of worker's digital skills (Machado *et al.*, 2019). Although the adoption of I4.0 by the large-scale companies is laudable, their presence in most countries is very minimal. In almost all countries, SMEs occupy a prominent position in the industrial and economic activity, so adopting I4.0 is very important (Reischauer, 2018). In this regard, it is essential to list and prioritize the critical factors that must be considered by the SMEs while adopting I4.0. Such prioritization will largely benefit SME management.

2.3 Use of multi-criteria decision-making approaches in industry 4.0

As the successful adoption of I4.0 is influenced by numerous factors, earlier studies on I4.0 have also used MCDM techniques. For instance, a study by Erdogan *et al.* (2018) in selecting the best strategy for I4.0 application used an integrated MCDM approach of fuzzy analytical hierarchy process and VIekriterijumsko KOmpromisno Rangiranje. Another similar study by Kumar *et al.* (2021) in evaluating the barriers in I4.0 used modified stepwise weight assessment ratio analysis (SWARA) and weighted aggregated sum product assessment. In analysing the challenges to I4.0 adoption, (Moktadir *et al.*, 2018) used best-worst method (BWM). Vinodh and Wankhede (2021) used fuzzy decision-making trial and evaluation laboratory (DEMATEL) and fuzzy combinative distance-based assessment to analyse readiness of industrial community located in developing economies. Like I4.0, in other field also MCDM techniques have been widely used. In analysing the barriers to lean and green supply chain management, (Rajak *et al.*, 2022) used BWM. Chandra *et al.* (2022) used SWARA and COPRAS methods in selecting appropriate method for additive manufacturing. From the above information, it is clear that MCDM techniques are widely used in many fields for analysing the challenges. Reasons like simple calculation steps and ability to handle large data favour the preference of MCDM techniques.

2.4 Research gaps and contributions

Overall, a comprehensive understanding of I4.0 is still unclear and remains partially understood. Even developed countries have only a partial grasp of I4.0 while developing countries have a hazy knowledge. Academicians and researchers working on I4.0 have identified rising trajectories in developed countries and embryonic development in developing countries. Following a study of the existing literature, it was discovered that the majority of I4.0 research focused on the barriers and challenges to adoption (Raj *et al.*, 2020; Da Silva *et al.*, 2020; Stentoft *et al.*, 2020). Most studies carried out so far in the I4.0 context are conceptual and critical reviews. Clearly, most studies seek to determine the difficulties in I4.0 adoption; studies that analyse the possibility of I4.0 adoption are very scant (Nimmi and Zakkariya, 2021). A study that considers the capability of industries in developing countries has not been explored. More specifically, a case study that examines leather garments within the leather industry has not been pursued. Against this drawback, this research strives to identify the suitable I4.0 technology for SMEs by considering basic requirements. For this, the COPRAS approach in a fuzzy context is used.

In summary, although some appreciable trajectory regarding I4.0 emerges from the literature, few studies are available for developing countries. As I4.0 is still nascent in most developing nations, a case study in an Indian context will provide an important picture of I4.0. Hence, this research intends to evaluate various I4.0 technologies by considering SMEs' ability with India as a reference. The case companies considered in this study meet the definition of SMEs whose presence is prevalent in all countries, especially Asian countries. This research will assist industrial managers and practitioners achieve a better understanding and awareness of I4.0. For this, the COPRAS approach in a fuzzy context is used.

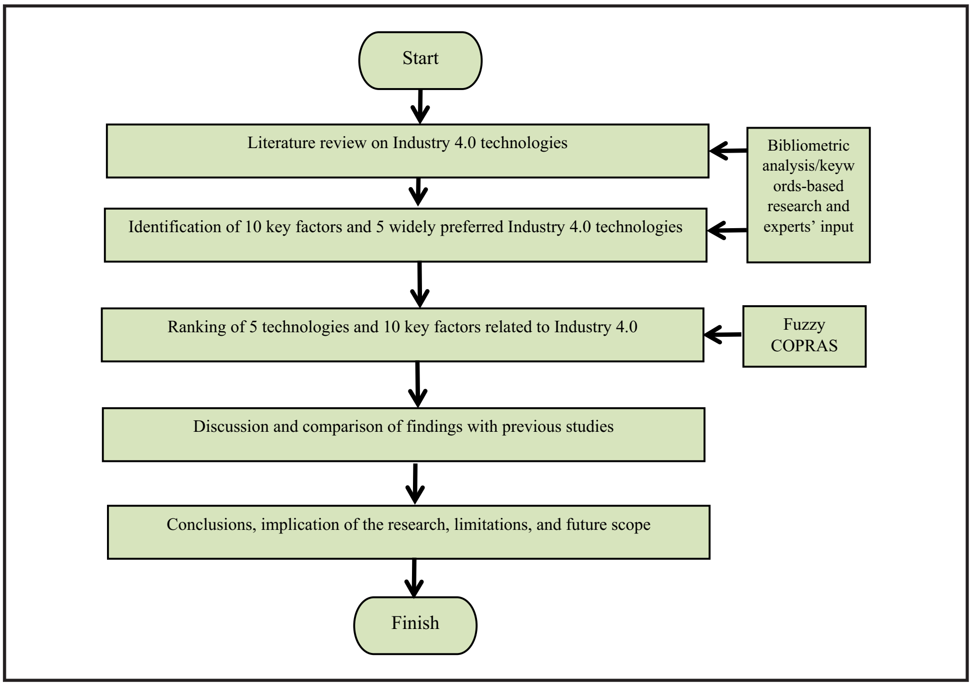
3. Research methodology

Technological advancement has become an essential need for the industrial sector to survive. This study aims to identify and rank the key factors that are needed for technological upgradation and to suggest the preferable I4.0 technology. The purpose of the study is achieved using the proposed framework given in Figure 1. The research methodology used in this study is divided into two sections. Based on the literature analysis and expert feedback, the basic factors required for the adoption of I4.0 and the commonly preferred I4.0 technology are identified in the first stage. In the second stage, the basic required infrastructure of the case companies considered are analysed from the perspectives of eight industrial experts using the fuzzy COPRAS approach. A matrix comprising the identified basic factors was given to the eight experts, and each expert was asked to rate them. Based on their responses, each factor's weight was calculated and compared with the identified I4.0 technologies. The result obtained was discussed with the experts for feedback.

3.1 Stage 1: identification of key factors for industry 4.0 adoption

Based on relevant literature analysis and expert feedback, basic required elements for successful adoption of I4.0 technology were determined in two steps. First, a literature review was performed (Vitolla *et al.*, 2019). Relevant research articles published in scientific publications with high citation ratings (Web of Science and Scopus) were first collected, with several keywords identified for literature collection: "Industry 4.0", "basic requirements for adoption of Industry 4.0", "Industry 4.0 and manufacturing process", "Industry 4.0 in developing countries" and "technological requirements for Industry 4.0". Eighty papers with some degree of overlap were found using this method (50 from Web of Science, 30 from Scopus). Several papers were eliminated due to exclusionary factors (non-English language, conference publications and repeated works), and 50 relevant and comparable

Figure 1 Proposed methodological framework



publications in the literature review remained for suitable investigation. Following the completion of these 50 publications, 10 essential factors for I4.0 adoption were determined. In the second step, a group of experts was selected and provided a questionnaire (Appendix) consisting of a list of identified key factors required for I4.0 adoption. Initially, 12 experts were approached, with eight agreeing to participate in the study. The number of experts considered in this study is acceptable. Sadly, there is no consensus among researchers on how many experts are required for a MCDM problem. For example, some studies considered only five experts (Bhatia and Srivastava, 2018) or fewer experts (Rajesh and Ravi, 2015). All experts consulted have an extensive understanding of I4.0 and have worked for at least eight years. The experts were selected based on the purposive sampling technique; only experts from the I4.0 background can adequately rate the factors. According to Sekaran (2006), the purposive sampling technique provides the chance to select experts based on their field of work, experience and knowledge, which can enhance the results. The eight experts considered in this study were approached from five different companies to follow heterogeneity. The 10 important factors found were distributed to eight experts for discussion, and the experts were free to alter the list of basic factors for I4.0 adoption. Frequent reminder emails were given to the experts to provide feedback. Ten important factors were identified as relevant to the adoption of I4.0 in the manufacturing industry based on expert feedback. The final list of key factors required for the adoption of I4.0 is given in Table 2. Likewise, the experts were also asked to suggest widely preferred I4.0 technologies. As a result, the experts suggested BD (T1), IoT (T2), CPS (T3), artificial intelligence (T4) and Smart factory (T5) as the most preferred I4.0 technologies.

3.2 Stage 2: fuzzy complex proportional assessment approach

In Zadeh (1965), fuzzy logic is used to solve problems involving uncertainty and ambiguity in data. Fuzzy logic can help solve situations where there are no sharp limits or precise values. Instead of quantitative expression, linguistic variables are used in fuzzy

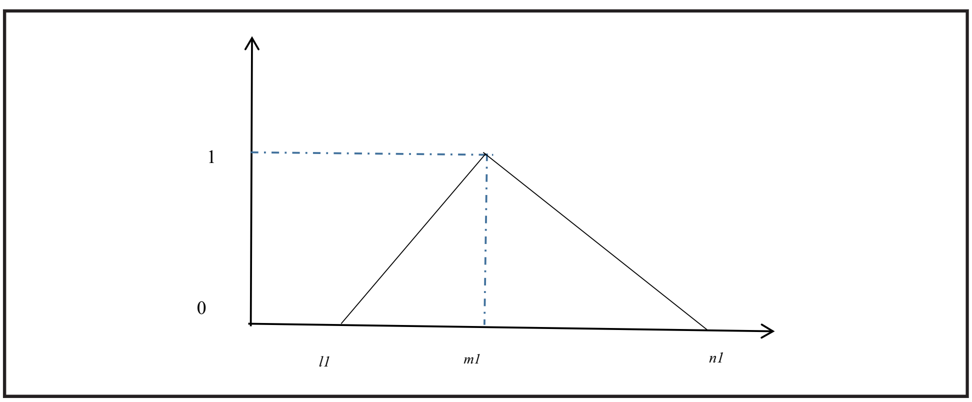
Table 2 Key factors for industry 4.0 adoption

S. No.	*Key factors*	*Description*	*Reference(s)*
1	Ability to expand IT infrastructure (F1)	To ensure seamless execution of operation, high-end computer infrastructure is required	(Chen and Chen, 2019; D'Adamo *et al.*, 2020; Osterrieder *et al.*, 2020)
2	Competence to ensure data protection and security (F2)	Data exchanged among different departments must be protected from cyber attack	(Frank *et al.*, 2019; Kamble *et al.*, 2018)
3	Ability to maintain reliable data (F3)	Consistent and reliable data on the industrial operation is required for seamless execution of the industrial operation	(Chen and Chen, 2019; Favaretto *et al.*, 2020)
4	Facility to maintain proper data storage system (F4)	A proper data storage system will act as a database and repository of industrial processes	(Kamble *et al.*, 2018)
5	Capacity to provide proper training to employees (F5)	Giving formal training to employees will assist in reliable data collection	(Kagermann, 2015; Raj *et al.*, 2020)
6	Readiness to integrate different departments (F6)	Proper information flow among different departments will greatly enhance industrial operations	(Haseeb *et al.*, 2019; Osterrieder *et al.*, 2020)
7	Willingness to change organization's culture (F7)	Industries have to change from conventional culture to clan culture	(Haseeb *et al.*, 2019; Kagermann, 2015)
8	Potential to reach consensus among the stakeholders (F8)	For the establishment of IT infrastructure, cooperation among the stakeholders is essential	(Bydon *et al.*, 2020; Sharma, 2016)
9	Ability to analyse key performance indicators (F9)	Concentrate and monitor more on the key performance indicators of the industrial performance	(Roblek *et al.*, 2016; Wortmann and Flüchter, 2015)
10	Ability to construct standard and reference architecture (F10)	Constructing a standard architecture will act as a benchmark for measuring the performance	(Favaretto *et al.*, 2020; Kagermann, 2015)

logic. As a result, it is a valuable idea to resolve situations that are overly complex or inadequately described (Zadeh, 1965). A fuzzy set is, in general, a subset of a crisp set. A fuzzy number typically falls between the closed-loop intervals of 0 and 1, where 1 represents full membership and 0 represents non-membership. Depending on the scenario, different forms of fuzzy numbers (triangular and trapezoidal numbers) are used. However, triangular fuzzy numbers (TFNs) are preferred due to their ease of usage. TFNs are easy to compute and useful for representing information in a fuzzy environment (Torlak *et al.*, 2011).

Consider a fuzzy number $\widetilde{K}$ on R as a triangular fuzzy number and its membership function $\mu_{\widetilde{k}}(x) : R \rightarrow [0, 1]$ (Figure 2).

Figure 2 Membership function of triangular fuzzy numbers (*l1, m1, n1*)



$$\mu_{\bar{k}}(x1) = \begin{cases} 0, & x1 \leq l1 \\ (x1 - l1)/(m1 - l1), & l1 \leq x1 \leq m1 \\ (n1 - x1)/(n1 - l1), & m1 \leq x1 \leq n1 \\ 0, & otherwise \end{cases} \quad (1)$$

Zavadskas and Kaklauskas (1996) was the first to introduce the COPRAS method. COPRAS is one of the most popular MCDM approaches for selecting the best alternatives from a large number of alternatives (Yazdani *et al.*, 2011). This study chose the COPRAS method because of its compensating method, independent and qualitative qualities that are turned into quantitative attributes. Also, this method is efficient and capable of handling uncertainties and vagueness in data. The importance and degree of utility are calculated to assess the direct and proportional dependence factors as well as the alternatives. One drawback of COPRAS method is its inefficiency in producing accurate and precise results in many real-time problem assessments when using crisp values. With crisp values, it is possible to get binary ratings. Such ratings fail to capture vagueness in data. To overcome these drawbacks, fuzzy COPRAS was first introduced by Zavadskas and Antucheviciene (2007). The fuzzy concept is used in this study to select ideal I4.0 technology. Using a fuzzy concept in COPRAS, the criteria weight and alternatives ratings are given in linguistic terms. COPRAS methods are widely used in fields such as risk assessment (Esbouei and Ghadikolaei, 2013), supplier selection (Madić *et al.*, 2014) and material selection for the reasons stated above (Chatterjee and Chakraborty, 2012). Zavadskas and Antucheviciene (2007) used the fuzzified COPRAS method for the selection of a rural building project. Turanoglu Bekar *et al.*, 2016) used fuzzy COPRAS to measure total productive maintenance performance.

The steps in fuzzy COPRAS are given below (Yazdani *et al.*, 2011):

Step 1: Select the linguistic ratings for factors and alternatives concerning factors

In this step, the weight relevance of variables and alternative factors are evaluated in a fuzzy environment using linguistic concepts. Table 3 shows the language values for the weight importance of factors, and Table 4 shows the linguistic values for the alternatives concerning factors.

Table 3 Linguistic terms for criteria

Linguistic terms	*Fuzzy no.*
Very high (VH)	(0.75, 1, 1)
High (H)	(0.50, 0.75, 1)
Medium (M)	(0.25, 0.50, 0.75)
Low (L)	(0, 0.25, 0.50)
Very low (VL)	(0, 0, 0.25)

Table 4 Linguistic ratings of alternatives

Linguistic terms	*Fuzzy rating*
Absolutely significant (A)	(0.75, 1, 1)
Very strongly significant (VS)	(0.50, 0.75, 1)
Really significant (R)	(0.25, 0.50, 0.75)
Equally significant (E)	(0, 0.25, 0.50)
Weakly significant (W)	(0, 0, 0.25)

Step 2: Establish fuzzy decision matrix

Consider $'n'$ number of factors and $'m'$ number of alternatives, and then the fuzzy decision matrix is obtained using $'m'$ rows and $'n'$ columns as follows:

$$
\begin{array}{c} \qquad\qquad f_1 \quad f_2 \quad f_3 \quad f_4 \\ -D = \begin{bmatrix} \widetilde{x_{11}} & \widetilde{x_{12}} & \cdots & \widetilde{x_{1n}} \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ \widetilde{x_{m1}} & \widetilde{x_{m2}} & \cdots & \widetilde{x_{mn}} \end{bmatrix} \begin{matrix} T_1 \\ T_2 \\ \vdots \\ T_m \end{matrix} \end{array} \tag{2}
$$

and factors are constructed as follows:

$$\widetilde{W} = \left(\widetilde{w_1}, \widetilde{w_2}, \cdots, \widetilde{w_n}\right) \tag{3}$$

The decision matrix and the weight of each factor are converted into crisp values by defuzzification. For defuzzification, the centre of area method was used (Runkler, 1996). The best non-fuzzy performance value for the fuzzy number $\widetilde{R_i} = \left(L\widetilde{R_i}, M\widetilde{R_i}, N\widetilde{R_i}\right)$ can be calculated using the following equation:

$$BNP_i = \left[\left(N\widetilde{R_i} - L\widetilde{R_i}\right) + \left(M\widetilde{R_i} - L\widetilde{R_l}\right)\right]/3 + L\widetilde{R_i} \tag{4}$$

Step 3: Normalization of the defuzzified decision matrix $\overline{X}$

The normalized values are calculated as:

$$\overline{x}_{ij} = \frac{x_{ij}}{\sum_{j=1}^{n} x_{ij}}; i = 1, \ldots, n \text{ and } j = 1, \ldots, m$$

Step 4: Calculate the weighted normalized decision matrix $\hat{x}$

The weighted normalized values $\hat{x}_{ij}$ are calculated as:

$$\hat{x}_{ij} = \overline{x}_{ij}.q_j \tag{7}$$

Step 5: Sums P_j *of alternatives values*

$$P_j = \sum_{j=1}^{k} \hat{x}_{ij} \tag{8}$$

Step 6: Sums R_i *of alternatives values*

$$R_i = \sum_{j=k+1}^{m} \hat{x}_{ij} \tag{9}$$

Step 7: Determine the minimum value of R_i

$$R_{\min} = \min_i R_i \tag{10}$$

Step 8: Calculate the relative weight of each alternative

$$Q_i = P_i + \min \frac{R_{\min}\sum_{i=1}^{n} R_i}{R_i \sum_{i=1}^{n} \frac{R_{\min}}{R_i}} \tag{11}$$

Step 9: Determine the optimality of the alternativeK

$$K = \max_i Q_i \tag{12}$$

Step 10: Calculation of utility degree of each alternative

$$U_i = \frac{Q_i}{Q_{\max}} 100\% \tag{13}$$

4. Application of the research methodology

A case study is conducted to ascertain whether the Indian manufacturing industry is prepared to adopt I4.0. The case study was carried out in five leather garments companies located in different parts of India. Garments situated in different locations were selected to access the spread of I4.0 knowledge. For this, as a first step, a comprehensive literature review and interaction with experts occurred to identify and finalize the set of basic industrial capacities for embracing I4.0 technology. In this research, five leather garments were considered for analysing the existing basic infrastructure along with eight experts. The basic profile of the experts is provided in Table 5. After the visit, a questionnaire including the identified key factors for adopting I4.0 was mailed to the experts. The experts were asked to assess the leather garments infrastructural facilities in detail. Based on the experts' responses, fuzzy COPRAS was used to do the analysis (Shaikh *et al.*, 2020).

The proposed study methodology was applied to real Indian businesses because they were believed to accurately reflect the backdrop and status of developing economies. Further, in the Networked Readiness Index, India occupies the 91st position, which is worrisome (Dutta, 2016). As a result, it is vital to ascertain the industrial community's readiness to leverage the benefits of developing technologies and to maximize the opportunities presented by digital technology in India. Also, the reason for selecting leather garments companies is that the Indian leather garments industry has created a niche market for itself

Table 5 Profile of the experts

Characteristics	*Classifications*	*No. of experts*	*Percentage (%)*
Gender	Male	5	62.5
	Female	3	37.5
Age	Up to 30 years	2	25
	31–45	3	37.5
	46–60	3	37.5
Experience	1–10	2	25
	11–20	2	25
	21–30	4	50
Education	Graduate	3	37.5
	Postgraduate	3	37.5
	Doctorate	2	25
Position	Technical manager	4	50
	Senior data scientist	2	25
	Research scientist	2	25

in the global leather market. Enhancing Indian leather garments' production capability with I4.0 may provide them with a greater competitive edge in globalized business trends.

The profile of the five leather garments case companies chosen is given in Table 6. Accessing the leather garments' technological capabilities may assist the industrial management in taking proactive steps for improvising the technical capability in I4.0 adoption. The application of the proposed approach is detailed below:

Step 1: A questionnaire consisting of the identified key technological factors was given to the experts. Once the present technological facilities have been visited and reached by case companies, specialists were asked to assess the technological requirements indicated by using the linguistic scale in Table 3. The average working experience of the expert panel is eight years, and each has proficient knowledge of I4.0. Initially, the finalized key factors for I4.0 adoption are divided into the cost and benefits category. In this study, as per experts' suggestion, the factors F1, F2, F3, F4 and F5 are categorized under cost category, while factors F6, F7, F8, F9 and F10 are categorized under benefit category. The initial (10×10) direct relationship matrix composed of linguistic variables was formed for the 10 factors. The initial direct-relationship matrix is formed based on experts' ratings, and it is the average of all the experts' ratings. Linguistic variables are converted into TFNs to determine the fuzzy weight of the elements. The triangular numbers are converted into crisp weight using equation (4) and are given in Table 7.

Step 2: The experts were then requested to create a direct relationship matrix between the identified I4.0 technologies and the necessary technological factors. For this, the fuzzy linguistic rating given in Table 4 is used. The constructed direct relationship matrix is given in Table 8. After constructing a fuzzy decision matrix, fuzzy values are converted into crisp values using equation (4). Then, in the fuzzy COPRAS approach, the fuzzy decision matrix needs to be normalized.

Step 3: The weight normalized matrix is obtained by multiplying the normalized decision-making matrix by the weight of the factors. Table 9 displays the weight normalized matrix that was obtained.

Table 6 Profile of leather garments companies

Business features	*Case company 1*	*Case company 2*	*Case company 3*	*Case company 4*	*Case company 5*
Year of establishment	2000	2002	2001	2003	2001
Number of workers	100–120	More than 100	120–150	80–100	100–150
Products manufactured	Leather jackets, belts	Leather bags, gloves	Leather wallet, bags	Leather decorative	Leather jackets
Turnover (in INR) yearly	100 crore	80 crore	120 crore	110 crore	130 crore

Table 7 Fuzzy weight of factors

Criteria	*Linguistic term*	*Fuzzy weight*	*Crisp weight*
F1	VH	(0.75, 1, 1)	0.916
F2	H	(0.5, 0.75, 1)	0.75
F3	M	(0.25, 0.50, 0.75)	0.50
F4	H	(0.5, 0.75, 1)	0.75
F5	H	(0.5, 0.75, 1)	0.75
F6	M	(0.25, 0.50, 0.75)	0.50
F7	VH	(0.75, 1, 1)	0.916
F8	H	(0.5, 0.75, 1)	0.75
F9	VH	(0.75, 1, 1)	0.916
F10	M	(0.25, 0.50, 0.75)	0.50

Table 8 Fuzzy decision matrix

	F1	*F2*	*F3*	*F4*	*F5*	*F6*	*F7*	*F8*	*F9*	*F10*
T1	A	R	R	VS	E	R	A	VS	VS	E
T2	A	A	R	VS	E	E	A	E	VS	R
T3	A	A	A	A	VS	R	VS	A	R	VS
T4	A	VS	R	VS	A	VS	E	A	E	A
T5	A	E	R	A	VS	R	R	E	R	R

Table 9 Weighted normalized fuzzy decision matrix

	F1	*F2*	*F3*	*F4*	*F5*	*F6*	*F7*	*F8*	*F9*	*F10*
T1	0.18	0.11	0.09	0.14	0.06	0.10	0.25	0.18	0.25	0.04
T2	0.18	0.21	0.09	0.14	0.06	0.05	0.25	0.06	0.25	0.09
T3	0.18	0.21	0.16	0.17	0.19	0.10	0.21	0.22	0.17	0.13
T4	0.18	0.17	0.09	0.14	0.24	0.15	0.07	0.22	0.08	0.16
T5	0.18	0.06	0.09	0.17	0.19	0.10	0.14	0.06	0.17	0.09

Step 4: Now, using equation (11), compute the relative weight of each I4.0 technology. Finally, using equation (13), determine the usefulness degree of each technology. Table 10 shows each technology's relative weight and utility degree.

5. Results and discussions

From the results, two critical elements were investigated to understand the research findings: weight importance of factors and utility degree of the alternatives. The weight of the basic required infrastructural factors is given in Table 7, and the degree of utility of the alternative technologies is given in Table 10.

5.1 Weight importance of the key factors

The weight importance of the factors will give a clear picture of the factors that need to be enhanced to adopt I4.0 technology. These identified 10 key infrastructural factors are designated as instrumental in the adoption of I4.0.

In this study, the factors "ability to expand IT infrastructure (F1)" and "ability to change the organization's structure (F7)" with the weight of 0.916 were identified as the crucial factors in adopting I4.0. Agostini and Filippini (2019) suggest that most industrial managers in developing economies are reluctant to change the organizational structure. The study also implies that such an attitude of reluctance by the industrial management towards technological advancement hampers industrial progress. For instance, in embracing new

Table 10 Fuzzy COPRAS output

	Q	*U*	*Rank*
T1	1.19	74.50	5
T2	1.40	87.36	4
T3	1.52	94.91	3
T4	1.55	96.82	2
T5	1.60	100.00	1

emerging technology, industrial management finds it difficult to reach a consensus among the stakeholders. Failure to reach a consensus among stakeholders restricts the financial support and flow. It is difficult for industrial management to expand its technological infrastructure (Bashtannyk *et al.*, 2020; Sung, 2018). Industrial management and stakeholders need to be aware that progress towards I4.0 not only needs knowledge of I4.0 but also needs investment in the technological infrastructure. Financial incapability of the industrial organizations often remains a major blockage in improving the ability to enhance IT infrastructure. Hence, it is clear that financial incompetence hinders the progress of embracing I4.0. Similarly, the factor "ability to analyze key performance indicators (F9)", also with a weight of 0.916 must be viewed as an equally important factor in I4.0 adoption. Poor monitoring strategy followed by industrial management may lead to an inefficient analysis of key performance indicators. In this connection, industrial management must improve the monitoring process (Popkova, 2019). Also, lack of technical knowledge and skilled workforce remains a major concern in the transition towards I4.0. Only with a knowledgeable workforce will it be possible to implement and maintain the I4.0.

Next, the factors "ability to ensure data protection and security (F2)", "ability to maintain proper data storage system (F4)", "ability to provide proper training to employees (F5)" and "ability to reach consensus among the stakeholders (F8)" with the weight of 0.75 require immediate attention. With limited technological advancement, a vital question arises on SMEs' capability to protect data (Kim *et al.*, 2019). Under such a situation, the SMEs are advised to reinforce the technological capability. Reinforcement of technological capabilities will help in the expansion of IT infrastructure and in ensuring data protection. To ensure seamless operation using I4.0 technology, the industrial community must have a proper data storage system. Before establishing a data storage system, managers must collect reliable data on the key performance indicators. For this, the industrial managers need to adopt a new data monitoring strategy (Das *et al.*, 2020). Further, the employees must be given sufficient training on data collection and monitoring. By providing proper training, it is possible to maintain reliable data. It should be noted that to fetch reliable data, it is mandatory to integrate different departments' function. Finally, it is necessary to have a standard and reference architecture system for efficient I4.0 adoption (Ardito *et al.*, 2019).

From Table 7, based on the weight of factors, it is visible that all the factors discussed above regarding I4.0 adoptions are interconnected. From this, it could be perceived that industrial management's ability to expand IT infrastructure will act as the linchpin in I4.0 adoption.

5.2 Utility degree of alternatives

In this research, based on the interaction with experts, the five widely preferred I4.0 technologies were chosen, namely, BD (T1), IoT (T2), CPS (T3), artificial intelligence (T4) and smart factory (T5). The ranks of alternatives are as follows: T5>T4>T3>T2>T1.

The appropriate I4.0 technology for the industries has been evaluated by comparing the factors considered with the chosen technologies. By making a pairwise comparison between the factors and the alternatives, it is found that the "smart factory" will be an appropriate choice. The finding was found to be in line with the findings of Won and Park (2020), which state that the smart factory is recognized as an essential change towards I4.0. The smart factory technique has also been defined as a sensitive manufacturing environment that efficiently manages the production system. Adopting smart factory technology makes it possible to minimize equipment downtime and improve the monitoring condition. Besides these benefits, it also offers improved productivity with high quality and increased production capacity with energy efficiency (Büchi *et al.*, 2020; Osterrieder *et al.*, 2020). Jerman *et al.* (2019) highlighted commitment from top management, training to employees and digitization as crucial factors in establishing the smart factory. In this research, these mentioned factors were considered, and hence, the finding of the research seems to be appropriate. As an initial step in establishing a smart factory, the industrial management must ensure a well-established machine-to-machine connection enabled with the latest technology. Further, data regarding the machines and the list of operations to be carried out has to be maintained up to date. With such requirements in an intact state, the industrial management may implement the smart factory concept with ease.

Next to the smart factory (T5), artificial intelligence (T4) has been found as a second choice of I4.0 technology. Artificial intelligence is a technique used for enhancing productivity (Watson *et al.*, 2017). Artificial intelligence plays a crucial role in carrying out the intended operation without any interruption. Any delay or disturbance in data exchange may cause the execution of faulty operations. Industrial management becomes critical to secure the data during the exchange (Turk, 2020). Only a seamless flow of correct and reliable data will assist in executing the intended tasks. For efficient artificial intelligence, industrial management must enhance the IT infrastructure, construct a reliable architecture framework and improve the technological capability (Saturno *et al.*, 2017). Further to implement CPS, the primary requirement is uninterrupted data flow, so it is vital to ensure hyper-connectivity between the machines. Also, a highly skilled workforce is required to ensure this information flow remains reliable with suitable algorithms and programming languages.

5.3 Comparison with earlier studies

The transition towards I4.0 has become inevitable for industrial communities across the world. However, few countries are advancing in their embrace of I4.0, while the remaining countries struggle to adopt I4.0 (Ś lusarczyk and Pypłacz, 2020). Regarding this difference in adopting I4.0, several types of research have been carried out to investigate such differences. This work also adds value to the literature on I4.0.

In this study, willingness to change organization's culture (F7) and capability to expand IT infrastructure (F1) were identified as the most crucial factors in the I4.0 transition. These findings were found to be in line with a similar study carried by Luthra and Mangla (2018) in analysing the challenges faced by the Indian supply chain network. The study highlighted that lacking behind in the technological capability limits the progress of the Indian industrial community in I4.0 adoption. Another study by Wagire *et al.* (2021) emphasizes that the aspiration of I4.0 is pretty high among the Indian industrial community; however, citing the initial capital requirements, the industrial community is hesitant about the transition. From this, it could be well understood that the role of industrial management is crucial to the successful attainment of I4.0. Regarding better I4.0 technological options, the smart factory (T5) has been identified as the ideal choice. This finding was endorsed in a study by Osterrieder *et al.* (2020), which advocated that the smart factory may act as a key construct in the I4.0 transition. The study also highlighted that the industries need to develop a concrete strategy roadmap in establishing the smart factory. Another study by Büchi *et al.* (2020) also indicated that smart factory technology has immense potential in harnessing the benefits of the I4.0 paradigm.

6. Conclusion

The transition towards I4.0 has become essential for all manufacturing sectors, ranging from multinational companies to SMEs. With abundant financial assistance, it looks easy for multinational companies to embrace I4.0. SMEs, on the other hand, are having difficulty implementing I4.0 technology due to a lack of financial resources. Keeping SMEs in mind, the goal of this research is to recommend the optimal I4.0 technology based on the available technological capability. A literature review was used to identify the five most preferred I4.0 technologies. After that, a literature review and interviews with experts were conducted to determine the basic requirements of I4.0 technologies, and 10 critical factors were found. Finally, the fuzzy COPRAS approach was used to suggest the optimal I4.0 technology.

The findings of the research indicate the ability to expand IT infrastructure, ability to change the organization's structure and the ability to analyse key performance indicators as the three most important key factors in the implementation of I4.0 technology. As a result of the findings, management must comprehend the relevance and impact of I4.0 in terms of improving production capabilities. In selecting an optimal I4.0 technology, the research suggests a smart factory as a first choice followed by artificial intelligence and CPS. The transformation of the conventional industrial environment to the smart factory will support industrial management in achieving sustainable manufacturing practice. Selecting a CPS will be essential for industries to improve production capacity and enhance the quality of the products.

6.1 Contributions

The following are some of the research's major contributions: first, this study illuminates the notion of I4.0 in the context of a developing economy where I4.0 expertise is limited. Second, this study analyses the critical factors that must be met in order for I4.0 technologies to be implemented in emerging economies. The feasibility of deploying various selected I4.0 technologies in underdeveloped economies was also examined in this study. Finally, the research offers appropriate I4.0 technologies based on expert responses and a pairwise comparison of critical factors and favoured technologies using fuzzy-COPRAS.

6.2 Implications

It is always a challenge for any kind of industry to solve technical issues as it progresses. However, the level of difficulty does vary among multinational companies and SMEs. In this direction, this study intends to explore the present technological capability of the Indian SMEs with a list of preferred I4.0 technology. This study's factors could serve as a guide for industrial managers and practitioners. Our findings reveal that industries should enhance the ability to expand IT infrastructure to implement I4.0 successfully. It should be noted that the ability to change the organization's structure is crucial in implementing I4.0. Accordingly, the industrial management must revamp its organizational structure (Cimini *et al.*, 2019). Besides improving the IT infrastructure, the industries must also ensure the safety and privacy of data. Developing countries should keep developing awareness and training programmes to pass on knowledge and increase workers' abilities (Brahma *et al.*, 2020). Based on the outcomes, this study offers some implications at both theoretical and managerial levels. Regarding theoretical contribution, this study proposes a framework comprising of fuzzy COPRAS. With fuzzy COPRAS, it is possible to estimate the critical factors' weight importance and to select the ideal alternatives from a list of suggested alternatives. Further, this work attempts to portray the difficulties faced by the SMEs of developing countries with India as a reference. In terms of managerial implications, this study suggests a drastic change in the organizational structure and insists industrial management strengthen technological capability.

6.3 Limitations of the study

Although the current study contributes significantly to the literature on I4.0, it does have several drawbacks. The findings cannot be generalized because the study is limited to Indian SMEs. Because the socio-economic conditions of other countries (Bangladesh, Thailand and Vietnam) may differ, caution should be exercised when applying the study's findings. In addition, the factors revealed in this study were based on a literature analysis and the opinions of experts. Another constraint is the number of experts who were contacted. More experts from various industry domains must be gathered and analysed to provide more generalized results. Also, this work has not approached an expert from the government body. However, in future work, experts from the government body may seek to be included as their views may give more detail on the role played by the government in moving towards I4.0.

6.4 Future scope

Only the importance of the essential factors for the application of I4.0 technology was considered in this study. The majority of the factors are connected, according to the findings. Hence, a future study using the DEMATEL and interpretative structural model technique may reveal the factors' hierarchical and contextual relationship. Other than the fuzzy concept, grey and Bayesian concepts could be used to evaluate the factors. Carrying a future study with a comparison of two or more developing countries may improve generalizability.

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Appendix

Survey questionnaire

Part A: Basic information

Please tick ☑ any one of the choices for the following questions:

1. How will you categorise your manufacturing organization?

- ☐ Small and medium sized enterprises (SMEs)
- ☐ Large scale industries

2. What is the approximate annual turnover of your organization?

- ☐ Less than or equal to 100 crore
- ☐ 101 - 150 crore
- ☐ Above 150 crore

3. Is there currently any kind of automation used in your organization?

- ☐ Yes
- ☐ No

4. What kind of ownership?

- ☐ Sole proprietorship
- ☐ Dual proprietorship
- ☐ Multiple stakeholders

Part B: Key factors to Industry 4.0 adoption in Indian industrial context

5. Rate the following key factors to Industry 4.0 adoption using 5-point Likert's scale (1-not important, 2-somewhat important, 3-important, 4-very important, 5-extremely important) (Please select only one in each row).

S. No	Key factors to Industry 4.0 adoption	Rating				
		1	2	3	4	5
1	Capability to expand IT infrastructure					
2	Competence to ensure data protection and security					
3	Ability to maintain reliable data					
4	Facility to maintain proper data storage system					
5	Capacity to provide proper training to employees					
6	Readiness to integrate different departments					
7	Willingness to change organization's culture					
8	Potential to reach consensus among the stakeholders					
9	Ability to analyse key performance indicators					
10	Ability to construct standard and reference architecture					
11	If any other, please specify					

Name of the respondent:

Organization:

Position:

Experience:

E-mail:

Thank you very much for answering the questionnaire

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