BJ O&PM
Brazilian Journal of Operations & Production Management

ISSN 2237-8960 (Online)

ABEPRO
ASSOCIAÇÃO BRASILEIRA DE ENGENHARIA DE PRODUÇÃO

RESEARCH PAPER

Assessment of Critical Barriers to Industry 4.0 Adoption in Manufacturing Industries of Bangladesh: An ISM-Based Study

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How to cite: Hossain, S., Hassan, S. and Karim, R. (2023), "Assessment of Critical Barriers to Industry 4.0 Adoption in Manufacturing Industries of Bangladesh: An ISM-Based Study", *Brazilian Journal of Operations and Production Management*, Vol. 20, No. 3 special edition, e20231797. https://doi.org/10.14488/BJOPM.1797.2023

ABSTRACT

Purpose: Regardless of the potential benefits of Industry 4.0, firms are still experiencing difficulties in properly integrating new technologies into their business. This study focuses on addressing critical barriers to implementing Industry 4.0 in the manufacturing industries of Bangladesh with a view to exploring readiness. The paradigm of adopting new technologies is yet to be unlocked in Bangladesh, which serves as this study's motivating force.

Approach: In order to accomplish the research objectives, "Interpretive Structural Modelling (ISM)" analysis is used, which identified and outlined the most significant barriers to adopting Industry 4.0. This was also combined with MICMAC analysis, which categorized the barriers based on their driving and dependent power. To evaluate the industries' preparedness, "cross-tabulation and frequency analysis" is performed using SPSS.

Key findings: According to the findings, "Lack of technical knowledge about industry 4.0" has been identified as the most crucial barrier.

Limitations of the study: To address the firm's preparedness, we looked at responses from management personnel. Nevertheless, if we could do this on a larger scale, a better scenario of Bangladesh's manufacturing industries toward Industry 4.0 might be shown.

Practical implication: The study's findings will be conceptually linked to relevant aspects of I4.0, particularly for strategic planning, decision-making, future opportunities, and formulating policy-related guidelines.

Originality: While several studies concentrate on particular sectors adopting Industry 4.0, no study has been conducted on manufacturing industries focusing on the industry's preparedness, which makes this study distinctive.

Keywords: Industry 4.0 (I4.0); Interpretive structural modelling (ISM); MICMAC; Internet of things (IoT); Artificial Intelligence (AI).

1. INTRODUCTION

The Fourth Industrial Revolution, or Industry 4.0, refers to the inclusion of cutting-edge

* This article is from Call for Papers, "When titans meet – Industry 4.0, Lean and Circular Economy Opportunities towards operational excellence and Sustainability". Due to their relevance and contribution to the field, the articles were published in the September/2023 Special Issue of the Brazilian Journal of Operations & Production Management.

Financial support: None.
Conflict of interest: The authors have no conflict of interest to declare.
Corresponding author: rubayet26@gmail.com
Received: 28 February 2023.
Accepted: 07 June 2023.
Editor: Daniel Nascimento, Guilherme Tortorella, Rodrigo Goyannes Gusmão Caiado, Juan Manuel Maqueira.

technology into industrial and manufacturing processes, such as artificial intelligence, the Internet of Things, and cloud computing. In developing countries such as Bangladesh, these technologies face several adaptation challenges. Many constraints must first be recognized and investigated before introducing Industry 4.0 in Bangladesh. This research aims to identify and prepare impediments to the implementation of Industry 4.0 in certain Bangladeshi manufacturing industries. This study is critical because it will help Bangladeshi stakeholders and policymakers make informed decisions about implementing Industry 4.0 and increasing Bangladesh's competitiveness in the global market.

The first industrial revolution (1760-1840) saw the development of water and steam power, mechanical production techniques, new modes of transportation, and the expansion of industries and mass manufacturing. This shift from manual labor to machine-based industry began with the development of new modes of transportation and the expansion of urban areas. The second industrial revolution saw the widespread use of electrical power, the development of new technologies, the expansion of businesses, and the creation of new modes of transportation, such as the electric tram. The third industrial revolution, known colloquially as the “digital revolution”, began in 1969 and continues today. It has brought about automation, globalization, and the interconnection of individuals and institutions, as well as the creation of the personal computer, the World Wide Web, mobile technology, and wireless communication. These innovations have enabled new types of collaboration, business, and communication to emerge.

The fourth industrial revolution was initially used to describe the present trend of automation and data interchange in manufacturing technology in 2011. The term Industry 4.0, which is taken from the German term Industry 4.0, is defined as a network of connected cyber-physical devices that may use big data analytics in the production and manufacturing industries (Vogel-Heuser & Hess, 2016). The Industry 4.0 environment has a high level of technical progress and collaborative structure, which is defined primarily by communication between diverse agents allowing data interchange, storage, and interpretation in an intelligent system (Cordeiro et al., 2019). The adoption of modern technologies like artificial intelligence (AI), the Internet of Things (IoT), and 5G connectivity in the production process define this new era of industrialization (Esmaeilian et al., 2020) and the influence of 5G technology and Industry 4.0 on company relationships is balanced by market expansion (Vilela & Faria Filho, 2022). Industry 4.0 is driven by the need for greater productivity, flexibility, and efficiency, which has been achieved through automation and data interchange, enhancing productivity and decision-making.

Elhusseiny & Crispim (2022) conducted their study within the SMEs and found that developing nations confront greater constraints yet see more potential in regard to Industry 4.0. On a further study (Kumar et al., 2023) proposed short-, medium-, and long-term strategic approaches for supply chain professionals who want to implement sustainability and I4.0 in SMEs. Another study conducted by (Kumar et al., 2021), based on the agricultural supply chain, specifies that implementation of the I4.0-CE model is hampered by the absence of government support and inducements, as well as the lack of regulations and procedures. However, there exists a research gap from a mixed industry approach that can integrate barriers in a common framework from a collective industry viewpoint, whereas studies within the scenario of Bangladesh are only limited to specific industry-based research, with the majority of studies providing only overviews of challenges. Therefore, a mixed industry-based strategy has to be developed and brought out in order to more effectively address impediments and improve industry readiness. This study focuses on it.
The following list contains the study's objectives:

- Determining the obstacles preventing I4.0's deployment.
- Examining the readiness of the companies to adopt I4.0.
- Using ISM and MICMAC analysis to determine the root barriers.

The remaining part of this paper is arranged as follows: section 2 highlights important literature to our study and underlines its uniqueness. Section 3 is about finding impediments. Section 4 describes the ISM methodology. Sections 5 and 6 discuss the Micmac study and the significant findings. Finally, Section 7 concludes the study with the potential future research areas as well as the study's drawbacks.

2. LITERATURE REVIEW

Regardless of any possible advantages of Industry 4.0, firms are still having trouble implementing new technology into their business models successfully (Kumar et al., 2021). Shabur et al. (2021) studied and surveyed the garments and apparel sectors of Bangladesh; found that the notion of Industry 4.0 in Bangladesh is not well established due to a lack of knowledge at the management level and the owners' belief that automation may add complexity rather than boost output. Inadequate knowledge and cheap labor in the region prevent the large-scale adoption of Industry 4.0. While studying the readiness for Industry 4.0 of SMEs' (Stentoft et al., 2021) addressed the deficiency of knowledge of managers about drivers and barriers of I4.0 as an obstacle. Because managers have to navigate the transition to Industry 4.0 by developing the appropriate goals, culture, and relationships (Cazeri et al., 2022).

Moktadir et al. (2018) identified "a lack of technological infrastructure" as the main challenge for Bangladesh's leather industry to implement Industry 4.0 and proposed revamping strategic approaches for a reconfiguring production system.

Türkeș et al. (2019) identified three primary obstacles to implementing I4.0: "Insufficient information on Industry 4.0," "More attention on operations at the cost of developing the company," and "Lack of understanding of the strategic value of Industry 4.0". Hofmann & Rüsch (2017) demonstrates the benefits of Industry 4.0 in the framework of logistics. They classified opportunities into decentralization, self-regulation, and efficiency. Machado et al. (2021) found that the biggest hurdles to implementing Industry 4.0 in Serbia are "Insufficient financial means" and "Weak competencies".

On the other side, "Lack of digital strategy" and "Resource scarcity" hinder industry 4.0 adoption in both developed and developing countries (Raj et al., 2020). Digitization is adversely associated with both inherent and external obstacles (Chauhan et al., 2021). Bhuiyan et al. (2020) and Attiany et al. (2023) addressed a few strategic solutions i.e., awareness building, capital formation, infrastructure development, recognizing the financial advantages, training, and skill development to cope with the adaption of industry 4.0.

Müller (2019) examined Industry 4.0 hurdles from the viewpoint of the workforce and discovered that industries need to create clear goals and ensure operational security, data protection, and IT security to successfully implement Industry 4.0. Industry 4.0 has implications for digitalizing supply chain management, as well as establishing interdependencies amongst supply chain innovations (Hahn, 2019).

According to Klaus Schwab [founder and chairman of WEF], future technological improvements will lead to long-term gains in productivity and efficiency, reducing costs of commerce, logistics, and supply chains, creating new markets, and fostering economic growth. Transportation and communication costs will also decline.

With the business model reshaping with technological outbursts aligning with Industry 4.0, companies need to evaluate and realize their maturity level. Ustundag et al. (2018) developed a maturity model to assess industries' readiness for a technological revolution. With enhancing maturity level, the need for skill development and process re-shaping should be addressed to ensure organizations can adapt to dynamic change (Alp Ustundag, 2018).

It is obvious that the implementation of new technology adoption strategies is also not well understood across industries, and Frank et al. (2019) proposed a conceptual framework to understand adoption patterns, consisting of two types of technologies with four dimensions. Another aspect of Industry 4.0 is that people are still hopeful about the sustainability options available (Ghobakhloo, 2020). Various sustainability functions have been identified and analyzed in different studies. Lu (2017) surveyed technologies and applications aligning with Industry 4.0 and gave an outline of its potential and breadth. Despite the many potential uses, applications, and opportunities for Industry 4.0 adoption, there are still significant implementation challenges. Companies of various sizes and geographies may have varied aims and approaches to using the same technology (Brunheroto et al., 2021).

In the context of Bangladesh, ICT policies should focus on modern industrialization to fill gaps in the country's Industry 4.0 and new technology integration policies (Suha et al., 2022). Bangladesh is a least developed country due to its inadequate infrastructure, a large population of unskilled workers, lack of resources, and improved cloud networking ("Fourth Industrial Revolution in Bangladesh: Prospects and Challenges," 2020). Therefore it would be very much challenging for the country to get the enormous benefits from Industry 4.0 (Islam et al., 2018).

According to the study referenced above, the majority of studies emphasize the technological implications of Industry 4.0, looking at its scope, difficulties, and prospects. This study aims to identify and appreciate potential implementation-related challenges in Bangladesh, which can help firms and the government decide how to help the manufacturing and industrial sector grow. It can provide insights and lessons that can be applied to other developing nations.

2.1 Identifying the barriers

The major barriers have been found through an extensive literature survey and data collection from industries like FMCG, Leather, Electronics, Automobile, Furniture, Plastics, etc. This study is conducted within the geographical region of Bangladesh.

The 10 specialists chosen from diverse areas have a minimum of five years of expertise in their respective professions. The contenders are from renowned industries in Bangladesh and university consulting experts with personal contacts. A standardized questionnaire is used to conduct the interview. Three weeks were set out to collect literature and data, expert opinion, and brainstorming sessions to determine the numerous barriers. As a consequence, fifteen barriers have been identified as having a direct or indirect impact on the deployment of Industry 4.0 (Table 1).

Table 1 - Barriers to I4.0 deployment, either directly or indirectly (continue)

No.	Barriers	References
B1	technical knowledge of I4.0	(From the responses)
B2	Infrastructure insufficiency	(Kamble et al., 2019; Kamble et al., 2018; Moktadir et al., 2018; Schröder, 2016)
B3	Requirement of high investment	(Kamble et al., 2019; Kamble et al., 2018; Khan & Turowski, 2016; Schröder, 2016)
B4	The Cyber-security Challenge	(Aggarwal et al., 2019; Kamble et al., 2018; Moeuf et al., 2020; Raj et al., 2020; Thoben et al., 2017; Wang et al., 2016)
B5	Inadequate workforce skill	(Kamble et al., 2019; Kamble et al., 2018; Machado et al., 2019)
B6	Job disruptions	(Kamble et al., 2018; Kergroach, 2017; Moktadir et al., 2018; Raj et al., 2020)
B7	Challenges posed by the continuous development of inventions and technology	(From the responses)
B8	Problems with data management and data quality	(Khan & Turowski, 2016)
B9	Lack of policy makers' support	(From the responses)
B10	Unsupportive top management	(From the responses)
B11	Poorly coordinated value chain	(Kamble et al., 2018; Raj et al., 2020; Suresh et al., 2018; Xu et al., 2018; Zhou et al., 2015)

Table 1 - Barriers to I4.0 deployment, either directly or indirectly (conclusion)

No.	Barriers	References
B12	Ambiguity over better economic outcome	(Kamble et al., 2018; Raj et al., 2020; Schröder, 2016)
B13	Employee apathy	(From the responses)
B14	Lack of coordination	(From the responses)
B15	Absence of third-party assistance	(From the responses)

2.2 Assessing I4.0 readiness

Our first objective is to assess industry readiness as well as people's knowledge and concepts of I4.0 in the framework of Bangladesh. According to Table 2, around 70% of managers from different industries are familiar with and aware of the 4th Industrial revolution concept.

Table 2 - Frequency table for knowing the awareness of IR 4.0

Are you aware of the upcoming IR4.0?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	1	10.0	10.0	10.0
	Heard of this	2	20.0	20.0	30.0
	Familiar with IR4.0	1	10.0	10.0	40.0
	aware	5	50.0	50.0	90.0
	Fully aware	1	10.0	10.0	100.0
	Total	10	100.0	100.0	

The result from Table 3 shows that 8 out of 10 industries/their personnel think that adopting the notion of I4.0 is necessary for their companies, which shows the responsiveness to the evocation.

Table 3 - Frequency table for assessing the company's mindset towards the adoption of I4.0

Is the Top management ready to adopt the concept of Industry 4.0 within your organization?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	2	20.0	20.0	20.0
	yes	8	80.0	80.0	100.0
	Total	10	100.0	100.0	

It also shows in Table 4 that in 8 out of 10 industries top management decisions aligned with an adaptation of technological advancement, thus ready to accept the idea of I4.0.

Table 4 - Frequency table about top management's mindset towards the deployment of I4.0

Do you think the infrastructure of your organization is suitable enough for this changeover?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	8	80.0	80.0	80.0
	yes	2	20.0	20.0	100.0
	Total	10	100.0	100.0	

Table 5 - Frequency table for assessing company's preparedness for I4.0

Do you think implementing the concept of I4.0 within your organization is necessary?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	1	10.0	10.0	10.0
	yes	9	90.0	90.0	100.0
	Total	10	100.0	100.0	

Table 6 - Frequency table about the infrastructural condition of industries

Have your company conducted any Feasibility Study that clearly supports the need for implementing I4.0?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	5	50.0	50.0	50.0
	yes	5	50.0	50.0	100.0
	Total	10	100.0	100.0	

At least 8 out of 10 industries do not have suitable infrastructure that aligns with the adoption of I4.0.

Table 7 - Frequency table for available flexibility of industries

Is the system flexible enough to retain the uncertainties i.e., regulatory harmonization and cyber-security that arose from the technological integration?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	5	50.0	50.0	50.0
	yes	5	50.0	50.0	100.0
	Total	10	100.0	100.0	

Table 8 - Frequency table regarding the cyber security issue

Cyber security is a common issue for I4.0. Do you think it would be challenging to manage data and protect your overall cyber system?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	8	80.0	80.0	80.0
	yes but we're capable	2	20.0	20.0	100.0
	Total	10	100.0	100.0	

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Table 9 - Frequency table for assessing the company's mindset towards the adoption of I4.0

Will you implement Industry 4.0 if your competitors do so?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	yes	10	100.0	100.0	100.0

From Tables 7, 8, and 9 it can be concluded that, though industries have a concern regarding cyber security and data protection issues, almost every company said that they will implement I4.0 if their competitors do so.

Table 10 - Cross-tabulation over the company's readiness

Cross-tabulation				
		Have your company conducted any Feasibility Study that clearly supports the need for implementing I4.0?		
Count		No	yes	Total
Do you think implementing the concept of I4.0 within your industry is necessary?	No	1	0	1
	yes	4	5	9
Total		5	5	10

Thus, considering several objectives, different questions from the questionnaire were chosen for frequency tests and responses were analyzed to see the readiness of enterprises, these are giving insights about how prepared they are to embrace the change-over.

2.3 ISM methodology

Warfield's ISM technique is used to simplify a difficult issue with the use of specialists' expertise and insight. ISM is a collaborative learning method that converts system mental models that are ambiguous and poorly articulated into observable, well-defined models that may be utilized for several objectives. ISM helps a team to establish order in the intricacy of elements. The method is interpretive in the context that the team's assessment governs either way, how items are connected; structural in the manner that a broad framework based on connections is retrieved from the intricate list of items; and modeling in the context that the particular connections and general framework are depicted in a digraph model.

The following are the key components of the ISM methodology:

• This is interpretative because this demonstrates the interdependence of variables.
• Diagraph is a visual system since it reveals all relations and the full framework.
• This is a process of accumulation and education.

Steps of ISM Methodology:

Step 1: Identify the main barriers impacting the implementation of I4.0 in large industry sectors of Bangladesh.
Step 2: Create a structural self-interaction matrix (SSIM) for the obstacles to illustrate their interdependence.
Step 3: An initial reachability matrix is built using SSIM, and a final reachability matrix is created after eliminating all transitivity links. Transitivity is just a fundamental precept for comparative relationships, such as if E equals F and F equals G, then E will inevitably equal G.
Step 4: Level up the final reachability matrix.
Step 5: Following the removal of transitivity, a diagraph is created to reflect the opposite link.
Step 6: Turn the diagraph into an ISM model.
Step 7: The contradictions in the ISM model generated in step 6 are evaluated(Thakkar, 2021).

2.4 SSIM (Structural Self-Interaction Matrix) Development

The SSIM was build based on the study, expert opinion, and the determination of contextual interrelationships among the fifteen major barriers listed in Table 1. The professionals come from a variety of backgrounds and are highly skilled in their own disciplines, such as industry and academia. Four symbols (V, A, X, O) describe the direction of interrelationship utilized in barrier analysis.

V- Barrier m will have an effect on barrier n.

A- Barrier n will have an effect on barrier m.

X- Barriers m and n will have an effect on each other.

O- Barriers m and n are unrelated and will have no effect on each other.(Kumar et al., 2021)

Here, Table 11 shows the SSIM based on the applicable relationships.

Table 11- SSIM

↓ m,n →	Absence of third-party assistance	Lack of coordination	Employee apathy	Ambiguity over better economic outcome	Poorly coordinated value chain	Unsupportive top management	Lack of policy makers' support	Problems with data management and data quality	Challenges posed by the continuous development of inventions and Tech.	Job disruptions	Inadequate workforce skill	The Cyber-security Challenge	Requirement of high investment	Infrastructure insufficiency	Inadequate technical knowledge of I4.0
Inadequate technical knowledge of I4.0	O	V	V	V	V	V	V	V	V	V	V	V	O	O	_
Infrastructure insufficiency	O	V	A	X	V	O	A	V	V	O	O	V	X	_	_
Requirement of high investment	X	O	O	A	V	V	A	O	V	V	A	O	_	_	_
The Cyber-security Challenge	A	X	A	O	A	A	O	X	A	O	A	_	_	_	_
Inadequate workforce skill	A	V	O	X	O	O	O	V	V	V	_	_	_	_	_
Job disruptions	A	V	A	A	O	X	A	O	O	_	_	_	_	_	_
Challenges posed by the continuous development of inventions and technology	A	O	A	A	X	A	O	X	_	_	_	_	_	_	_
Problems with data management and data quality	O	X	A	O	V	A	O	_	_	_	_	_	_	_	_
Lack of policy makers' support	O	O	X	V	V	V	_	_	_	_	_	_	_	_	_
Unsupportive top management	O	V	A	A	V	_	_	_	_	_	_	_	_	_	_
Poorly coordinated value chain	A	X	A	A	_	_	_	_	_	_	_	_	_	_	_
Ambiguity over better economic outcome	A	O	O	_	_	_	_	_	_	_	_	_	_	_	_
Employee apathy	V	V	_	_	_	_	_	_	_	_	_	_	_	_	_
Lack of coordination	O	_	_	_	_	_	_	_	_	_	_	_	_	_	_
Absence of third-party assistance	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_

2.5 Formation of Initial Reachability Matrix

In the next step, the SSIM was turned into a binary matrix, known as the initial reachability matrix, by replacing V, A, X, and O with 1 and 0 as appropriate. The following principles govern the replacement of 1s and 0s:

- In the initial reachability matrix, if (m, n) value in the SSIM is V, then we put 1 for the (m, n) value and 0 for the (n, m) value;
- In the initial reachability matrix, if (m, n) value in the SSIM is A, then we put 0 for the (m, n) value and 1 for the (n, m) value;
- In the initial reachability matrix, if (m, n) value in the SSIM is X, then we put 1 for the (m, n) value and also 1 for the (n, m) value;
- In the initial reachability matrix, if (m, n) value in the SSIM is O, then we put 0 for the (m, n) value and also 0 for the (n, m) value (Singh et al., 2007).

The initial reachability matrix for the barriers is attained based on these notions. As seen in Step 3 of the ISM method, the final reachability matrix is built after including transitivity. The directing and reliant power of each parameter is then computed. The entire quantity of parameters (including itself) that it may contribute to gaining is the driving force for every variable. Dependency, on the contrary, refers to the entire quantity of elements (including itself) that can assist you in gaining your objective. These driving and dependence abilities will be utilized to classify obstacles into four groups: autonomous, dependent, linkage, and drivers (independent).

Table 12 exhibits the initial reachability matrix for the obstacles based on these principles. Table 13 shows the final reachability matrix after including the transitivity stated in Step 3 of the ISM technique. Table 12 also shows the driving power and dependence power of every element. These driving power and dependence power are intended to categorize the obstacles into four groups: autonomous, dependent, linkage, and drivers (independent).

Table 12 - Initial Reachability Matrix

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15
B1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0
B2	0	1	1	1	0	0	1	1	0	0	1	1	0	1	0
B3	0	1	1	0	0	1	1	0	0	1	1	0	0	0	1
B4	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0
B5	0	0	1	1	1	1	1	1	0	0	0	1	0	1	0
B6	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0
B7	0	0	0	1	0	0	1	1	0	0	1	0	0	0	0
B8	0	0	0	1	0	0	1	1	0	0	1	0	0	1	0
B9	0	1	1	0	0	1	0	0	1	1	1	1	1	0	0
B10	0	0	0	1	0	1	1	1	0	1	1	0	0	1	0
B11	0	0	0	1	0	0	1	0	0	0	1	0	0	1	0
B12	0	1	1	0	1	1	1	0	0	1	1	1	0	0	0
B13	0	1	0	1	0	1	1	1	1	1	1	0	1	1	1
B14	0	0	0	1	0	0	0	1	0	0	1	0	0	1	0
B15	0	0	1	1	1	1	1	0	0	0	1	1	0	0	1

Table 13 - Final Reachability Matrix

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	Driving Power
B1	1	1*	1*	1	1	1	1	1	1	1	1	1	1	1	1*	15
B2	0	1	1	1	1*	1*	1	1	0	1*	1	1	0	1	1*	12
B3	0	1	1	1*	1*	1	1	1*	0	1	1	1*	0	1*	1	12
B4	0	0	0	1	0	0	1*	1	0	0	1*	0	0	1	0	5
B5	0	1*	1	1	1	1	1	1	0	1*	1*	1	0	1	1*	12
B6	0	0	0	1*	0	1	1*	1*	0	1	1*	0	0	1	0	7
B7	0	0	0	1	0	0	1	1	0	0	1	0	0	1*	0	5
B8	0	0	0	1	0	0	1	1	0	0	1	0	0	1	0	5
B9	0	1	1	1*	1*	1	1*	1*	1	1	1	1	1	1*	1*	14
B10	0	0	0	1	0	1	1	1	0	1	1	0	0	1	0	7
B11	0	0	0	1	0	0	1	1*	0	0	1	0	0	1	0	5
B12	0	1	1	1*	1	1	1	1*	0	1	1	1	0	1*	1*	12
B13	0	1	1*	1	1*	1	1	1	1	1	1	1*	1	1	1	14
B14	0	0	0	1	0	0	1*	1	0	0	1	0	0	1	0	5
B15	0	1*	1	1	1	1	1	1*	0	1*	1	1	0	1*	1	12
Dependence Power	1	8	8	15	8	10	15	15	3	10	15	8	3	15	8	142

2.6 Level Partitions

For level partitioning, the reachability set and the antecedent set are computed from the final reachability matrix. The reachability set is made up of the element itself and other elements that it may attain, whereas the antecedent set is made up of the element itself and other elements that may attain it. For each item, a common set is determined. If the reachability and the intersection sets are identical, then we regard the elements (barriers) as top-level elements. These top-level components will never physically ascend above their own level. Top-level barriers are removed from other barriers to produce the next level of barriers, and the procedure is carried out again. The partitioning approach emphasizes the creation of precedence linkages and the placement of the parts in hierarchical order (Durge et al., 2021).

Table 14 - Iteration I (continue)

Barriers	Reachability Set	Antecedent Set	Intersection Set	Level
B1	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	1	1	
B2	2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 14, 15	1, 2, 3, 5, 9, 12, 13, 15	2, 3, 5, 12, 15	
B3	2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 14, 15	1, 2, 3, 5, 9, 12, 13, 15	2, 3, 5, 12, 15	
B4	4, 7, 8, 11, 14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	4, 7, 8, 11, 14	I
B5	2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 14, 15	1, 2, 3, 5, 9, 12, 13, 15	2, 3, 5, 12, 15	
B6	4, 6, 7, 8, 10, 11, 14	1, 2, 3, 5, 6, 9, 10, 12, 13, 15	6, 10	
B7	4, 7, 8, 11, 14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	4, 7, 8, 11, 14	I
B8	4, 7, 8, 11, 14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	4, 7, 8, 11, 14	I

Table 14 - Iteration Ⅰ (conlusion)

Barriers	Reachability Set	Antecedent Set	Intersection Set	Level
B9	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	1, 9, 13	9, 13	
B10	4, 6, 7, 8, 10, 11, 14	1, 2, 3, 5, 6, 9, 10, 12, 13, 15	6, 10	
B11	4, 7, 8, 11, 14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	4, 7, 8, 11, 14	Ⅰ
B12	2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 14, 15	1, 2, 3, 5, 9, 12, 13, 15	2, 3, 5, 12, 15	
B13	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	1, 9, 13	9, 13	
B14	4, 7, 8, 11, 14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	4, 7, 8, 11, 14	Ⅰ
B15	2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 14, 15	1, 2, 3, 5, 9, 12, 13, 15	2, 3, 5, 12, 15	

Table 15 - Iteration Ⅱ

Barriers	Reachability Set	Antecedent Set	Intersection Set	Level
B1	1, 2, 3, 5, 6, 9, 10, 12, 13,15	1	1	
B2	2, 3, 5, 6, 10, 12, 15	1, 2, 3, 5, 9, 12, 13, 15	2, 3, 5, 12, 15	
B3	2, 3, 5, 6, 10, 12, 15	1, 2, 3, 5, 9, 12, 13, 15	2, 3, 5, 12, 15	
B5	2, 3, 5, 6, 10, 12, 15	1, 2, 3, 5, 9, 12, 13, 15	2, 3, 5, 12, 15	
B6	6, 10	1, 2, 3, 5, 6, 9, 10, 12, 13, 15	6, 10	Ⅱ
B9	2, 3, 5, 6, 9, 10, 12, 13, 15	1, 9, 13	9, 13	
B10	6, 10	1, 2, 3, 5, 6, 9, 10, 12, 13, 15	6, 10	Ⅱ
B12	2, 3, 5, 6, 10, 12, 15	1, 2, 3, 5, 9, 12, 13, 15	2, 3, 5, 12, 15	
B13	2, 3, 5, 6, 9, 10, 12, 13, 15	1, 9, 13	9, 13	
B15	2, 3, 5, 6, 10, 12, 15	1, 2, 3, 5, 9, 12,13, 15	2, 3, 5, 12, 15	

Table 16 - Iteration Ⅲ (continue)

Barriers	Reachability Set	Antecedent Set	Intersection Set	Level
B1	1, 2, 3, 5, 9, 12, 13,15	1	1	
B2	2, 3, 5, 12, 15	1, 2, 3, 5, 9, 12, 13, 15	2, 3, 5, 12, 15	Ⅲ
B3	2, 3, 5, 12, 15	1, 2, 3, 5, 9, 12, 13, 15	2, 3, 5, 12, 15	Ⅲ
B5	2, 3, 5, 12, 15	1, 2, 3, 5, 9, 12, 13, 15	2, 3, 5, 12, 15	Ⅲ
B9	2, 3, 5, 9, 12, 13, 15	1, 9, 13	9, 13	

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Table 16 - Iteration Ⅲ (conclusion)

Barriers	Reachability Set	Antecedent Set	Intersection Set	Level
B12	2, 3, 5, 12, 15	1, 2, 3, 5, 9, 12, 13, 15	2, 3, 5, 12, 15	Ⅲ
B13	2, 3, 5, 9, 12, 13, 15	1, 9, 13	9, 13	
B15	2, 3, 5, 12, 15	1, 2, 3, 5, 9, 12, 13, 15	2, 3, 5, 12, 15	Ⅲ

Table 17 - Iteration Ⅳ

Barriers	Reachability Set	Antecedent Set	Intersection Set	Level
B1	1, 9, 13	1	1	Ⅴ
B9	9, 13	1, 9, 13	9, 13	Ⅳ
B13	9, 13	1, 9, 13	9, 13	Ⅳ

2.7 Formation of ISM

From the final reachability matrix's vertices or nodes and edge lines, a structural model is built. An arrowhead directing from m to n defines the link between factors m and n. This is called a diagraph. The diagraph is turned into ISM when transitivities are removed as explained in the ISM approach.

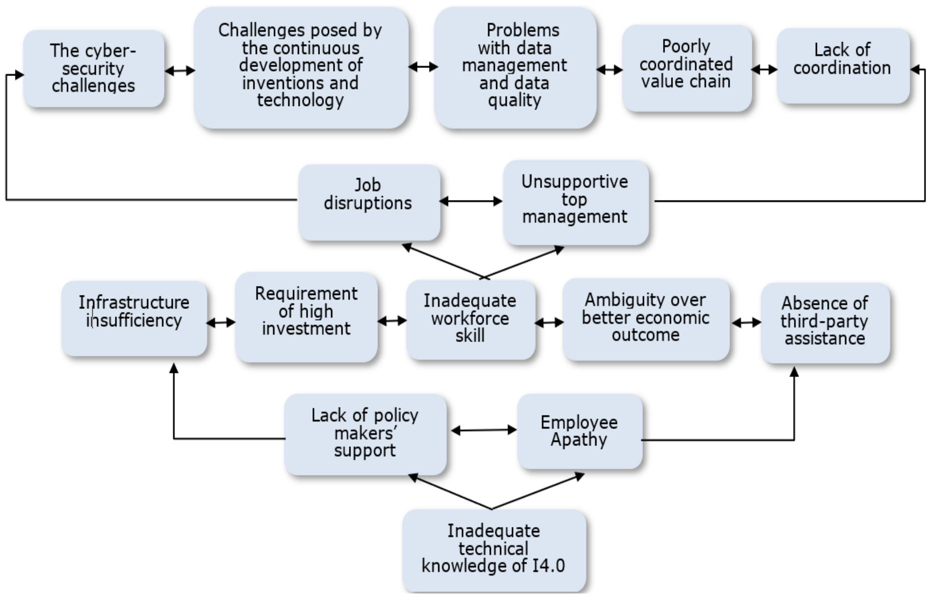

Figure 1 - ISM Model of the Barriers of Implementing I4.0

2.8 MICMAC Analysis

The purpose of MICMAC analysis is to identify the barriers based on their driving power and reliance power. The final reachability matrix determines this driving and reliance or dependency power. In Figure 1, basic two-dimensional graphs complete the MICMAC study. The barriers to I4.0 implementation are grouped into four different types.

- The first category is made up of Independent and self-ruling components with weaker driving power and dependence power.
- The second category is made up of reliant components, which have lower driving power but strong dependency.
- The tertiary or third category includes linking elements, which have strong influencing power and strong dependence power. These factors are unstable, and every activity taken on them will affect others as well.

- The final category includes key components, which have strong influencing power but weaker dependency on other elements. These factors drive others significantly.

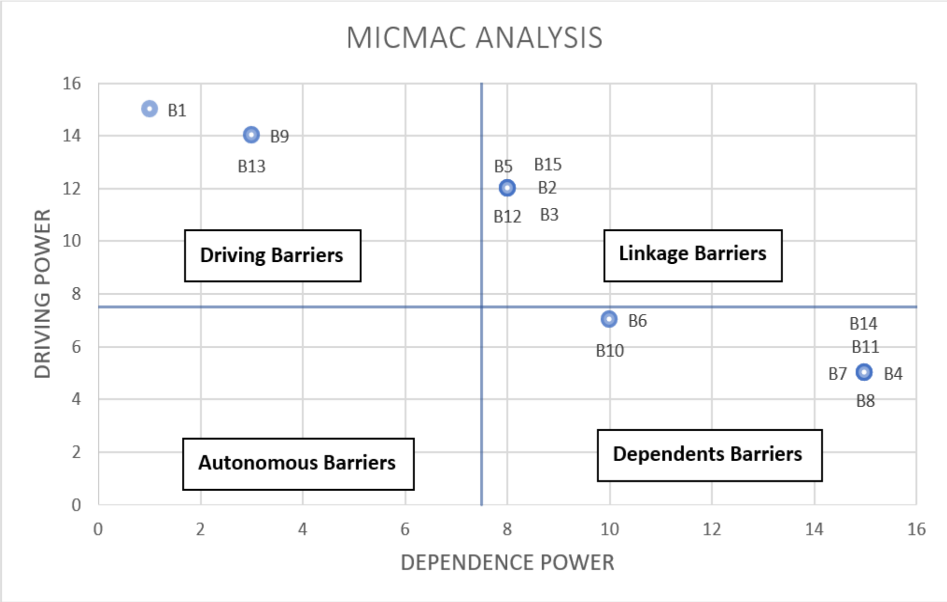

Figure 2 - MICMAC Analysis of the Barriers

3. RESULTS

The created ISM model has five-level hierarchical structures. From the model, we can see that 'The cyber-security challenges', 'Challenges posed by the continuous development of inventions and technology', 'Problems with data management and data quality', 'Poorly coordinated value chain', and 'Lack of coordination' are on the initial level and level two is composed of ' job disruptions' and 'Unsupportive top management'. Then level three has barriers called 'infrastructure insufficiency', 'Requirement of high investment', 'inadequate workforce skill', 'Ambiguity over better economic outcome', and 'Absence of third-party assistance'. The fourth level occupies the barriers called 'lack of policy makers' support' and 'employee apathy'. 'Inadequate technical knowledge of I4.0' is at the base level and the most crucial impediment to implementing I4.0, which is affecting others.

In this study, a significant driver at the structural model's lowest level—namely, inadequate technical knowledge of I4.0—is identified.

Further, the MICMAC analysis is done to categorize the barriers into four groups, as shown in Fig.2.

1. The first segment has the 'autonomous barriers'. The barriers that have weaker driving power and dependence power fall on this part. There is no such barrier in this cluster.

2. The second segment has the 'dependent barriers'. These have lower driving power but strong dependency. Here, B8 (Problems with data management and data quality), B11 (Poorly coordinated value chain), B14 (Lack of coordination), B4 (The Cyber-security Challenge), B6 (Job disruptions), B10 (Unsupportive top management), B7 (Challenges posed by the continuous development of inventions and technology) are categorized. These barriers are dependent on others. Thus, they require all other barriers to be cast aside for better adoption of the concept of I4.0.

3. The third segment has the 'linkage barriers'. These have strong influencing power and strong dependence power. Here, B12 (Ambiguity over better economic outcome), B3 (Requirement of high investment), B2 (Infrastructure insufficiency), B15 (Absence of third-party assistance), and B5 (Inadequate workforce skill) are categorized. Changes in these barriers will influence others as well as themselves and the system.

4. The fourth segment has 'driving barriers'. These have strong influencing power but weaker dependency. Here, B13 (Employee apathy), B9 (Lack of policymakers' support), and B1 (Inadequate technical knowledge of I4.0) are categorized. These driving barriers have strong driving power and low dependence power and require much attention from management while formulating. Management should address cautiously as these factors strongly drive others.

The clustering of the barriers aids in understanding the impacting factors as well as the barriers' dependency. It provides some helpful perceptions on the relative significance and interdependence of the impediment and pushes one to keep a watch on the most important aspects that radically alter the system.

4. DISCUSSION

I4.0 requires extensive focus and tenacity to make the best use of available resources. To successfully deploy it, companies must create awareness among their employees and managerial bodies about I4.0. This will help them make the best use of available resources and embrace the notion of I4.0. Other important aspects in this study are the lack of policymaker support, employee reluctance, unsuitable infrastructure, high investment, and uncertainty over economic benefits in Bangladesh, which negatively affects the eagerness for implementation. This is due to the third-world country's lack of technological advancement, which necessitates the assistance of professionals from outside the country, which necessitates a large investment and increases complexities. Concerning job disruptions, they can be mitigated by training employees and providing skills associated with technological attachments, while top management can be inspired by the government promoting Industry 4.0 and making technological aid for manufacturing industries mandatory. Challenges such as the continuous development of inventions and technology, data management and data quality, and a poorly coordinated value chain must be taken into account when choosing a strategic plan. They affect the value chain and the efficient operation of the system and should be considered hierarchically.

This study found that industries are more concerned with immediate profits than long-term profitability, so the industry should develop strategies to enhance drivers. Additionally, accurate and detailed information about Industry 4.0 should be recognized both within the industry and in academia, and the government should encourage the adoption of new technologies to make them easy to apply at all levels. This study's recommendations for the industry include developing strategies to enhance drivers, recognizing accurate and detailed information about Industry 4.0, and encouraging the adoption of new technologies.

5. CONCLUSION

This paper focuses on the identification of several barriers in Bangladesh using the ISM (Interpretive structural model) approach. 15 barriers were identified and confirmed from an extensive literature review and questionnaire, and pairwise interrelations between them were introduced as ISM demands. This led to the level identification of each barrier. The MICMAC analysis identified several barriers with strong driving power that need to be addressed, and the company's readiness was checked using a frequency table. It was found that a lack of proper knowledge is responsible for hindering the deployment of I4.0.

This study emphasized several of the 15 barriers that need priority and extensive attention when deploying Industry 4.0. It will help regulatory organizations, legislators, and decision-making authorities address the issue more quickly. It also raises the concern that limitations to technological innovation's spread in underdeveloped nations can hinder businesses from using the 4th industrial revolution's benefits.

Though the research findings are justifiable in many ways, they do have some limitations, just like any other qualitative study. Several industries' responses were covered to address company readiness and identify barriers, but it would be great if it could be done on a large scale to give a generalized idea, and by that the entire scenario of Bangladesh's manufacturing industries towards I4.0 could be depicted. This study was limited to examining the significance of 15 barriers to Industry 4.0 adoption; therefore, future studies examining additional barriers using more expert opinions are required. The current result classified barriers into five levels, with levels 1 and 3 having the greatest number of barriers. A new study of these ten obstacles is required to rank the barriers in levels 1 and 3.

This study's findings will be conceptually linked to significant parts of the 4th industrial revolution, particularly for decision-making, leading technology deployment, technology installment, and future opportunities. It might also help in formulating policy-related guidelines.

The additional study can address issues like volatility, interruptions to human-based economies, and how compliance and CSR-based activities might be taken into account to rectify any inequities that Industry 4.0 may bring about after full adoption in a variety of sectors. Furthermore, there isn't a clear organizational-focused guideline or a particular approach for adopting Industry 4.0 that will yield substantial benefits. This could be a future research scope.

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Author contributions: SH and SH: Conceptualization, Methodology, Writing-Original draft preparation, reviewing; RK: Supervising and Editing.