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Navigating Barriers to Industry 4.0 Integration: Insights from the Manufacturing Sector in India

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ABSTRACT
Industry 4.0, a transformative paradigm, holds significant implications from theory to practice. Despite its potential, adoption in developing countries lags. While prior research reveals benefits, limitations, and the forces behind Industry 4.0, limited empirical research exists on barriers to Industry 4.0 integration within manufacturing enterprises. This study focuses on identifying key barriers in an Indian manufacturing context. Drawing from existing literature, notable barriers are identified. An expert committee comprising professionals from various organizational levels is formed, and the analytical hierarchy process is employed to identify criteria weights. The study reveals that the foremost barriers include "Lack of coordination and information flow across departments" and "Lack of commitment from top management." Addressing these barriers is crucial for the effective execution of Industry 4.0, necessitating policymakers' attention and strategic planning to overcome them effectively.
Keywords : Industry 4.0, Analytic Hierarchy Process, Barriers, Manufacturing industry

I. INTRODUCTION

Industry 4.0, the fourth industrial revolution, has recently become an increasingly popular study topic. It is the meeting point of numerous cutting – edge ideas and innovations, including big data, radio-frequency identification (RFID), machine learning (ML), sensors, cloud computing, robotics, artificial intelligence (AI), additive manufacturing (AM), internet of things (IoT), and augmented reality (AR) [1], [2]. The phrase "industry 4.0" was initially used in a November 2011 German government document that was a component of the high-tech strategy for 2020 initiative [18]. The emergence of digital manufacturing, popularly referred to as the "smart factory," is the central component of industry 4.0. It entails the adoption of creative business models, process mobility, intelligent networking between industry units, flexibility and interoperability of industrial operations, and integration with suppliers and clients. Industry 4.0 relies heavily on intelligent networks constructed on top of cyber-physical systems (CPS). Utilizing the CPS, Industry 4.0 unifies the digital and physical domains to boost organizational production and efficiency. The CPS is made up of intelligent devices, storage systems, and production plants with the ability to interact, initiate actions, and exert autonomous control over one another. Industry 4.0's cutting-edge technology has the capacity to dramatically increase a production system's productivity and overall efficiency [4]. For example, according to a McKinsey report [5], transitioning to an automated system from traditional production can increase organizational productivity by 45% to 50%.Scholars, executives, and decision-makers assert that integrating CPS and Industry 4.0 methodologies into smart factories facilitates flexible production, enhances supply chains, and produces more efficient company management, all of which have important ramifications for society, the economy, and technology [18].

Industry 4.0integrates personnel, computers, robots, and data into a cohesive platform to improve supply chain agility and responsiveness [7].Even though supply chains can benefit from the introduction of Industry 4.0, there are various barriers that might impede Industry 4.0 advancement [3], [6]. Each obstacle has a varied impact on Industry 4.0 acceptability and performance. For example, according to a recent McKinsey [5] Industry 4.0 worldwide expert survey conducted in several countries, only 14% of CEOs are certain that their companies are sufficiently prepared to adopt the changes required for Industry 4.0 deployment. Because Industry 4.0 adoption presents so many obstacles, the majority of businesses have made little or no progress. Studies [7], [8] indicate that Implementing Industry 4.0 isa challenging process, and numerous businesses worldwide are having trouble with it [9]. Organizations in underdeveloped nations are still in the early phases of implementing Industry 4.0, whereas organizations in affluent nations have already benefited somewhat from implementing Industry 4.0 [10]. This is because organizations in developing nations face a number of obstacles, including inadequate infrastructure, an inadequate regulatory environment, a dearth of governmental laws, and a lack of financial support [8]. Because of this, determining the obstacles and their respective effects is essential to creating a mitigation plan that will facilitate Industry 4.0 adoption more smoothly [9].For Industry 4.0 adoption, developed countries have often created national action plans, whereas developing nations are more likely to rely on private sector efforts than on coordinated government strategies [11].Scientific research on the barriers to the implementation of Industry 4.0 has not been done extensively byresearchers.A portion of the previous research has focused on developing a structural model of the barriers to Industry 4.0 [13], [14], [15], and [16]. However, because barriers have only been identified without the support of a uniform framework, little is known about how they interact. The following research questions have been established in light of the debate above:

(i) What significant obstacles exist for the adoption of Industry 4.0 in developing nations?
(ii) What is the main obstacle that managers need to take into account in order to successfully deploy Industry 4.0 across manufacturing companies?

This research attempts to identify the most important hurdles to Industry 4.0 adoption in light of industrial organizations to ensure that the aforementioned knowledge gaps. For this research, a real-life scenario in the Indian manufacturing sector is being investigated. The barriers investigated in this research were found after a thorough literature review and interaction with industry professionals. Data is gathered through the construction of questionnaires and organized interviews with industry experts. To prioritize different hurdles, AHP isutilized. Finally, the most significant impediment is determined. The remaining portion of this research study is organized as follows: The method employed in this study is described in Section 2. Section 3 describes the suggested research framework. Section 4 demonstrates the use of the suggested research framework. Finally, section 5 summarizes the results and identifying limitations and future research opportunities.

Methods

This study uses AHP [17] to determine the most important obstacles to the implementation of Industry 4.0. AHP is a "multi-criteria decision-making (MCDM)"approach that integrates the subjective judgments of decision makers (DMs), which would otherwise be hard to quantify. Several researchers use the AHP method in a variety of domains, including quality factor analysis of manufacturing processes, sustainable supplier selection, prioritization of renewable energy resources, and barrier analysis of solar PV energy deployment, green building planning, and sustainability risk assessment. The following are the primary advantages of AHP over other decision-making techniques: (i) it may take into account the relative importance of factors, (ii) it has a lower computing complexity, and (iii) it ensures consistency in the final conclusion, and (iv) it does not necessitate the use of real data sets. The AHP method's step-by-step technique is outlined below.

Step 1: **Development of pairwise comparison matrix (D)**

If the data set has$n$ factors to access, then the square matrix that results from the pair wise comparison of i^{th}andj^{th}factor is as follows:$D = (d_{ij})_{n \times n}$. In this matrix, d_{ij} denotes the weight of the i^{th}factor in relation to thej^{th} factor. In this matrix, $d_{ij} = 1$, when $i = j$, and $d_{ji} = {}^{1}/_{d_{ij}}$. Also, in this matrix all diagonal elements are equal to unity (1).

Step 2: **Computation of the normalized matrix (B)**

The pair wise comparison matrix is normalized by dividing each column entry by the total of the corresponding 'D' column entries for each column. Let b_{ij}represent the i^{th} factor's normalized value relative to thej^{th} factor and is calculated using equation (1).

$$b_{ij} = \frac{d_{ij}}{\sum_{i=1}^{n} d_{ij}}, \text{ for } 1 \leq j \leq n \tag{1}$$

By averaging each row element, the normalized matrix can be used to determine the normalized relative weight of the matrix elements. The AHP weight (w_i) of each element is calculated using equation (2)

$$w_i = \frac{\sum_{j=1}^{n} b_{ij}}{n} \tag{2}$$

Now, two matrices, P and Q are developed in such a way that $P = D \times D' = [p_i]_{n\times 1}$ and$Q = [q_i]_{n\times 1}$ where$q_i = {}^{p_i}/_{w_i}$, $i = 1,2,3, \dots, n$, and$D' = [w_i]^{\tau}$, where τ is the transpose of the matrix. Next, calculate 'λ_{max}' that is the average of the element's matrix Q i.e $\lambda_{max} = \frac{\sum_{i=1}^{n} q_i}{n}$

Step 3: **Determine the consistency ratio (CR)**

Consistency ratio is evaluated as $CR = {}^{CI}/_{RI}$. Where, CI denotes the consistency index and it is expressed as follows: $CI = {}^{(\lambda_{max} - n)}/_{n-1}$. A lower CI value indicates only a little consistency deviation. RI is the random index for the elements in the system. The different values of RI corresponding to different values of n can be found in the literature of Saaty [17]. Basically, a CR value of 0.1 of less is acceptable as a measure of consistency. If the value is greater than 0.1, then further investigation is required in the pairwise comparison matrix.

Proposed research framework

The research is demonstrated in the subsequent steps as shown in Fig.1.

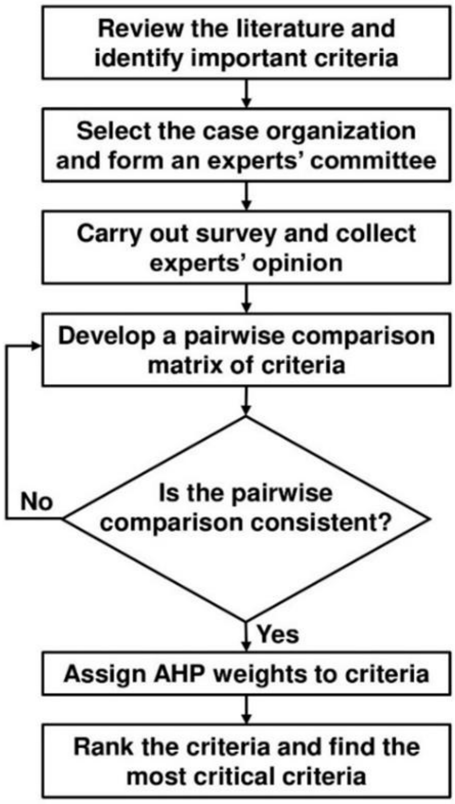

Fig.1 Flow diagram for the suggested framework

First, a research organization is chosen, and significant criteria (barriers) are determined from the body of existing literature. After then, a group of industry experts from different case organization departments create an expert committee. To gather pertinent data, a survey has been conducted. Experts' subjective preference over the relative importance of criteria is taken and measured against a Saaty's9-point linguistic scale [17], which is shown in Table 1.

Table 1 Saaty's 9-point scale of subjective preference

Numerical value	Measure of preference
9	Extremely preferred
7	Very strongly preferred
5	Strongly preferred
3	Moderately preferred
1	Equally preferred
2, 4, 6, 8	Intermediate values

The elements (d_{ij}) in the pairwise comparison matrix is derived from the experts' opinion using this 9-point scale. For example, if the element d_{12} is 7 then, it can be said that according to the decision maker or expert's perception, first criteria is extremely preferred with respect to second criteria.Thus, the pairwise comparison matrix among criteria is developed with the help of 9-point scale (Table 1). Now, the criteria weights are determined using equation (2). Afterwards, consistency is verified by calculating the consistency ratio (CR). If the CR value lies within the acceptable range, then final weights are assigned to criteria. Otherwise, pairwise comparison matrix needs further assessment by experts. Finally, criteria are ranked according to their AHP weights. The criterion that has the highest weight is identified as the critical criteria.

Application

To show the applicability of the suggested research approach, a real-world challenge of Industry 4.0 deployment in an India-based manufacturing organization is explored. The name, location, company profile, and other identifiable characteristics of the organization are not provided in this study according to the privacy policy. The chosen organization is a well-known name in the Indian manufacturing business. It has implemented various efforts and careful moves towards Industry 4.0 deployment. The organization is working to achieve company sustainability by implementing Industry 4.0 technology. Nonetheless, the company is having a lot of trouble modernizing and bringing the current organizational structure into compliance with Industry 4.0 norms. In practice, it is simply impossible to determine which barriers are more important than others in terms of the degree of their opposition to Industry 4.0 adoption. Furthermore, policymakers in organizations cannot devise methods to remove all hurdles at once. As a result, it is critical to determine which of the barriers is the most obstructive in nature. This study seeks to identify a collection of significant impediments identified in the literature by diverse writers. The most significant obstacle is determined using the suggested research approach, which will assist managers and policymakers in developing effective strategies to remove crucial barriers. The selected criteria are shown in Table 2.

Table 2 List of selected criteria (barriers)

Name	Notation	Source
Lack of IT competence and infrastructure	B1	Müller et al. [13]; Kamble et al. [9]
Lack of data accessibility, data protection and IT security	B2	Orzes et al. [6]; Horváth et al. [10]
Lack of financial support and investment	B3	Tay et al. [14]; Majumdar et al. [16]
Lack of government legislation and regulatory framework	B4	Sony et al. [7]; Raj et al. [12]
Lack of coordination and flow of information across departments	B5	Chauhan et al. [8]; Machado et al. [1]
Lack of willingness of top management	B6	Kumar et al. [15]; Stentoft et al. [3]

A range of experts are chosen from the case organization. Twenty experts have been appointed to a committee, five of whom will be chosen from the tactical, five from the strategic, and ten from the operational levels. Each member has over twenty years of business experience and is extremely talented in their respective fields. The general manager, an engineer for research and development, a manager for quality control, a project manager, facility managers, a process engineer, supervisors, and technicians are among the chosen personnel. Relative importance of criteria in the pair wise comparison matrix is obtained from the subjective ratings (9-point scale) provided by the experts. As there are twenty experts, the average of their ratings is considered for each element in the matrix. For example, if the rating of d_{ij} provided by the experts is denoted by ${d_{ij}}^k$, where k represents the number of experts (here, $k = 20$), then the average rating of d_{ij} will be $\frac{1}{k}\sum_{k=1}^{k} {d_{ij}}^k$ (for, $1 \leq i \leq n, 1 \leq j \leq n$), where, n is the number of criteria. Thus, the pairwise comparison matrix (D) is constructed (Table 3).

Table 3 Pair wise comparison matrix (D)

	B1	B2	B3	B4	B5	B6
B1	1	0.50	0.33	0.20	0.25	0.13
B2	2	1	0.25	0.33	0.25	0.14
B3	3	4	1	0.25	0.33	0.14
B4	5	3	4	1	0.50	0.50
B5	4	4	3	2	1	0.50
B6	8	7	7	2	2	1

Now, the above matrix is normalized using equation (1) and the normalized matrix (B) is shown in Table 4.

Table 4 The normalized matrix (B)

	B1	B2	B3	B4	B5	B6
B1	0.04	0.03	0.02	0.03	0.06	0.05
B2	0.09	0.05	0.02	0.06	0.06	0.06
B3	0.13	0.21	0.06	0.04	0.08	0.06
B4	0.22	0.15	0.26	0.17	0.12	0.21
B5	0.17	0.21	0.19	0.35	0.23	0.21
B6	0.35	0.36	0.45	0.35	0.46	0.41

The weight (w_i) of each element is calculated using equation (2) and is shown in Table 5.

Table 5 Weights of criteria (w_i)

Criteria	B1	B2	B3	B4	B5	B6
Weights	0.04	0.05	0.10	0.19	0.23	0.40

Now the consistency is examined by finding the CR value. This is shown in Table 6.

Table 6 Consistency ratio table

Particulars	Expressions	Values
Maximum eigen value	λ_{max}	6.38

Consistency index	$CI = {(\lambda_{max} - n)}/{n-1}$	0.076
Random index	$RI_{n=6}$	1.24
Consistency ratio	$CR = {CI}/{RI}$	0.0613

The consistency ratio is 0.0613, which is less than 0.1 and satisfies the condition for consistency. As a result, the pairwise comparison may be considered to be consistent. As a result, the AHP weights are allocated to the appropriate criterion. The criteria are now sorted according to their AHP weights. B6 comes first, followed by B5 > B4 > B3 > B2 > B1. As a result, B6 is given the most weight and is the most important criterion.

Discussions and Conclusion

The findings show the barriers' priority ordering based on their AHP weights. According to Table 5, In the hierarchy of criteria determined by their weights, B6 comes in first. As a result, the 'lack of willingness of top management' is a remarkable barrier to Industry 4.0. This finding agrees with Horváth et al. [10], Jayashree et al. [11], Majumdar et al. [16], and Müller et al. [13]. According to Horváth et al. [10], organizational aversion at various employee and management levels might severely impede Industry 4.0 adoption. According to Jayashree et al. [11], Adoption of Industry 4.0 and overall sustainability are significantly impacted by top management and IT infrastructure.According to Majumdar et al. [16], a key barrier to Industry 4.0 implementation is a lack of commitment from senior management. According to Müller et al. [13], Industry 4.0 can only be successfully implemented if senior management is totally committed and dedicated in its adoption. As a result, this study shows that employee acceptability and management willingness to transition to Industry 4.0 are critical. B5, or 'lack of coordination and information flow among departments,' is ranked second. It is also a powerful barrier. This supports the conclusions of Machado et al. [1] and Saatçiolu et al. [2], who stated that coordination, and communication across departments is critical for the efficient adoption of Industry 4.0. To effectively deploy Industry 4.0, the organisation must tear down the fictional wall separating departments and bring ideas from all divisions together on the same platform. Concurrent engineering principles, in other words, should be implemented. Other than B6 and B5, the remaining barriers have lower weights. As a result, in comparison to B6 and B5, the remaining barriers have no substantial impact on Industry 4.0 deployment. This study makes several theoretical advances, such as revealing that the 'lack of commitment of top management' and the 'lack of coordination and flow of information across departments' are two important barriers. The findings also imply that managers and governments should prioritise these barriers and devise appropriate methods to overcome them. In practice, the AHP weight-based framework may be an effective option for analysing many aspects and determining the most important component in a variety of decision-making sectors. It is simple to utilise and put into action. To the best of the authors' knowledge, no study has been carried out that looks into the major barriers to Industry 4.0 adoption while conducting a field-based investigation in a developing country.

Although this study finds six significant barriers based on the literature, more significant barriers may have been ignored. Because Industry 4.0 is a new field of study that has yet to be completely adopted in most businesses in both developed and developing nations, quantitative data and exact estimations may be unavailable in real-world circumstances. In such instances, decision-makers must rely on professional qualitative assessment. AHP is a great decision-making method for dealing with qualitative data. To assess the relative relevance of criteria, this study combines experts' subjective preferences. As a result, ambiguity may exist in the end result. Future research may seek to eliminate ambiguity by including fuzzy set theory into the suggested technique. Future research can look at a larger number of barriers to determine the most significant ones. Other decision-making methodologies, such as “Interpretative Structural Modelling” (ISM) and “decision-making trial and evaluation laboratory” (DEMATEL), can be used to identify important obstacles and their interactions. Furthermore, future research might use the presented paradigm to determine obstacles facing Industry 4.0 deployment in additional industrial sectors.

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