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Modeling and Analysis of Industry 4.0 Adoption Challenges in the Manufacturing Industry

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Abstract: The manufacturing sector is a fast-growing sector demanded by the increasing population. The adoption of information technology is a boon in the manufacturing industry. The industrial transformation from the third generation to the fourth generation has significantly impacted sustainable development. On account of this, different sectors are adopting industry 4.0 technologies to smooth their process flows. The industry 4.0 technologies implementation in the manufacturing sector will not only enhance its productivity, but also lead to sustainable growth. In this regard, this study intended to examine the challenges associated with adopting industry 4.0 technologies in the manufacturing sector. A thorough literature review was carried out from the Scopus database, and a list of ten important challenges was shortlisted for analysis. The article uses interpretive structural modeling to analyse the challenges of industry 4.0 and make a structural model between identified challenges. "Lack of employee skills" and "lack of technological infrastructure" were identified as the topmost challenges in adopting industry 4.0 technologies in the manufacturing sector. This study will enable decision makers, policymakers, and industrial practitioners to effectively analyse the challenges of I4.0 for its smooth adoption in the manufacturing sector. Practical implications of the study and future research directions were also highlighted in the article.

Keywords: industry 4.0; manufacturing sector; challenges; sustainable development; structural model

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1. Introduction

The manufacturing sector is an important sector that contributes to world economic growth. The revenue generated from the manufacturing sector in Saudi Arabia was around 170.24 billion USD in the year 2021, and it is expected to achieve 209.22 billion USD in 2025, which is around 22.8% growth [1]. The increasing demand for the manufacturing segment enables the use of information technologies to enhance the system's efficiency.

Nowadays, industries are focusing more on acquiring intelligent systems that can mimic humans for efficient decision making. In response to these, Germany has coined a long-term strategy term as industry 4.0 (I4.0) (fourth industrial revolution) [2,3]. The fourth industrial revolution brings new technologies, namely Internet of things, artificial intelligence, augmented/virtual reality, cyber-physical system, etc. [4]. Adoption of such technologies not only improves productivity but enables the smooth flow of information and product.

The acceptance of I4.0 technologies is still in the infant stage in the manufacturing sector [5,6]. Many researchers have worked on adopting I4.0 technologies in different areas such as manufacturing [7,8], textile [9], supply chains [10], aerospace [11], and healthcare [12].

Increasing population and demand have become drivers to implementing I4.0 technologies in the manufacturing sector for its sustainable growth and development. Before embracing I4.0 technologies in the manufacturing sector, it is necessary to analyse the associated challenges [13]. In this regard, this study intends to identify the critical challenges associated with adopting I4.0 technologies in the manufacturing sector.

1.1. Literature Review on I4.0 Adoption Challenges

The literature review discussing I4.0 challenges in manufacturing industries is discussed below:

The survey approach was used by Khan and Turowski [14] to analyse current issues in traditional production processes about Industry 4.0 transition. Furthermore, they defined Industry 4.0 and demonstrated its significance in today's manufacturing organization. Fifteen contemporary difficulties and most pressing ones, such as process flexibility, data integration, and security were discussed. To address these issues, they also explored future possibilities such as predictive maintenance and real-time access. Future research should focus on identifying additional difficulties and future circumstances to ensure a seamless transition to Industry 4.0. Zhou et al. [15] explored many elements of Industry 4.0 for the Chinese manufacturing industry, including strategic planning, possibilities, difficulties, and essential technologies. They provide advice on cyber physical system (CPS) network design, intelligent manufacturing, horizontal and vertical integration, and standardization during strategic planning. As a result, they discovered that in comparison to industrialised nations, Chinese manufacturing industries still face issues such as poor productivity, uneven development, and low total output levels. Technology innovation, according to the authors, is a critical aspect of upgrading China's industries. Kergroach [16] examined the problems and prospects for the labor market in Industry 4.0, and in the digital transformation the author noticed a skills gap. Various I4.0 technologies, namely Internet of things, cyber physical systems, etc., improve the labor market by monitoring operations and tracking real-time data.

When Internet of things (IoT) and Big Data analytics are coupled, fresh predictive ways for effective decision making are possible. Along with these advantages, the author also mentioned a few drawbacks, such as the conversion of full-time work to temporary part-time positions, the conversion of standard occupations to non-standard jobs, and the need for new labor capabilities, among others. Agostini and Filippini [17] described the organizational and management hurdles in adopting I4.0 technology at multiple levels. A study of Italian manufacturing companies in the form of survey was performed, which employed a cluster analysis and the t-test methods. Based on the adoption level of I4.0 tools, the authors established two clusters: high and low. Then, utilizing the statistical analysis it was shown that enterprises with more effective management and organizational practices had higher adoption levels of I4.0 technology. The authors stated that, to integrate Industry 4.0 technologies, managers and organizations need to concentrate on upgrading their information and communication systems, developing employee skills, and adopting a lean approach at the management and administrative levels.

Sevinç et al. [18] looked at the challenges that small and medium enterprises (SMEs) face as they transition to I4.0. Analytic hierarchy process (AHP) and analytic network process (ANP) approaches were applied to rank the challenges and compare the outcomes. With the support of a 15-person SMEs expert team, criteria (4) and its sub-criteria (14) were defined, and the findings were presented. Because of the substantial investment in technology, the findings indicated that the most critical factors in the transition process are cost and organization. Both strategies yielded findings that were consistent with each other. Future research should identify additional relevant criteria and prioritise them in a fuzzy environment to aid decision making. Further, statistical assessment was proposed by considering more experts. Moktadir et al. [19] examined ten significant difficulties for integrating I4.0 in the leather manufacturing industry in Bangladesh. The difficulties were investigated using the best–worst method (BWM). With the support of eight specialists from four organizations, the authors studied these issues. According to the findings, the most important challenge that may impede the execution of I4.0 is a "lack of technological infrastructure". In contrast, the least important difficulty is environmental side effects, which may hamper the I4.0 acceptance in leather manufacturing industries based in Bangladesh. Because the leather industry involves extensive chemical operations, the authors discussed environmental protection and process safety consequences. The authors recommended that Bangladeshi leather businesses pay attention to the problems outlined in order to adopt Industry 4.0 smoothly. Because the present study focuses on the leather business, different obstacles for other industries can be recognised in the future, to ensure a seamless adoption of Industry 4.0. A framework was formed by Yadav et al. [20] to overcome the challenges pertaining to supply chain management, ensuring sustainability through I4.0 in manufacturing industries. From the literature research, they discovered 28 challenges and 22 solution measures. The solution methodology was an integrated strategy of best–worst method (BWM) and elimination and choice expressing reality (ELECTRE). They employed the BWM method to calculate sustainable supply chain management problems and discovered that economic, organizational, and managerial challenges were extremely important for long-term supply chain implementation. In addition, the solution measures were prioritized by ELECTRE technique. Supplier commitment for recyclable materials, supplier commitment and engagement for sustainability acceptance, and sustainable resource management are all important solution strategies to address sustainable supply chain management (SSCM) difficulties, according to the superiority ratio. Future studies should recognise large-scale difficulties and use structural modeling techniques such as interpretative structural modeling to depict the structural link between the identified components. Because the study was only applicable to developing nations, the authors recommended that practitioners do a precise analysis for developed countries in the future.

Further, the applicability of I4.0 technologies in SMEs was analysed by Turkyilmaz et al. [21]. The study analyses the impact of I4.0 and its readiness level among SMEs belonging to Kazakhstan. Tseng et al. [22] analysed the indicators of industrial engineering in the domain of I4.0. The study identified thirty indicators which were further grouped in eight categories, and a bibliometric study was also carried out in the study. Aoun et al. [23] discussed the challenges related to the I4.0 adoption. Blockchain technology was identified as a potential tool for the empowerment of the fourth industrial revolution. Further, barriers, challenges, and limitations of I4.0 were also discussed.

Apart from the above studies, other studies discussed the issues associated with interoperability and compatibility of I4.0 technologies in manufacturing [24–27]. Interoperability is an important aspect in I4.0 as it ensures seamless exchange of information and data sharing between different heterogenous systems under same organization. Wherein, Lelli [24] discussed the intelligent interoperability between the different sensors and actuators for a shared goal. Zeid et al. [25] presented a review on different types of interoperability in smart manufacturing. The study suggested that interoperability occurs mainly because lack of coordination and interaction between different segments of organization.

1.2. Research Gaps

Based on the previous studies, it has been observed that most of the studies on I4.0 adoption challenges were from supply chain management perspectives. Moreover, some of the studies discussed I4.0 challenges for manufacturing industries from an organizational and managerial viewpoint [28]. Karadayi-Usta [29] used the Interpretive structural modeling (ISM) approach and constructed a structural model of I4.0 adoption difficulties. The research was carried out in the Bosch industry, and the literature search yielded nine difficulties. The inputs were compiled in the structural self-interaction matrix with the assistance of Bosch specialists, and the analysis was carried out using ISM. The constructed interpretative structural model suggested that obstacles such as "lack of sophisticated education system" were discovered at the bottom of the pyramid, while "delay in transformation" was identified at the top. The ISM model was verified using MICMAC analysis, which revealed that the difficulty of the "lack of sophisticated education system" was independent of all other obstacles. According to the MICMAC study, one difficulty belongs to the linkage category, one to the independent category, five to the autonomous category, and two towards the dependent category. Future research should incorporate additional difficulties and engage more decision experts to eliminate bias in decision making. Few studies also discussed I4.0 challenges adoption in Saudi Arabian manufacturing industries, specifically the steel industry. However, to the author's best knowledge, very few concrete studies were done regarding I4.0 challenges with regards to the Saudi Arabian manufacturing industry. Thus, in this article, the author attempted to address the potential challenges of I4.0 in the manufacturing industry and examined it using the ISM approach. The research questions below aimed to analyse this in the present study:

- RQ1. What are the possible challenges in the I4.0 technologies adoption with regards to the manufacturing sector?
- RQ2. How can these challenges be analysed to develop a structural model between them?
- RQ3. What can be the potential solutions to mitigate critical challenges?

To analyse the above research questions, this study starts by identifying research articles relevant to the investigating field. Scopus database was used to collect the relevant work in the investigating field [30,31]. The identified articles were studied, and I4.0 challenges were shortlisted from the literature review. A modeling approach named interpretive structural modeling (ISM) was used in the present study to develop a structural model of identified challenges. The hierarchical model was developed that depicts the most dominant challenges in embracing I4.0 disruptive technologies in the manufacturing sector. Further, the results are theoretically validated using "Matrice cross-impact multiplication applied to a classification" (MICMAC) evaluation. This study helps the decision maker for the effective implementation of I4.0 technologies in the manufacturing sector.

The identified challenges in the I4.0 technologies adoption are presented in Table 1. Through extensive literature review we identified 10 potential challenges for the adoption of industry 4.0 technologies in the steel manufacturing sector. The challenges with their descriptions are presented in Table 1.

Table 1. I4.0 challenges for its adoption in the manufacturing sector.

Challenges	Description	References
High investment (C1)	High investment refers to the capital expenditure for establishing I4.0 infrastructure in the manufacturing industry. Several organizations face difficulty due to a lack of funding.	[32–34]
Data insecurity (C2)	Data insecurity due to losing existing security system.	[35,36]
Complexity in reconfiguring manufacturing systems (C3)	Lack of capabilities in reconfiguring of fabrication pattern for effortless execution of I4.0 in the manufacturing organization. Traditional manufacturing firms are not flexible enough to adopt I4.0 technologies. Different sensors and actuators may not be fitted into traditional manufacturing system. So, manufacturing firms must reconfigure their systems to adopt I4.0 technologies	[19,37,38]
Computational ability (C4)	High computational ability results in agile decision making.	[36,39,40]
Lack of employee skills (C5)	Employee skills refer to the higher level of skill sets of employees in I4.0.	[41–43]
Lack of technological infrastructure (C6)	Deployment of advanced technologies smoothens the I4.0 execution in an organization. Traditional manufacturing firms may not have good data information system. So, collecting information is quite difficult with traditional systems. Moreover, exchange of information among different departments is difficult with traditional systems. So, there must be sound technological infrastructure to support I4.0 technologies.	[44–46]
Less understanding about I4.0 technologies (C7)	Less knowledge on I4.0 technologies may result in resistance to the change with respect to I4.0 implementation.	[46–48]
Poor existing data quality (C8)	Good data quality improves the overall productivity of an organization.	[45,49]
Lack of government support (C9)	Government support is essential in the smooth adoption of I4.0 technologies.	[46,50]
Unclear economic benefits (C10)	Unclear economic benefits refer to the poor understanding of the advantages of I4.0 implementation.	[51,52]

The remaining structure of the paper is: Section 2 includes a materials methods and case study. Results of the study are presented in Section 3. Section 4 includes discussion on findings and implications of the study. Further, Section 5 includes conclusions and limitations of the study.

2. Materials and Methods

The methodology of the study is shown in Figure 1. Warfield developed interpretive structural modeling (ISM) [53] with an aim to investigate the complex economic systems representing complicated relationships amongst several elements involved in the complex systems under consideration. The complex system is disintegrated into various sub-elements to establish a multilevel hierarchical structural model, using the knowledge and experience of the experts. Several researchers have extensively used ISM to examine the complexity of relationships.

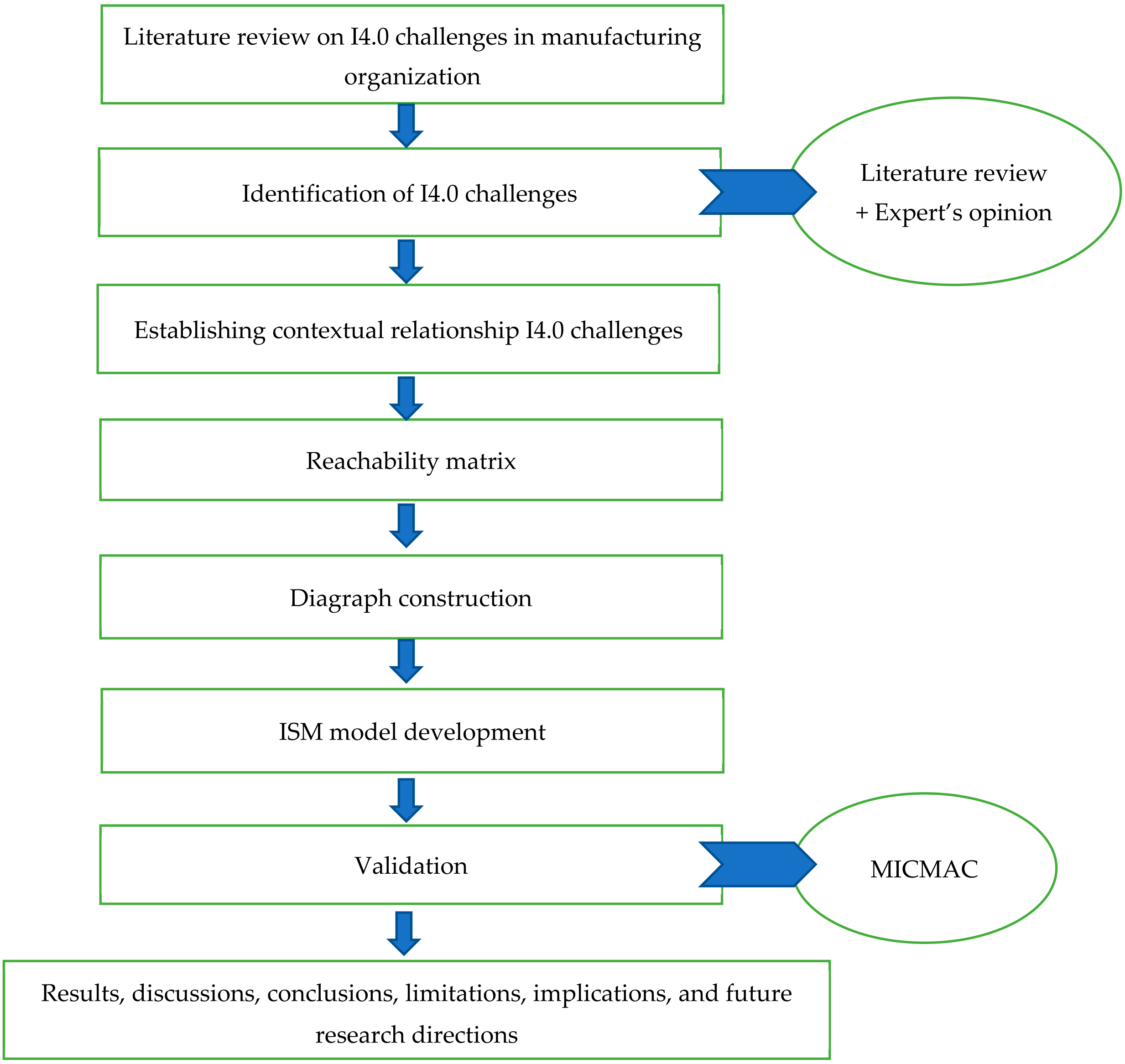

Figure 1. Flowchart of the study.

The characteristics of ISM methodology include Interpretive, Structural and Modeling technique. Interpretive refers to the relationships between the factors assessed using a panel of experts' opinions from the particular domain [54]. Structural characteristics represent establishing a complete structure of the complex set of factors based on the identified relationship. Finally, the modeling technique provides the outcome in the digraph model, showing a logical relationship amongst elements. However, the findings of the ISM possess limitations due to the biases of the person assessing the elements.

The steps involved in establishing ISM methodology are as follows [55,56]:

Step 1: Factors Identification—Recognition of factors influencing the system under consideration. This step is all about collecting factors from literature review or from discussion with experts in the investigating field.

Step 2: Contextual relationship—Examining the contextual relationship among various factors using experts' opinions. Once the contextual relationship is determined, a structural self-interaction matrix (SSIM) is developed through pair-wise computation of factors. In this step, authors aimed to collect data regarding relationships between different factors, and then developed an SSIM that depicts the key relationship among different factors.

Step 3: Reachability matrix—Using SSIM, the initial reachability matrix is established. The initial reachability matrix is checked for transitivity property to remove the inconsistencies associated with the data collection from experts. The transitivity property refers to an additional relationship that existed due to relationships mentioned in the reachability matrix. For instance, if $M \rightarrow N$ and $N \rightarrow O$, then it may be implied that $M \rightarrow O$ ($\rightarrow$ denotes relationship).

Step 4: Level partitions—The level partitioning is done from the reachability matrix using each variable's reachability set and antecedent set. The levels are computed by performing several iterations. In this step, several iterations are done to determine which factors will come in which level.

Step 5: Diagraph construction—In this step, based on levels of different factors, we construct a diagraph. A directed graph is generated by joining the nodes and vertices after level partitioning. The digraph represents relationships between the factors as shown in the final reachability matrix.

Step 6: Structural model—Based on the digraph, the final structural model is extracted. The structural model is developed by removing transitive links and the lines of edges from the digraph. This model represents the ISM.

Step 7: MICMAC analysis: The developed ISM model is validated using MICMAC analysis. In this step, the results of ISM approach are being validated using MICMAC analysis. The detailed step is presented in the case study section.

2.1. Case Study

This section presents an analysis of challenges in adopting I4.0 in the manufacturing sector located in Saudi Arabia. Data were gathered from Saudi Arabian steel manufacturing industry experts. We formed a team of experts based on their industrial and research experience. A team of five experts was formed (1 operations manager, 1 production head, 2 shift engineer, and 1 quality engineer), and their consensus opinion was collected before ISM methodology was used to develop a structural model. Further, the computation steps are shown below:

Computations of ISM

2.1.1. Building the SSIM

For analysing the identified I4.0 challenges, the following notations are used to show the path of the relationship between the selected challenges (j and k) to establish SSIM:

Challenge j helping to obtain challenge k = 'V'.
Challenge k obtained with the help of challenge j = 'A'.
Challenge j and k helped each other for accomplishment = 'X''.
No relationship = 'O'.

The relationships between the challenges were gathered from the five industry experts in the form of consensus opinion. The same group of experts was used for providing the inputs, which helped in finalizing the challenges earlier. The developed relationships were finalised after several rounds of discussion between authors and a group of experts. The disagreement between the two was resolved by revisiting the relationship, and thus, final data were considered for the analysis. These relationships are shown in Table 2.

Table 2. Structural self-interaction matrix for I4.0 challenges.

	High Investment	Data Insecurity	Complexity in Reconfiguring Manufacturing System	Computational Ability	Lack of Employee Skills	Lack of Technological Infrastructure	Less Understanding about I4.0 Technologies	Poor Existing Data Quality	Lack of Government Support	Unclear Economic Benefits
High investment	-	V	A	A	O	A	X	O	A	O
Data insecurity	-	-	X	A	A	A	A	A	X	O
Complexity in reconfiguring manufacturing system	-	-	-	O	A	A	A	A	O	O
Computational ability	-	-	-	-	A	A	A	A	O	O
Lack of employee skills	-	-	-	-	-	V	V	V	X	O
Lack of technological infrastructure	-	-	-	-	-	-	O	V	O	V
Less understanding about I4.0 technologies	-	-	-	-	-	-	-	A	V	O
Poor existing data quality	-	-	-	-	-	-	-	-	O	V
Lack of government support	-	-	-	-	-	-	-	-	-	A
Unclear economic benefits	-	-	-	-	-	-	-	-	-	-

2.1.2. Initial Reachability Matrix

The initial reachability matrix was established by transforming the values of SSIM to binary values 1 and 0. The values of V, A, X, and O are replaced by 1 and 0 as per the condition given in Table 3. Further, the initial reachability matrix is presented in Table 4.

Table 3. Initial reachability matrix.

Condition	Relationship	Entry in SSIM	Binary Value
1	j → k	V	1
	k → j		0
2	j → k	A	0
	k → j		1
3	j → k	X	1
	k → j		1
4	j → k	O	0
	k → j		0

2.1.3. Final Reachability Matrix

The final reachability matrix is obtained by removing the inconsistencies associated with the transitivity of the relationship, as mentioned in Step 3 of the Methodology section. The transitivity analysis was carried out using MATLAB R2022a software, ensuring the reliability of the developed model. The final reachability matrix is shown in Table 5.

Table 4. Initial reachability matrix for I4.0 challenges.

	High Investment	Data Insecurity	Complexity in Reconfiguring Manufacturing System	Computational Ability	Lack of Employee Skills	Lack of Technological Infra-Structure	Less Under-Stand-Ing about I4.0 Technologies	Poor Existing Data Quality	Lack of Government Support	Unclear Economic Benefits
High investment	1	1	0	0	0	0	1	0	0	0
Data insecurity	0	1	1	0	0	0	0	0	1	0
Complexity in reconfiguring manufacturing system	1	1	1	0	0	0	0	0	0	0
Computational ability	1	1	0	1	0	0	0	0	0	0
Lack of employee skills	0	1	1	1	1	1	1	1	1	0
Lack of technological infrastructure	1	1	1	1	0	1	0	1	0	1
Less understanding about I4.0 technologies	1	1	1	1	0	0	1	0	1	0
Poor existing data quality	0	1	1	1	0	0	1	1	0	1
Lack of government support	1	1	0	0	1	0	0	0	1	0
Unclear economic benefits	0	0	0	0	0	0	0	0	1	1

Table 5. Final reachability matrix for I4.0 challenges.

	High Investment	Data Insecurity	Complexity in Reconfiguring Manufacturing System	Computational Ability	Lack of Employee Skills	Lack of Technological Infrastructure	Less Understanding about I4.0 Technologies	Poor Existing Data Quality	Lack of Government Support	Unclear Economic Benefits
High investment	1	1	1 *	1 *	0	0	1	0	1 *	0
Data insecurity	1 *	1	1	0	1 *	0	0	0	1	0
Complexity in reconfiguring manufacturing system	1	1	1	0	0	0	1 *	0	1 *	0
Computational ability	1	1	1 *	1	0	0	1 *	0	1 *	0
Lack of employee skills	1 *	1	1	1	1	1	1	1	1	1 *
Lack of technological infrastructure	1	1	1	1	0	1	1 *	1	1 *	1
Less understanding about I4.0 technologies	1	1	1	1	1 *	0	1	0	1	0
Poor existing data quality	1 *	1	1	1	0	0	1	1	1 *	1
Lack of government support	1	1	1 *	0	1	0	1 *	1 *	1	0
Unclear economic benefits	1 *	1	0	0	1 *	0	0	0	1	1

* Represents transitive link.

2.1.4. Level Partitions

Using the final reachability matrix, the reachability and antecedent sets are computed. Reachability sets comprise of I4.0 challenge itself and other challenges which it may assist in achieving; on the other hand, antecedent sets consist of I4.0 challenge itself and other challenges which may help in achieving it. Further, the intersection set is computed for all the identified challenges. Based on this, the challenge of having the same reachability and intersection set is recognised as the top level in the hierarchy of the ISM model. The top-level would not assist in achieving other levels positioning above it. Once the top level is recognised, it is separated, and the same process is repeated for other challenges. In this way, the levels of the ISM model are determined. The level partitioning procedure is shown in Table 6. Based on the level partitions, the digraph was constructed.

Table 6. Level partitioning for I4.0 challenges.

Challenges	Reachability Set	Antecedent Set	Intersection Set	Level
		Iteration 1		
C1	(1,2,3,4,7,9)	(1,2,3,4,5,6,7,8,9,10)	(1,2,3,4,7,9)	I
C2	(1,2,3,5,9)	(1,2,3,4,5,6,7,8,9,10)	(1,2,3,5,9)	I
C3	(1,2,3,7,9)	(1,2,3,4,5,6,7,8,9)	(1,2,3,7,9)	I
C4	(1,2,3,4,7,9)	(1,4,5,6,7,8)	(1,2,4,7)	
C5	(1,2,3,4,5,6,7,8,9,10)	(2,5,7,9,10)	(2,5,7,9,10)	
C6	(1,2,3,4,6,7,8,9,10)	(5,6)	(6)	
C7	(1,2,3,4,5,7,9)	(1,3,4,5,6,7,8,9)	(1,3,4,5,7,9)	
C8	(1,2,3,4,7,8,9,10)	(5,6,8,9)	(8,9)	
C9	(1,2,3,5,7,8,9)	(1,2,3,4,5,6,7,8,9,10)	(1,2,3,5,7,8,9)	I
C10	(1,2,5,9,10)	(5,6,8,10)	(5,10)	
		Iteration 2		
C4	(4,7)	(4,5,6,7,8)	(4,7)	II
C5	(4,5,6,7,8,10)	(5,7,10)	(5,7,10)	
C6	(4,6,7,8,10)	(5,6)	(6)	
C7	(4,5,7)	(4,5,6,7,8)	(4,5,7)	II
C8	(4,7,8,10)	(5,6,8)	(8)	
C10	(5,10)	(5,6,8,10)	(5,10)	II
		Iteration 3		
C5	(5,6,8)	(5)	(5)	
C6	(6,8)	(5,6)	(6)	
C8	(8)	(5,6,8)	(8)	III
		Iteration 4		
C5	(5,6)	(5)	(5)	
C6	(6)	(5,6)	(6)	IV
		Iteration 5		
C5	(5)	(5)	(5)	V

3. Results

3.1. Establishment of ISM Model

Using the final reachability matrix, the structural model is established. The model should make clear sense to the industry practitioners, and the nodes may be modified to arrive at a logical conclusion. The ISM model is shown in Figure 2.

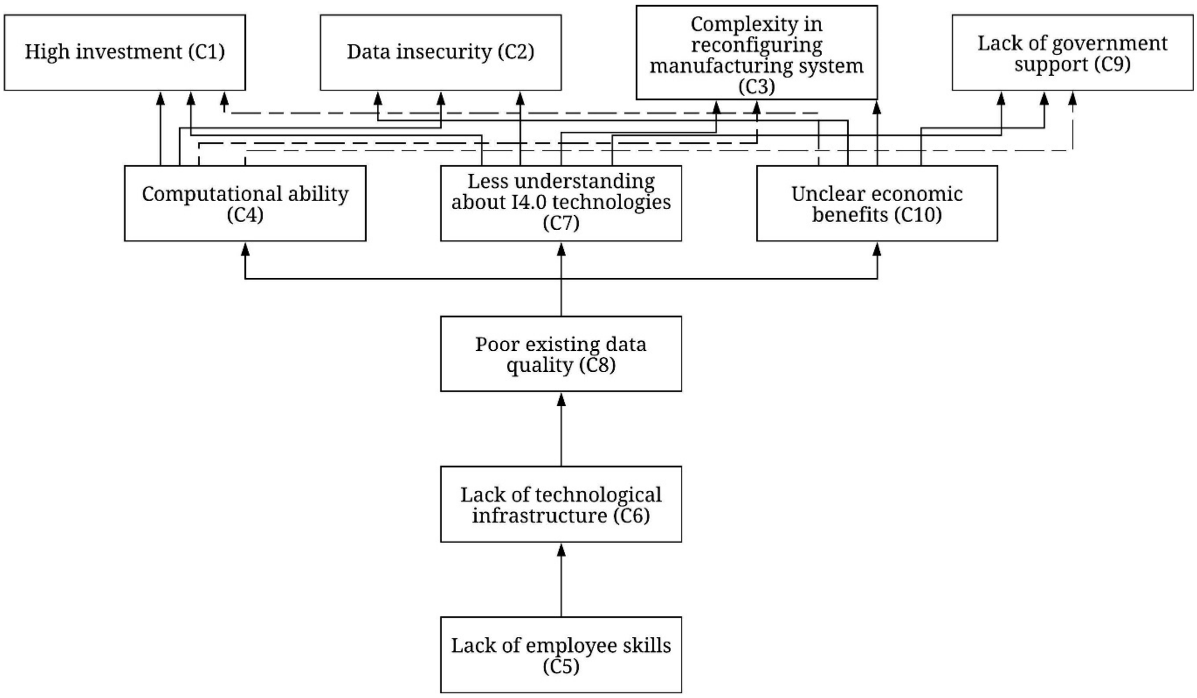

Figure 2. Developed structural model for I4.0 challenges.

The study aimed to model and analyse I4.0 adoption challenges in the manufacturing industry. For this purpose, the author identified the 10 potential challenges through extensive literature review and experts' opinions. To understand the relationship between the identified challenges, an ISM methodology was deployed. Based on the developed model, it is reflected that level 1 was occupied by the challenges 'High investment (C1)', 'Data insecurity (C2)', 'Complexity in reconfiguring manufacturing system (C3)' and 'Lack of government support (C9)'. The challenges 'Computational ability (C4)', 'Lack of understandings about I4.0 technologies (C7)', and 'Unclear economic benefits (C10)' occupied at level 2. Further, Level 3 was occupied by the challenge 'Poor existing data (C8)'. The I4.0 challenge 'Lack of technological infrastructure (C6)' is positioned at level 4. Finally, the challenge 'lack of employee skills (C5)' captured the last level, i.e., 5.

The result of the study shows that the most important challenge in adoption of I4.0 technologies in manufacturing is 'lack of employee skills' as it came at bottom. Industrial practitioners need to focus more on enhancing the employee skills to adopt I4.0 technologies in manufacturing [48]. The industry practitioners and manufacturing managers must utilize the results to build short-term and long-term strategies for effective adoption of I4.0 technologies in manufacturing sector.

3.2. MICMAC Analysis

MICMAC analysis was utilised to validate the developed ISM model. The driving and dependence power of each challenge was used to find out the grouping. Driving power shows the summation of row values in final reachability table, whereas dependent power shows the summation of column values in final reachability table. Figure 3 shows the grouping of I4.0 challenges.

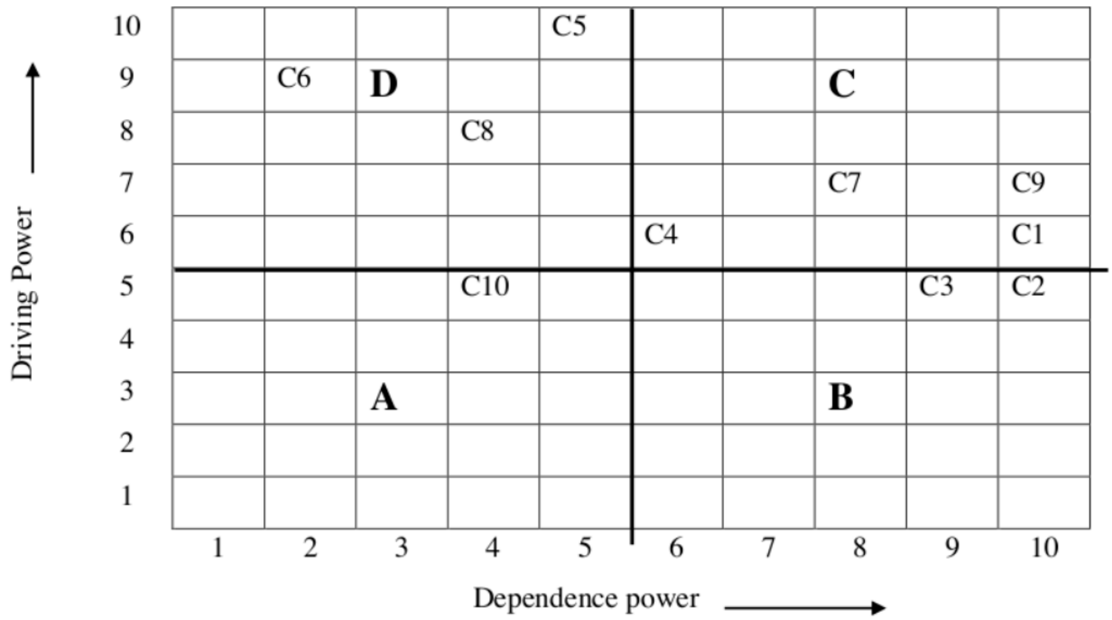

Figure 3. Grouping of I4.0 challenges.

4. Discussions

The structural hierarchy order of I4.0 challenges will assist the industry practitioners to implement the I4.0 in their industry. Moreover, the MICMAC approach was made to validate the developed ISM model and helped with providing dependence and driving power for each challenge. The MICMAC analysis categorised the challenges into four groups (autonomous, driver, dependent, and linkage) based on their dependence and driving power:

Group A—Autonomous—The challenges of having low driving and dependence power were placed into the Autonomous group. In the present study, the challenge 'Unclear economic benefits (C10)' is identified as the autonomous challenge of I4.0 adoption.

Group B—Dependent—The challenges of high dependence and low driving power were considered in the Dependent category. The challenges 'Data insecurity (C2)' and 'Complexity in reconfiguring manufacturing system (C3)' formed the dependent group.

Group C—Linkage—The challenges of having high driving and dependence power were placed into the Linkage group. The challenges are 'High investment (C1)', and 'Lack of government support (C9)'. The challenges 'Computational ability (C4)' and 'Lack of understanding about I4.0 technologies (C7)' were found in the Linkage group.

Group D—Driver—The challenges of having high driving power and low dependence power were placed in the driver group. The challenges 'lack of employee skills (C5)', 'Lack of technological infrastructure (C6)' and 'Poor existing data (C8)' were found to be in the Driver category.

Thus, the most significant challenges that need focus during implementation are 'lack of employee skills (C5)', 'Lack of technological infrastructure (C6)' and 'Poor existing data (C8)'.

In the study conducted by Wankhede and Vinodh [34], the analysis of the I4.0 challenges with respect to the Indian manufacturing industry was carried out. The authors concluded that the Real-time linkage between physical and digital systems was the most significant challenge of I4.0 adoption. The present study's findings resulted in lack of technological infrastructure as one of the most significant challenges, which highlighted the significance of real-time linkage. Kamble et al. [57] show legal and contractual uncertainties as one of the most significant challenges for I4.0 adoption. This finding also substantiates the result of the present study. The industry practitioners should focus on deploying the training about I4.0 and enhancing the employee skills. Further, Luthra and Mangla [46] have discussed the challenges in adopting I4.0 in supply chains to achieve sustainability.

The study shows that a lack of standard systems to adopt I4.0 technologies and lack of technological infrastructure are the prominent barriers that restrict its implementation in supply chains. In the present study also, lack of technological infrastructure is identified to be the 2nd most important barrier for adoption of I4.0 technologies in manufacturing.

Practical and Managerial Implications

The findings of the present study provide significant implications to industrial managers and practitioners. The industry practitioners can utilise the findings of the study to develop the strategic plan concerning the I4.0 adoption. The potential challenge of I4.0 adoption was a lack of employee skills; this will allow industry managers to execute the training program for the employees. The present study also categorised the challenges using MICMAC analysis, which will help the industry key decision makers understand the I4.0 adoption process. The developed ISM framework will help the industry practitioners to realise the interrelationship between various challenges to create the sustainable I4.0 based digital manufacturing platform. The industry practitioners and managers can utilise the methodology followed in this study to analyse the additional challenges. It is also observed that the most significant challenges that need to be focused on during implementation are 'lack of employee skills (C5)', 'Lack of technological infrastructure (C6)' and 'Poor existing data (C8)'. The higher authorities from industry can focus on building the technological infrastructure, which provides the foundation to incorporate further advancement in the technology.

5. Conclusions

Industry 4.0 is a significant revolution in the manufacturing industry. Although the manufacturing sector has always remained at the forefront in accepting advanced technologies, it possesses several challenges due to infrastructure limitations and expertise deficiency. In the present study, the critical challenges for implementing I4.0 in the manufacturing industry have been recognised and investigated using the ISM approach. The developed framework was validated using MICMAC analysis and verified with the industry experts. The findings of the study revealed 'lack of employee skills (C5)' as the significant challenge that needs to focus on during the implementation of I4.0. The MICMAC analysis categorised the challenges into four groups: autonomous, driver, dependent, and linkage, based on their dependence and driving power. This study will enable manufacturing firms to adopt I4.0 technologies by critically focusing on the important hindrances. The industrial practitioners must develop strategies based on the results of the present study to mitigate the hinderance in adoption of I4.0 technologies to achieve digitalization in manufacturing.

Limitations, and Future Research Directions

The present study considered 10 crucial challenges of I4.0 adoption in the manufacturing industry. However, other challenges could be investigated in the future for strengthening the derived model. Moreover, the present study considered a small sample size of five experts in the form of consensus opinion. In the future, a more significant number of experts could be involved to make the model robust, and cross-country analysis may be done to benchmark the readiness of the organizations. The developed model may be further tested using the structural equation modeling technique. Moreover, the ranking of the challenges could be obtained using suitable decision making techniques.

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