An empirical analysis of critical factors of Industry 4.0: A contingency theory perspective

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Abstract

The implementation of Industry 4.0 (I4) technologies have gained momentum due to several inherent benefits associated with their adoption. However, the benefits of I4 technologies are yet to be realized to the full potential, specifically in the case of emerging economies. Managers need to focus on certain critical factors for the successful implementation of I4 technologies. Though some studies have proposed factors for implementing I4 technologies, empirical examination of critical factors still lacks in the published literature. This study proposes and empirically analyzes the critical factors for adopting I4 technologies in the following Indian manufacturing industries: electrical/electronics, automotive, textiles, paper and plastics. The key factors across six different categories (organizational, workforce management, external support, technological infrastructure, usage of data and regulations) are examined. Further, the contingency effects of firm size and industry sector are also examined. The results are useful for managers in manufacturing industries as it can help them to understand the key factors for adopting I4 technologies. The results are equally useful for managers who are planning to implement I4 technologies in their firms or are in the early phase of I4 implementation.

Keywords: Industry 4.0; critical success factors; India; manufacturing

1. Introduction

In today's world, manufacturing environment has become very competitive (Caliskan et al., 2020), and there are several factors which are challenging the survival of firms. These factors include efficiency, product quality, responsiveness to change in demand of the customers, etc. (Brousell et al., 2014). The expectations of customers have also increased (Bhatia and Kumar, 2022), as they anticipate innovative and customized products with more responsiveness. To sustain in such an environment, processes adopted by the firms need to be flexible and smart, and can act autonomously and intelligently (Bechtold et al., 2014). In this regard, automation, digitization and connectivity are required for seamless integration of manufacturing systems (Shamsuzzoha et al., 2016; Rashid and Tjahjono, 2016). Industry 4.0 (I4) technologies can aid in digitization, automation and integration of manufacturing systems (Naqvi et al., 2015; Liboni et al., 2019).

I4 is "*a new approach for controlling production processes by providing real-time synchronization of flows and by enabling the unitary and customized fabrication of products*" (Kohler and Weisz, 2016). In I4 environment, production systems are integrated with information & communication technologies (ICT), which leads to the formulation of Cyber-Physical Systems (CPS) (Jeschke et al., 2017). I4 involves CPS and Internet of Things (IoT), which can aid to achieve connectivity in production systems (Li et al., 2012; Queiroz et al., 2020). The enhanced integration provided by I4 technologies can help in improving efficiency (LaValle et al., 2011; Sharma et al., 2020). From the operational viewpoint, I4 technologies can help in the reduction of set-up and processing times, material and labor costs, ultimately increasing the productivity of manufacturing processes (Brettel et al., 2014; Jeschke et al., 2017). Further, I4 technologies can also aid organizations to contribute towards sustainability (Kumar and Bhatia, 2021).

Many manufacturing industries are now going through a transformation with the advent of I4 technologies (Lasi et al., 2014; North et al., 2020). Organizations are re-framing their business models with the implementation of I4 technologies (Wang et al., 2015). The adoption of advanced technologies such as those involved in I4 can be a huge challenge for firms in developing countries such as India (Wagire et al., 2020). Further, as the economies of developing nations are more concentrated towards extraction and commercialization of products, firms in such countries commonly lag behind in the adoption of new technologies as compared to firms in the developed nations (Castellacci, 2008). In this regard, understanding the critical factors for adoption of new technologies becomes essential.

Recently, several studies have been published which have discussed potential critical factors of I4 technologies; however, those studies are conceptual and lack any empirical examination. Therefore, empirical studies which use large scale/survey data are required that can help to examine the critical factors (Koh et al., 2019; Frederico et al., 2020). This study fills the above-stated gap in the literature and tries to empirically understand critical factors for implementing I4 technologies. The study considers twenty-three factors for the implementation of I4 technologies, which are divided into six categories (organizational, workforce management, external support, technological infrastructure, usage of data and regulations). As critical factors can be dependent on a particular context, we further examine the effect of contingency variables, such as firm size and industry sector on the adoption of I4 technologies. The factors are analyzed across five sectors in the Indian manufacturing industry, which include: automotive, electrical / electronics, plastics, textiles and paper.

The Indian manufacturing sector is growing rapidly, and several firms are looking to start their operations in India[1]. The "Make in India" initiative started by the Indian Government intends to increase the share of manufacturing industries to gross domestic product from 16% to 25% by 2022. For example, manufacturing of automobiles showed a cumulative growth rate of 2.36% between 2016 and 2020, with 26.36 million vehicles being manufactured in 2020[2]. The Indian textiles industry is one of the oldest and second-largest textiles exporter. In 2020, it contributed about 13% to the industrial output. The Indian paper industry accounts for the production of 4% of the world's paper[3]. Several Indian firms have already begun transition towards I4; however, there is still a long way towards complete transformation. Therefore, to cope with the growing competition and demand, it is imperative that Indian manufacturing firms need to implement I4 technologies in the best possible way.

In nutshell, this study has the following objectives:

1. Identification of critical factors for implementing I4 technologies
2. Empirical analysis of critical factors in the five Indian manufacturing sectors (automotive, electrical / electronics, plastics, textiles and paper)
3. Understand the effect of contingency factors (firm size and industry) on critical factors

The remaining paper is structured as follows. Section 2 discusses literature on I4 technologies, and recent studies on critical factors of I4 technologies. Section 3 discusses critical factors of I4 technologies considered in this study. In Section 4, methodology is presented; Section 5 presents

[1]https://www.ibef.org/industry/manufacturing-sector-india.aspx, accessed on 2-Jan-2021
[2] https://www.ibef.org/industry/india-automobiles.aspx, accessed on 2-Jan-2021
[3] http://ipma.co.in/overview/, accessed on 2-Jan-2021

findings; Section 6 provides implications for practice and theory; finally, paper concludes with Section 7 that presents conclusions.

2. Literature review

2.1 Concept of I4 technologies

I4 is one of the trending area, both in academic as well as in professional world (Liao et al., 2017; Queiroz et al., 2020; Frederico et al., 2020). The focus of I4 is on the implementation of digital technologies which aid in collection and analysis of real time data, and provide useful information to the manufacturing systems (Wang et al., 2016). I4 integrates the use of big data, IoT and Artificial Intelligence (AI) (Tjahjono et al., 2017), and has tremendous potential for firms in achieving economic and social benefits. The integration of digital equipment in the production environment by ICT, robots, electronic devices, etc. leads to computer integrated manufacturing systems, also known as CPS. CPS is "the conjunction of the physical and digital worlds by creating global networks for businesses that integrate their technology, warehousing systems, and production facilities" (Shafiq et al., 2015). CPS facilitate manufacturing systems to be changeable and modular, necessary for manufacturing highly customized products in mass production environment (Kagermann et al. 2013).

I4 is based on the concept of advanced / smart manufacturing, where processes are automatically adjusted according to the changes in conditions for different types of products (Schuh et al., 2017). This helps to increase productivity, flexibility, quality and production of customized products at a larger scale with better consumption of resources (Dalenogare et al., 2018). I4 also accounts for supply chain integration and information exchange, synchronizes suppliers and manufacturing facilities, thereby reducing distortion of information and delivery time (Ivanov et al., 2016). The integration further drives organizations to pool resources in collaborative manufacturing.

2.2 Studies on critical factors of I4

Recently, a number of studies have discussed about the potential critical factors for implementing I4 technologies. The list of studies and contribution of our study in comparison to other studies is given in Table 1.

Table 1. Studies on critical factors of I4

Study	**Objective**	**Methodology**	**Industry**
Fatorachian and Kazemi (2018)	Discusses key technological enablers of I4 implementation	Review	Manufacturing
de Sousa Jabbour et al. (2018)	Proposed eleven critical success factors for I4 implementation to achieve sustainability	Review	Manufacturing
Bag et al. (2018)	Discussed factors of I4 as a driver of sustainability	Review	Manufacturing
Sony and Naik (2019a)	Proposed ten key lessons for managers during I4 implementation	Review	Manufacturing
Moeuf et al. (2020)	Investigated critical success factors of I4	Delphi study	Small and medium enterprises
Luthra et al. (2020)	Identified causal relations among nine critical factors of I4 as a driver for sustainability	Grey-DEMATEL	Manufacturing
Sony and Naik (2019b)	Proposed ten critical success factors for I4 implementation	Review	Manufacturing
Sony and Naik (2019c)	Proposed six key factors for assessing readiness of I4 implementation	Review	Manufacturing
Yadav et al. (2020)	Examined five enablers for I4 technologies	Best Worst method	Manufacturing
Narula et al. (2020)	Identified technological drivers	Empirical	Manufacturing

Pozzi et al. (2021)	Identified adoption and contextual factors	Case study	Manufacturing
Our study	Empirically examine the critical factors in five manufacturing sectors	Empirical	Five manufacturing sectors

It can be seen from Table 1 that most of these studies are review / conceptual in nature. Some studies have examined critical factors using the case study approach (Luthra et al., 2020; Moeuf et al., 2020; Yadav et al., 2020; Pozzi et al., 2021). Luthra et al. (2020) analyzed nine critical factors for I4 implementation in achieving sustainability using grey-DEMATEL technique. However, the study considered limited factors and considered input of only five experts in the application of grey-DEMATEL technique. Using small sample size limits the generality of results, which can reflect the state of entire population (Merriam, 1985). Further, grey-DEMATEL only establishes causal relations among the factors and does not ranks the factors. Moeuf et al. (2020) examined critical factors using the inputs from twelve experts, which also included academicians. Thus, it is evident that more studies are required which consider an exhaustive list of factors and use large scale / empirical data for analyzing the critical factors (Koh et al., 2019). It should also be noted that these two studies have not taken into consideration the effect of any contingency factors. Recently, Narula et al. (2021) empirical examined the technological critical factors; however, their study neither focused on other factors nor considered the effect of contingency factors.

In this study, we consider twenty-three factors for I4 implementation, divided across the six categories (organizational, workforce management, external support, technological infrastructure, usage of data and regulations). The twenty-three factors are firstly identified by thorough literature review. Then, to operationalize the constructs, we discussed the identified factors with five industry experts and two academicians. Then, a survey is conducted in Indian manufacturing industry to collect data for examining the critical factors. We have also considered the firm size and industry sector as the two contingency factors.

3. Critical factors for I4 implementation

According to Boynton and Zmud (1984), critical factors are "those few things that must go well to ensure success." These are "the few key areas where things must go right for the business to flourish. If results in these areas are not adequate, then the organization's efforts for the period will be less than desired" (Rockart, 1979). While planning for strategies to achieve desired goals, decision making and planning becomes difficult due to the presence of a large number of factors. The identification of critical factors is essential for prioritizing of specific valuable resources, specifically in resource-constrained contexts (Mittal and Sangwan, 2014). Next, we discuss critical factors for I4, which are then empirically examined.

3.1 Organizational

Firms can be influenced by organizational factors when implementing I4 technologies. The organizational factors include support from top management, leadership style, culture and teamwork. The support from top managers is recognized as necessary for managing change (Young and Jordan, 2008), and can help in successful integration of I4 technologies. The style of leadership can also influence the implementation of emerging technologies in firms (Shao et al., 2017). Transformational leaders can motivate and inspire employees, which can result in smooth transformation and bring desired results (Politis, 2001). I4 requires a lot of changes, such as acquiring new skills and changes in the way of working. Resistance to change is one of the barriers to implementing I4 technologies. Therefore, a culture that is open to change can be crucial in the adoption of I4 technologies. As I4 involves integration of systems horizontally and vertically, teamwork is another organizational factor as employees must work collectively as a team towards achieving the specified goals (Stock and Seliger, 2016).

3.2 Workforce management

Workforce management is mainly related to imparting skills and knowledge to employees about I4 technologies, communication with employees on I4 implementation and empowering them to have autonomy and be innovative (Boudrias et al., 2009). As implementing I4 technologies requires employees to possess new skills and knowledge, they need to be provided with training which can help them to acquire expertise (Waibel et al., 2017; Kazancoglu, and Ozkan-Ozen, 2018). Top management also needs to have frequent communication with employees regarding the objectives of I4 implementation. This can also help in agility as well as mutual adjustments, required for implementing I4 technologies. Employee empowerment can also contribute to agility necessary for working in the I4 era.

3.3 External support

The implementation of I4 technologies requires technical competencies which can support exploitation of technologies. Experts have recommended that support from academicians and consultants can be useful as it can aid in integrating knowledge in the organizations. Further, as I4 requires implementing new technologies and equipment, financial support from government and financial institutions can also play a significant role in successful execution.

3.4 Technological infrastructure

Technological infrastructure includes information technology (IT) equipment such as cloud computing, big data, industrial internet, etc. (Fatorachian and Kazemi, 2018; Kamble et al., 2018). The synchronized communication of these technologies is crucial in the I4 era. Further, integrating industrial Internet with the machinery will result in smart process as well as products, which can communicate and interact with machines and enterprise systems. Thus, investments in technological infrastructure and IT facilities is a key factor for successful adoption of I4 technologies.

3.5 Usage of data

Data is considered as a key factor in I4 era (Moeuf et al., 2020), and comprehensive collection and analysis of data can bring forth the required performance outcomes, such as optimizing the tasks, prioritizing of production orders, etc. (Lee et al., 2015). Moeuf (2020), conducted a Delphi study in the context of SMEs and put forth the importance of data as well as simulation tools for generating the required results. The authors' further found that firms which exploited the data have lesser chances of failures while implementing the I4 technologies.

3.6 Regulations

Government regulations can facilitate the smooth implementation of I4 technologies. These may include regulations related to cybersecurity, and removal of unfair trade barriers (for improving exports and imports) (Bag et al., 2018). In I4 era, robots will replace many of the activities performed by humans; thus, this may cause a large number of job losses. Governments also need to form legislations related to employment, which can help to avoid such substantial job losses.

Finally, improved IT standards need to be formed for reducing potential risks and improving overall system security, as I4 involves running the system primarily with information technologies (Benias and Markopoulos, 2017; Sung, 2018). Table 2 summarizes the key factors and sub-factors associated with each factor.

Table 2. Critical factors for I4

Critical factors	**Code**	**References**
Organizational		
Support of top management	O1	Shamim et al. (2016), Savtschenko et al. (2017), Bag et al. (2018), Sony and Naik (2019c)
Transformational leadership style	O2	Shao et al. (2017), de Sousa Jabbour et al. (2018), Bag et al. (2018), Schroeder et al. (2019)
Organizational culture which is open to change	O3	Jabbour and Jabbour (2016), Bag et al. (2018), Moeuf et al. (2020)
Teamwork for achieving objectives in organizations	O4	Jabbour and Jabbour (2016)
Workforce management		
Imparting proper training and skills to the employees	W1	Lin et al. (2017), Waibel et al. (2017), Bag et al. (2018), Moeuf et al. (2020), Luthra et al. (2020)
Communication with employees regarding I4 implementation	W2	Moeuf et al. (2020), Bhatia and Kumar (2020)
Empowering employees to enable them to have autonomy and be innovative	W3	de Sousa Jabbour et al. (2018), Bhatia and Kumar (2020)
External support		
Strong support from government	E1	Hermann et al. (2016), Bonilla et al. (2018), Lin et al. (2018)
Support by academic researchers	E2	Bag et al. (2018), Moeuf et al. (2020)
Support by consultants	E3	Moeuf et al. (2020)
Availability of financial resources for I4 implementation (E4)	E4	Bag et al. (2018), Moeuf et al. (2020)
Technological infrastructure		
Investment in the latest equipments required for I4	T1	Bag et al. (2018), Sony and Naik (2019c), Luthra et al. (2020)
Implementation of new IT technologies such as big data, etc.	T2	Moeuf et al. (2018), Sony and Naik (2019c), Lin et al. (2018), Bag et al. (2018)

Usage of Industrial internet	T3	Fatorachian and Kazemi (2018)
Implementation of CPS	T4	Yen et al. (2014), Sony and Naik (2019c)
Creation of smart networks (including cloud computing)	T5	Fatorachian and Kazemi (2018)
Integration of industrial internet with production machines	T6	Fatorachian and Kazemi (2018), Sony and Naik (2019c)
Usage of data		
Appropriate IT infrastructure in organizations to capture, store and analyze data	U1	Moeuf et al. (2020), Luthra et al. (2020)
Comprehensive collection and usage of data by the organization	U2	Brettel et al. (2014), Rüßmann et al. (2015), Moeuf et al. (2020)
Exploitation of data and simulation tools for decision making	U3	Bag et al. (2018), Moeuf et al. (2020)
Regulations		
IT security and standards related to I4	R1	Bag et al. (2018)
Government legislations on cyber security	R2	Bag et al. (2018)
Labor and employment laws for safeguarding human essence in digital era	R3	Bag et al. (2018)

3.7 Critical factors and contingency theory

In accordance with the contingency theory, there are no best processes or ways which can lead firms to success (Donaldson, 2001). Contingencies are those characteristics that make each situation different from others (Netland, 2016). The processes or practices to be implemented depend on the characteristics of an organization and the context in which it functions (Galbraith, 2007). Therefore, for critical factors to be effective, they should be tailored according to the particular environment. If contingencies associated with an organization are not considered in the analysis, it can result in implausible conclusions (Shah and Ward, 2003). E.g. White et al. (1999) found that in United States, larger firms implemented just in time practices more often than smaller firms. Such conclusions are meaningless with the consideration of firm size (contextual variable).

Marodin and Saurin (2013) called for "investigations on how the company's context influences the success factors". Therefore, we also address this gap in literature and contribute by examining the effect of contingencies on critical factors. We use contingency approach as suggested by Sousa and Voss (2008), and consider two contextual variables (firms size and type of industry), which may affect the adoption of I4 technologies. We briefly discuss the two contingency variables below:

Firm size: The size of an organization can have a crucial role in the use of certain practices (Sousa and Voss, 2008). Researchers have proposed that structural inertial forces may inhibit implementation of certain practices in larger organizations (Hannan and Freeman, 1984). Smaller size of certain firms enables then to have a quicker turnaround time than larger firms (Netland, 2016). On the other hand, small and medium firms lack organizational and financial resources, which larger firms generally possess for implementing certain practices. Therefore, we argue that firm size need to be considered as a contextual variable in evaluation of critical factors for I4 implementation. In this regard, we investigate the following:

H1: *Do critical factors for I4 implementation depend on firm size?*

Type of industry: Critical factors for I4 adoption are expected to differ with the kind of manufacturing sector. This is due to several reasons: manufacturing of different products and use of different processes and technologies. Delery and Doty (1996) suggested that "findings need to be validated in other industries to rule out the industry as an important contingency factor". In line with this suggestion, many studies have considered the contingency effect of the type of industry (Ahmad and Schroeder, 2003; Lai and Cheng, 2003; Abdulrahman et al., 2014). Thus, we expect that critical factors for each industry may differ in the implementation of I4 technologies. In this regard, we investigate the following:

H2: *Do critical factors for I4 implementation differ depending on the type of industry?*

4. Methodology

4.1 Development of questionnaire

A survey-based approach is used for the purpose of collecting the data. In this regard, a questionnaire is prepared that includes factors for adoption of I4 technologies. The factors are identified from an extensive review of published literature in I4 technologies. To ensure content validity, the questionnaire is pre-tested with industry experts and academicians. The questionnaire was iteratively modified to ensure an enhanced level of readability and understanding for respondents. The final version of the questionnaire has two sections. The first section aims to capture demographics of respondents and the corresponding firms. The second section aims to capture importance of factors for implementing I4 technologies in Indian manufacturing industries. The importance of each factor is captured using a 5-point Likert scale (1: "Not important"; 5: "Extremely important"). A brief introduction about I4 technologies was also given to each potential respondent at the beginning of the questionnaire.

4.2 Data collection

The study aims to evaluate the critical factors for implementing the I4 technologies in Indian manufacturing industries. We included the following five manufacturing sectors: automotive, electrical, electronics, plastics, textiles, and paper. The consideration of more number of sectors helps to generalize the results. Further, we also classified critical factors based on the industry sector to test for any contingency effects (Abdulrahman et al., 2014). For collecting data, we took the service of data collection firm, *NexGen Market Research*. The firm employed convenient sampling for data collection, and have used the list of prospective respondents from the already created proprietary database. From complete database, 390 professionals were requested to complete the survey questionnaire. In total, we received 154 completed and valid responses for analysis, a response rate equal to 39.4%. This response rate is considered acceptable in survey studies (Malhotra and Grover, 1998). The demographics of firms and respondents are given in Table 3.

Table 3. Profile of respondents and corresponding firms

Characteristics	**Total**	**Percentage (%)**
Rank		
Top management	33	21%
Middle management	80	52%
Lower management	41	27%
Experience		
Less than 5 years	18	12%
5 - 10 years	59	38%
10 - 15 years	54	35%
15 - 20 years	15	10%
More than 20 years	8	5%
Industry		
Automotive	48	31%
Electrical / Electronics	36	23%
Plastics	21	14%
Textiles	23	15%
Paper	26	17%
Years since establishment		
Less than 5 years	1	1%
5 - 10 years	45	29%

10 - 15 years	27	18%
15 - 20 years	16	10%
More than 20 years	65	42%
Number of employees*		
Less than or equal to 500	86	56.57%
More than 500	66	43.42%

*Two firms did not report the firm size

4.3 Data analysis technique

The critical factors for each category are evaluated using confirmatory factor analysis (CFA). The similar approach has been used by Abdulrahman et al. (2014) to analyze critical barriers to reverse logistics for local and foreign firms in China. However, before proceeding with CFA, we performed several tests that are pre-requisites for carrying out CFA. Firstly, Kaiser-Meyer-Olkin (KMO) test is done to measure the sampling adequacy of collected data. For each category, KMO value is found to be more than 0.5, which is considered as acceptable (Kaiser, 1974). Then, Bartlett test of sphericity (BTS) is done to determine if determinant of the correlation matrix is significantly different from 1. BTS signifies that all for all the categories of factors, correlation matrices are not identity matrices. Therefore, CFA can be used to analyze the collected data.

5. Research findings

The results of CFA for all the manufacturing sectors are given in Table 4. It provides statistics on how each sub-factor loads on its categorized factor (organizational, workforce management, external support, technological infrastructure, usage of data and regulations), variance explained and cronbach’s alpha. Each category has variance explained value greater than the minimum recommended value of 50% (Fornell and Larcker, 1981) and cronbach alpha value more than 0.60 (Hair et al., 2005).

Table 4. CFA of critical factors for I4 technologies (All industries)

Critical factors	Loading	Cronbach's alpha	Variance explained
Organizational (KMO = 0.73; BTS sig. = 0.000)		0.73	55.22%
Commitment and support from top management	0.72		
Transformational leadership	0.81		
Organizational culture which is open for change	0.71		
Teamwork for achieving the objectives	0.72		
Workforce management (KMO = 0.66; BTS sig. = 0.000)		0.68	60.97%
Providing training to employees	0.78		
Communication with employees	0.81		
Employee empowerment	0.75		
External support (KMO = 0.74; BTS sig. = 0.000)		0.77	59.34%
Government support	0.74		
Support from academic community	0.85		
Support from consultants	0.73		
Financial support	0.76		
Technological infrastructure (KMO = 0.84; BTS sig. = 0.000)		0.80	50.68%
Investment in the latest equipments	0.69		
Implementation of IT facilities such as cloud computing, etc.	0.71		
Industrial internet for I4 implementation	0.76		
Implementation of CPS	0.73		
Creation of smart networks	0.73		
Integration of industrial internet and production machines	0.65		
Usage of data (KMO = 0.66; BTS sig. = 0.000)		0.70	62.65%
Comprehensive collection of data	0.76		

Appropriate IT infrastructure to capture, store and analyze data	0.83		
Exploitation of data and simulation tools	0.78		
Regulations (KMO = 0.59; BTS sig. = 0.000)		0.60	55.79%
IT security and standards related to I4	0.77		
Government legislations on cyber security	0.64		
Labor and employment laws for safeguarding human essence in digital era	0.83		

Then, we categorized the firms into two groups based on firm size. However, there is no universal standard regarding small and large organizations (Sunder and Prashar, 2020). This is because each country follows a different convention regarding this context. We categorized the firms into two categories. The first category of firms has less than or equal to 500 employees, and second category of firms has more than 500 employees. The respondents from two of the firms did not reported the firm size, therefore two responses are dropped from this analysis. CFA is conducted for these two groups to examine any differences in critical factors. The results are shown in Tables 5 and 6.

Table 5. CFA of critical factors for I4 technologies (Firm size less than or equal to 500) (n=86)

Critical factors	**Loading**	**Cronbach's alpha**	**Variance explained**
Organizational (KMO = 0.58; BTS sig. = 0.000)		0.67	60.83%
Commitment and support from top management	0.53		
Transformational leadership	0.76		
Organizational culture which is open for change	0.54		
Teamwork for achieving the objectives*	-		
Workforce management (KMO = 0.65; BTS sig. = 0.000)		0.66	60.05%
Providing training to employees	0.79		
Communication with employees	0.81		
Employee empowerment	0.72		

External support (KMO = 0.69; BTS sig. = 0.000)		0.70	52.99%
Government support	0.65		
Support from academic community	0.79		
Support from consultants	0.68		
Financial support	0.78		
Technological infrastructure (KMO = 0.74; BTS sig. = 0.000)		0.70	52.66%
Investment in the latest equipments*	-		
Implementation of IT facilities such as cloud computing, etc.	0.74		
Industrial internet for I4 implementation	0.78		
Implementation of CPS	0.68		
Creation of smart networks	0.70		
Integration of industrial internet and production machines*	-		
Usage of data (KMO = 0.63; BTS sig. = 0.000)		0.62	57.41%
Comprehensive collection of data	0.79		
Appropriate IT infrastructure to capture, store and analyze data	0.80		
Exploitation of data and simulation tools	0.68		
Regulations (KMO = 0.50; BTS sig. = 0.000)		0.60	71.35%
IT security and standards related to I4	0.84		
Government legislations on cyber security	-		
Labor and employment laws for safeguarding human essence in digital era	0.84		

Table 6. CFA of critical factors for I4 technologies (Firm size more than 500) (n=66)

Critical factors	**Loading**	**Cronbach's alpha**	**Variance explained**
Organizational (KMO = 0.76; BTS sig. = 0.000)		0.79	61.56%
Commitment and support from top management	0.74		
Transformational leadership	0.82		
Organizational culture which is open for change	0.74		
Teamwork for achieving the objectives	0.83		

Workforce management (KMO = 0.67; BTS sig. = 0.000)		0.71	63.10%
Providing training to employees	0.78		
Communication with employees	0.82		
Employee empowerment	0.79		
External support (KMO = 0.76; BTS sig. = 0.000)		0.83	66.82%
Government support	0.83		
Support from academic community	0.91		
Support from consultants	0.77		
Financial support	0.76		
Technological infrastructure (KMO = 0.84; BTS sig. = 0.000)		0.86	58.20%
Investment in the latest equipments	0.79		
Implementation of IT facilities such as cloud computing, etc.	0.75		
Industrial internet for I4 implementation	0.78		
Implementation of CPS	0.78		
Creation of smart networks	0.77		
Integration of industrial internet and production machines	0.71		
Usage of data (KMO = 0.64; BTS sig. = 0.000)		0.78	69.44%
Comprehensive collection of data	0.73		
Appropriate IT infrastructure to capture, store and analyze data	0.89		
Exploitation of data and simulation tools	0.88		
Regulations (KMO = 0.57; BTS sig. = 0.000)		0.60	60.83%
IT security and standards related to I4	0.75		
Government legislations on cyber security	0.71		
Labor and employment laws for safeguarding human essence in digital era	0.87		

Next, we compare overall categories of critical factors across two groups of firms and check whether there are significant differences in factors between the two groups. The results are shown in Table 7. It is observed that though there are minor differences in mean values between two group of firms, the differences are not statistically significant, as indicated by t-statistics. Overall, mean values of firms with larger size are slightly greater, which suggests that they are giving slightly higher importance to these factors towards I4 implementation, though no statistical differences are observed. Therefore, we can conclude that critical factors for I4 implementation do not depend on firm size.

Table 7. Comparison of critical factors for two groups of firms based on size

Critical factors	**Mean1 (n=86)**	**Mean2 (n=66)**	**T Sig.**
Organizational	3.77	3.85	0.499
Workforce management	3.79	3.88	0.454
External support	3.80	3.87	0.591
Technological infrastructure	3.70	3.74	0.715
Usage of data	3.81	3.92	0.379
Regulations	3.73	3.89	0.151

We then compared critical factors in five manufacturing sectors. The analysis is performed for each category of factor and sub-factors for all the five manufacturing industries. To evaluate if significant differences exist in critical factors among five industries, a one-way analysis of variance (ANOVA) is performed. The analysis for different sub-factors and categories of factors are given in Table 8 and Table 9, respectively. It is observed from table 8 that there are significant differences in organizational and technological infrastructure sub-factors. Further, this finding is also reflected in the overall evaluation of statistical differences in category of factors (Table 9). The analysis shows statistical differences in organizational and technological infrastructure. The analysis also shows statistical difference on usage of data among five manufacturing sectors, though no differences in its sub-factors is observed. Therefore, we confirm that critical factors for I4 implementation do depend on the industry sector.

Table 8. Comparison of sub-factors in five industrial sectors

Critical factors	**Automotive**	**Electrical / Electronics**	**Plastics**	**Textiles**	**Paper**	**F**	**Sig.**
E1	3.83	3.83	3.9	3.39	3.81	1.118	0.35
E2	3.88	3.75	3.67	3.48	3.77	0.771	0.545
E3	4.04	3.89	3.62	3.57	3.81	1.497	0.206
E4	4.19	3.92	4.14	3.83	3.73	1.42	0.23
O1*	4.04	3.75	4.05	3.52	3.62	2.037	0.092
O2**	3.69	3.94	4.05	3.26	3.77	2.811	0.028
O3**	3.96	4.25	3.9	3.48	3.81	2.776	0.029
O4	3.73	3.86	3.9	3.48	3.73	0.776	0.543
R1	3.77	3.92	3.9	3.57	3.88	0.642	0.633
R2	3.94	3.64	3.86	3.48	3.77	1.183	0.321
R3	3.92	4.06	3.76	3.61	3.65	1.258	0.289
T1**	3.85	3.67	3.62	3.26	4.04	2.728	0.031
T2*	3.98	3.78	3.62	3.52	4.12	2.009	0.096
T3	3.75	3.75	3.33	3.3	3.69	1.611	0.174
T4**	3.9	3.97	3.52	3.35	3.77	2.654	0.035
T5*	3.79	3.64	3.81	3.17	3.73	2.375	0.055
T6	3.92	3.75	3.76	3.39	3.65	1.355	0.252
U1	4.35	4.08	4.14	3.61	4.08	1.767	0.138
U2	3.81	3.83	3.52	3.43	3.92	1.53	0.196
U3	3.92	3.72	3.71	3.43	3.81	1.103	0.357
W1	3.92	3.92	3.95	3.65	4.12	0.805	0.524
W2	3.94	3.72	3.9	3.65	3.77	0.519	0.722
W3	3.85	3.97	3.57	3.48	3.81	1.368	0.248

**p<0.05; p<0.01

Table 9. Comparison of critical factors in five industrial sectors

Critical factors	**Automotive**	**Electrical / Electronics**	**Plastics**	**Textiles**	**Paper**	**F**	**Sig.**
Organizational**	3.85	3.95	3.98	3.47	3.73	2.697	0.033
Workforce management	3.90	3.87	3.81	3.59	3.90	0.820	0.515
External support	3.98	3.85	3.83	3.57	3.78	1.410	0.233
Technological** infrastructure	3.86	3.76	3.61	3.33	3.83	3.290	0.013
Usage of data*	4.03	3.88	3.79	3.49	3.94	2.025	0.094
Regulations	3.88	3.87	3.84	3.55	3.77	1.028	0.395

**p<0.05; *p<0.1

To identify significant factors in different manufacturing sectors, descriptive statistics are used for discriminating most and least influential factors because of heterogeneous sample size within each manufacturing sector. Though there are minor differences in mean values within each manufacturing sector, the factor with highest mean value is stated as most important and the factor with lowest mean value is stated as least important (Table 10). The similar method has also been used by Abdulrahman et al. (2014) to categorize critical barriers to reverse logistics practices in Chinese manufacturing industries.

Table 10. Synthesis of principal critical factors in industries

Critical factors	**Least / Most influencing**	**Automotive**	**Electrical / Electronics**	**Plastics**	**Textiles**	**Paper**
Organizational	Least influencing	Transformational leadership style	Support of top management	Support of top management, Organizational culture which is open to change	Transformational leadership style	Support of top management
	Most influencing	Support of top management	Organizational culture which is open to change	Transformational leadership style, Teamwork for achieving objectives in organizations	Support of top management	Organizational culture which is open to change
Workforce management	Least influencing	Empowering employees to enable them to have autonomy and be innovative	Communication with employees regarding I4 implementation	Empowering employees to enable them to have autonomy and be innovative	Empowering employees to enable them to have autonomy and be innovative	Communication with employees regarding I4 implementation
	Most influencing	Communication with employees regarding I4 implementation	Empowering employees to enable them to have autonomy and be innovative	Imparting proper training and skills to the employees	Imparting proper training and skills to the employees, Communication with employees regarding I4 implementation	Imparting proper training and skills to the employees

External support	Least influencing	Strong support from government	Support by academic researchers	Support by consultants	Strong support from government	Availability of financial resources for I4 implementation
	Most influencing	Availability of financial resources for I4 implementation	Availability of financial resources for I4 implementation	Availability of financial resources for I4 implementation	Availability of financial resources for I4 implementation	Strong support from government, Support by consultants
Technological infrastructure	Least influencing	Usage of Industrial internet	Creation of smart networks	Usage of Industrial internet	Creation of smart networks	Integration of industrial internet with production machines
	Most influencing	Implementation of new IT technologies such as big data, etc.	Implementation of CPS	Creation of smart networks	Implementation of new IT technologies such as big data, etc.	Implementation of new IT technologies such as big data, etc.
Usage of data	Least influencing	Appropriate IT infrastructure in organizations to capture, store and analyze data	Exploitation of data and simulation tools for decision making	Appropriate IT infrastructure in organizations to capture, store and analyze data	Appropriate IT infrastructure in organizations to capture, store and analyze data, Exploitation of data and simulation tools for decision making	Exploitation of data and simulation tools for decision making

	Most influencing	Exploitation of data and simulation tools for decision making	Comprehensive collection and usage of data	Comprehensive collection and usage of data	Comprehensive collection and usage of data	Comprehensive collection and usage of data
Regulations	Least influencing	IT security and standards related to I4	Government legislations on cyber security	Labor and employment laws for safeguarding human essence in digital era	Government legislations on cyber security	Labor and employment laws for safeguarding human essence in digital era
	Most influencing	Government legislations on cyber security	Labor and employment laws for safeguarding human essence in digital era	IT security and standards related to I4	Labor and employment laws for safeguarding human essence in digital era	IT security and standards related to I4

6. Managerial implications

The results offer several implications for managers in manufacturing industries, who are planning or have begun the implementation of I4 technologies. We discuss about each factor below to provide relevant managerial insights.

Organizational factors: The analysis revealed that transformational leadership is the most critical organizational factor for implementing I4 technologies. The finding resonates with Yadav et al. (2020) and Luthra et al. (2020), who found management support to be one of the crucial factor. It is evident that implementation of I4 technologies requires substantial investments, changes in the way people work. etc. Therefore, this change has to begin at top leadership and the role of top leaders becomes essential; thus, it is imperative that they take lead, encourage I4 transformation by motivating employees, and bringing appropriate changes. Considering the effect of firm size, it is observed that both the categories of firms believe that transformational leadership is important. However, larger firms also equal emphasize the importance of teamwork. The reason may be that in larger firms, teams comprise people from various departments; thus coordination and a consensus among team members especially when working with the new technologies is a challenge (DeBrusk, 2018). Overall, we also observe that textiles and paper industries regard organizational factors as less important than other industries.

Workforce management: The key factors in this category include: communication with employees and providing training to employees. Communication with employees can aid managers in getting ideas from employees on smooth transformation in I4 era and also help them to understand about expectations of employees. In this way, managers can find a workaround to remove any barriers that hinder I4 implementation. Training is necessary for employees as there are several new technologies in I4, and having appropriate knowledge is necessary to work with such technologies (Jabbour and Jabbour, 2016; Margherita and Braccini, 2020). The significance of training employees for I4 is also identified by Moeuf et al. (2020) in smaller firms. Large firms also consider employee empowerment as an important factor. This is because, in larger firms, there are established procedures which employees have to adhere to strictly, and there is less room for change, unlike smaller firms. However, in I4 era, employees need to be empowered to make quick decisions, be innovative and make any appropriate changes according to the situation (de Sousa Jabbour et al., 2018). Based on the industry sector, there are no significant differences among the industries regarding workforce management. All the industries equally emphasize the importance of workforce management.

External support: The key factor in external support is support from the academicians. The finding is similar to Moeuf et al. (2020), who found that support of academics is important for transferring knowledge. The smaller firms also emphasize the importance of external financial support. This is quite evident as such firms generally have limitations about resources and finance (Dey et al. 2020); thus, they also consider financial support as a critical factor for I4. In this respect, governments need to provide adequate financial support in the form of loans at lower rates or any possible subsidies so that smaller firms can also move towards implementation of I4 technologies.

Technological infrastructure: The key technological factors include: Industrial internet, implementation of CPS and creation of smart networks. Gillani et al. (2020) also found that adoption of relevant technologies is important for successful digitization. However, Yadav et al.

(2020) found technological enablers are less important as compared to other factors. The industrial internet is the foremost technological requirement, as evident from the analysis of this study (Fatorachian and Kazemi, 2018; Luthra et al., 2020). It acts as a centre of connectivity among devices, systems and machines (Thramboulidis, 2015). Thus, managers should ensure that high-speed internet systems are installed. CPS can drive effective communication among machines, humans and products (Einsiedler, 2013).

Usage of data: The analysis indicates IT infrastructure to capture, store and analyze data and exploitation of data and simulation tools as crucial variables. Managers need to have all the necessary tools in place, and they make use of these tools to get relevant insights (Moeuf et al., 2020; Gillani et al., 2020). In this case, it becomes essential that employees engaged in data analytics know about the usage of such tools and what related ideas to draw from data. Managers need to make ensure employees are given relevant training to maximize the benefits of using such tools. The smaller firms perceive a comprehensive collection of data as an important variable in this category. A justification for this may be that smaller firms are not involved in extensive data collection as compared to larger firms, primarily due to lack of appropriate resources. Thus, they emphasize its importance and consider this as a more important variable for I4 implementation, as compared to larger firms who already have data, and therefore consider tools for concluding as more important.

Regulations: The analysis reveals IT security and standards related to I4 and labour and employment laws for safeguarding human essence in the digital era to be the key variables in this category. Both the categories of firms also agree with the importance of these sub-factors. In I4 era, robots are expected to replace much of the work done by humans, which may result in unemployment. Therefore, laws need to be framed by governments to protect human quotas (Bag et al., 2018). Governments also need to develop the framework so that unemployed people can be supported (Sung et al., 2018). The sustainability of I4 technologies is entirely based on adequate security protocols related to I4 because the system has to interact with smart objects. Further, the privacy risks posed by intelligent objects needs to be addressed.

6.1 Theoretical implications

Our work contributes to the theory by identifying the key factors for implementing I4 technologies and empirically examining the critical factors in multiple manufacturing industries. The earlier studies in this are conceptual based on literature review or based on case studies. Our study proposes and empirically examines the critical factors for implementing I4 technologies in five manufacturing industry sectors in India. Further, based on the contingency theory, our study adds to the extant literature by examining the effect of two contingent factors – firm size and industry type on critical factors for I4 technologies. The study paves way for future research in the area of critical factors for implementing I4 technologies.

7. Conclusions and future directions

I4 technologies are gaining increased attention due to several benefits associated with their implementation. These benefits include improved operational performance, increased responsiveness, customization of products, improved quality and productivity, etc. Many organizations are still planning or are in the initial phases of implementation of I4 technologies. Though some studies have discussed the potential critical factors, empirical examination of these factors still lacks in the literature. In this study, we have empirically examined critical factors for I4 with respect to the following six categories: organizational, workforce management, external support, technological infrastructure, usage of data and regulations. The critical factors are analyzed in the following Indian manufacturing industries: automotive, electrical / electronics, plastics, textiles and paper. Besides empirically analyzing the critical factors, we also put light on critical factors based on firm size and compare the critical factors across five manufacturing sectors. The results show that critical factors of I4 technologies do not depend on the firm size. Further, organizational and technological infrastructure factors do show statistical difference between the type of industries. The findings can be useful for managers in the manufacturing firms who are planning to implement I4 technologies or who are in beginning stages of the implementation of I4 technologies. The managers can put focus on the most critical factors during the implementation, rather than putting focus on all the factors.

The study has a few limitations. Firstly, in this study, the views of industry professionals are considered, and these views are based on what they think, and hence may not be factually proved. However, it is rational to assume that there is substantial overlapping. Secondly, we have considered twenty-three factors divided across the six categories. Though the factors considered are comprehensive, there may be few other factors which have not been considered. Thirdly, we have considered two contingency variables – firm size and industry; future studies can consider other contingency variables such as annual turnover. Finally, critical factors can be investigated in developed countries and comparison can be done with results obtained in this study.

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