International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Journal Européen des Systèmes Automatisés
Vol. 57, No. 1, February, 2024, pp. 239-253
Journal homepage: http://iieta.org/journals/jesa

Challenges in Adopting Industry 4.0 for Indian Automobile Industries: A Key Experts' Perspective

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https://doi.org/10.18280/jesa.570123

Received: 6 December 2023
Revised: 24 January 2024
Accepted: 5 February 2024
Available online: 29 February 2024

Keywords:
industry 4.0, automotive industry, technological change, OEMs, suppliers, technology implementation

ABSTRACT

Industry 4.0 has revolutionised manufacturing, presenting significant challenges for adoption, particularly in developing countries like India. This study identifies and evaluates challenges specific to the Indian automobile industry's implementation of Industry 4.0 to address this. Leveraging Latent Dirichlet Allocation (LDA), a machine learning-based text analysis algorithm, we discerned challenges from existing literature. Subsequently, employing the Delphi method, we refined these challenges, leading to a questionnaire-based survey and fuzzy Decision-Making Trial and Evaluation Laboratory (f-DEMATEL) data analysis to prioritise them. Our research framework involved collaboration with original equipment manufacturers (OEMs), suppliers, and academic experts who ranked 20 challenges by influence. Findings reveal divergent perspectives: OEM experts highlight concerns regarding outdated infrastructure, high initial costs, financial uncertainty, and a lack of strategy and standards. Supplier industries emphasise the importance of Information Technology and Research & Development departments, the maturity of Industry 4.0 tools, industry-academia collaboration, and addressing strategy and standards gaps. Academia underscores the need for financial support, government assistance, and organisational adjustments. These insights offer crucial guidance for managing Industry 4.0 challenges in the Indian automobile industry, facilitating targeted and practical implementation strategies.

1. INTRODUCTION

The fourth industrial revolution, Industry 4.0, integrates digital technologies with physical systems, decentralising decision-making in manufacturing [1]. Originating from Germany in 2011 [2], Industry 4.0 has gained global traction, especially in developed countries, where it transforms production environments through tools like cyber-physical systems (CPS) and the Internet of Things (IoT) [3]. This digital transformation extends to the automobile sector, where Industry 4.0 tools facilitate designing, product development, and manufacturing processes [4]. It helps manufacture high-quality automobiles with smart features that can be customised per customer requirements [5]. Industry 4.0 can support all the value chain components, from designing and development, manufacturing, supply chain, sales, and service of automobiles [6-8]. Therefore, it is crucial to identify and evaluate the challenges for automobile companies implementing Industry 4.0, especially in emerging and developing economies such as India [9]. Much literature with a comprehensible and clear description presents the challenges and barriers to Industry 4.0 implementation in the manufacturing sector [10, 11]. However, there is a need for an empirical study to establish clarity in understanding the challenges/barriers of Industry 4.0 implementation specific to an industry considering the economic and geographical factors of that location.

The Indian automobile sector faced a significant slump of 40% during the third quarter of 2018-19, starkly contrasting its annual sales growth of 9.3% in 2017 [12]. This downturn underscores the pressing need to address the challenges hindering the adoption of Industry 4.0 within the sector. Factors contributing to this downturn include the global economic crisis, dwindling consumer demand, ineffective government policies, and the industry's gradual transition towards electric mobility. Additionally, delays in technology upgrades and reluctance to invest in Industry 4.0 tools have further exacerbated the challenges automobile companies face. As a result, this study seeks to shed light on the hurdles impeding the implementation of Industry 4.0 in the Indian automobile industry, thereby providing valuable insights to overcome these obstacles and foster sustainable growth in the sector [13].

This study employs the fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique to assess the implementation challenges faced by the Indian automobile industry in adopting Industry 4.0 [14]. The fuzzy-DEMATEL method is chosen for its ability to analyse complex relationships among criteria and handle inherent biases in expert evaluations. Unlike other multi-criteria decision-making approaches, fuzzy-DEMATEL prioritises criteria and illustrates causality, essential for evaluating challenges and their interdependencies in Industry 4.0 implementation. This study identifies critical challenges and provides insights into their managerial and theoretical implications by prioritising challenges and elucidating their causal relationships. The purpose of this study is not only to prioritise the challenges but also to assess the interactions that affect the implementation of Industry 4.0 in the Indian automotive industry. The present research work expands on the concurrent theme of analysing the factors challenging the implementation of Industry 4.0.

The research objectives of this paper are:

(1) Identify the challenges to implementing Industry 4.0 tools in the Indian automobile industries.

(2) Structure the identified challenges to find their interdependency and causal relationship.

(3) Elucidate the managerial and theoretical implications of the result obtained.

The novelty lies in (i) the use of text analysis to identify the themes using the machine learning tool named Latent Dirichlet Allocation (LDA) algorithm, (ii) applying the fuzzy-DEMATEL method through Python programming to prioritise the challenges and (iii) the exclusivity of its relevance to the automobile manufacturing industries in India.

The paper is organised into five parts. The next part contains a review of past research works. The third part presents the research framework, data collection methods, and the calculation of fuzzy-DEMATEL weight used to prioritise the challenges. The results obtained by applying the fuzzy-DEMATEL approach are presented in the fourth part, followed by their implications. In the last part, the conclusion and future research scope is discussed.

2. THEORETICAL BACKGROUND

The literature review process was used to identify the challenges in implementing Industry 4.0 in Indian automobile industries:

(1) 256 journal articles, relevant reports, and conference papers were collected from Scopus and Web of Science databases using keywords; "Industry 4.0" AND {"implement" OR "adopt"} AND {"barriers" OR "challenges"}. These keywords were selected as they best describe the intent of the research in understanding and analysing the challenges or barriers in implementing or adopting Industry 4.0.

(2) These shortlisted articles were screened based on their time frame, i.e., papers published during 2015-2022 were included. This screening yielded 114 articles. As the research needs to remain relevant, only the latest developments and associated challenges in implementing Industry 4.0 were included in the review.

(3) In the next stage, those articles with missing abstracts, titles, or author keywords were removed. Based on this, 79 articles were included.

(4) Finally, 33 articles with clearly stated methodology and problem statements were selected in their abstract.

The literature review provided insights into the current state of research on Industry 4.0 and the challenges faced by the Indian automobile industry in implementing it. To comprehensively understand these challenges, we applied Latent Dirichlet Allocation (LDA) [15], a topic modelling algorithm, to identify latent topics within 33 relevant articles. The LDA method was employed due to its capability to uncover latent topics within a corpus of textual data in significantly less time. LDA is a widely recognised and effective topic modelling algorithm in natural language processing and machine learning, specifically designed to unveil hidden thematic structures in large datasets [16]. By applying LDA to the selected pool of 33 articles in the literature review, we aimed to extract 30 latent topics, each representing a distinct theme or challenge related to Industry 4.0 implementation. This unsupervised clustering technique allowed us to capture nuanced patterns and interconnections among challenges, providing a comprehensive understanding of the multifaceted issues faced by the industry.

2.1 LDA topic modelling

Latent Dirichlet Allocation (LDA) is a popular unsupervised topic-modelling technique in machine learning and natural language processing. The idea behind topic modelling is to use machine learning to find patterns in word usage and give a semantic meaning. A topic is a collection of words semantically clustered frequently [17]. Topic modelling links words with related meanings, making it easier to analyse large amounts of unlabelled text and distinguish between words with multiple meanings. Generally, topic modelling is used to identify hidden themes or topics within a corpus of textual data (i.e., a large group of text documents). This method views every topic as a composite of a text's numerous themes. The present investigation employed the Latent Dirichlet Allocation (LDA) methodology, as shown through the code in Table 1, to discern the latent subjects concealed within the abstracts of the chosen literature [18].

Thirty distinct themes, as shown in Table 2, representing different facets of Industry 4.0 implementation in the Indian automobile industry, were produced by performing an LDA analysis on the titles, abstracts, and author keywords. These themes, or subjects, highlight several of the difficulties related to this undertaking.

Table 1. Code for LDA analysis

Function	Code
Libraries	import pandas as pd from gensim import corpora from gensim.models import LdaModel from gensim.parsing.pre-processing import STOPWORDS from nltk.tokenise import word_tokenize from nltk.corpus import stopwords from nltk.stem import WordNetLemmatizer

Loading dataset and extracting abstract	# Load datasets
	df=pd.read_csv('dataset.csv')
	# Extract abstract from each dataset
	abstracts=df['Abstract'].dropna().tolist()

Stop words	stop_words = set(stopwords.words('english')).union(set(STOPWORDS))

Pre-processing function	def preprocess_text(text):
	lemmatizer = WordNetLemmatizer()
	# Tokenise and remove punctuation
	tokens=word_tokenize(text)
	tokens=[word.lower() for word in tokens if word.isalpha()]
	# Remove stopwords and lemmatise
	tokens=[lemmatizer.lemmatize(word) for word in tokens if word not in stop_words]
	return tokens

Calling pre-processing function	processed_abstracts=[preprocess_text(abstracts) for Abstract in abstracts]
LDA function	def perform_lda(dataset): dictionary=corpora.Dictionary(dataset)

	corpus=[dictionary.doc2bow(dataset) for review in reviews]
	# Set the number of topics (adjust as needed)
	num_topics=30
	lda_model=LdaModel(corpus, num_topics=num_topics, id2word=dictionary, passes=100)
	return lda_model

Calling LDA function	lda_model=perform_lda(processed_abstracts)

Table 2. Topics determined by the LDA analysis on bibliometric data

Challenge Areas Identified by LDA Analysis
Smart Data Management
Industry Operation and Development
Leadership in a Changing Landscape
Education and Skill Development
Data Analytics and Predictive Maintenance
Mathematical Modeling and Decision-Making
Pervasive Connectivity and Cloud Solutions
Cognitive Computing and Adaptability
Innovative Production Technologies
Lean Manufacturing and Job Automation
Digital Tools and Design
Quality Assurance and Smart Auditing
Supply Chain Optimisation
Financial Digitalization and Leadership
Asset Management and Accessibility
Robotics and Automation Services
Crime Prevention and Data Security
Digital Transformation in Construction
Auxiliary Support and Remote Monitoring
Supply Chain Collaboration and Traceability
Work Culture and Contextual Management
Intelligent Fleet Maintenance
Technological Transformation and Policy
Technological Criteria and Decision-Making
Industrial Research and Data Utilization
Seamless Industry Transformation
Digital Supply Chain Management
Operational Flexibility and Digitalisation
Adaptive Response to Unexpected Events
Industrial Design and Model Support

2.2 Delphi-based expert consensus

With the help of the 30 topics extracted through LDA analysis, we identified the specific challenges from the 33 documents in the Scopus and Web of Science database utilised for the LDA analysis. We engaged industry experts in a Delphi method-based consensus-building exercise to refine these challenges to eliminate or combine these challenges to reduce complexity and remove repetition. Industry 4.0 experts were chosen based on their expertise and background in the Indian automobile industry. A list of the challenges mentioned in the database was given to the panel, and they were asked to order them according to importance. The panel was also asked to recommend any additional challenges the literature investigation did not identify. After rigorous discussions and evaluations, the challenges were distilled down to a final set of 20 challenges. The Delphi method's outcomes agreed on the potential challenges the Indian automobile sector encounters in implementing Industry 4.0.

The final challenges selected in the study were classified into four categories: (i) Internal, (ii) External, (iii) Apprehensive, and (iv) Prospective challenges. Internal challenges included challenges that were specific to the automobile industry, such as an outdated infrastructure, lack of strategy and standards, lack of knowledge and awareness, the reluctance of top management, lack of support from employees and stakeholders, lack of skilled workers [19], poor internet connectivity and an inability to collect and identify data. External challenges were factors outside the control of the automobile industry, such as lack of government support [20], lack of financial aid, lack of customer awareness, and recession due to the COVID-19 pandemic. Apprehensive challenges included fears and concerns of stakeholders, such as concern for data security [19], fear of loss of employment [21], uncertainty about financial benefits [19], and changes in work organisation. Prospective challenges included challenges inherently expected to deter the implementation of Industry 4.0 tools in the automobile industry, such as the absence of an IT and R&D department, lack of research and collaboration with academia, high initial investment cost, and low maturity level Industry 4.0 tools [19].

Table 3. Identified barriers to Industry 4.0 implementation in the Indian automobile industry

Category	Code	Challenges	Description
Internal	B01	Outdated infrastructure and machinery	Indian automobile industries use outdated technology and equipment [22], leading to low productivity, increased downtime, higher maintenance costs, and an inability to adapt to new technologies.
	B02	Absence of strategy and standards	There must be more strategy and standardisation of processes and systems to avoid increased costs, lower productivity, and increased wastage. A lack of standardisation also leads to difficulties in collaboration and communication between different departments and organisations within the industry.
	B03	Lack of knowledge/awareness	The lack of understanding of Industry 4.0 concepts and technologies among the automobile industries can lead to resistance to change and reluctance to invest in new technology. Inadequate competency enhancement training and education programs exacerbate this challenge, making it harder to implement Industry 4.0.
	B04	The reluctance of top management	The lack of interest or hesitation shown by top management in adopting Industry 4.0 practices. It can be due to various reasons, such as a lack of understanding, fear of change, or concerns about the costs involved. The reluctance of top management can lead to underutilisation of resources for Industry 4.0 implementation.
	B05	No support from employees and OEMs/supplier industries	With support from key stakeholders, implementing the necessary infrastructure, processes, and culture changes can be easier for industries. This challenge highlights the importance of building a collaborative and supportive environment.

	B06	Lack of skilled workers	Implementing Industry 4.0 requires a workforce well-versed in new technologies and can operate and maintain them effectively. However, the lack of continued skill development opportunities has aggravated this challenge, as workers need to gain the necessary skills and knowledge to operate and maintain advanced machinery and technologies effectively.
	B07	Poor internet connectivity	More internet connectivity is needed to ensure the smooth flow of data between machines, workers, and systems. Industry 4.0 relies heavily on data collection and transfer, which require fast and reliable internet connections.
	B08	Inability to collect and identify data	Proper data collection and identification make it easier to make data-driven decisions, optimise processes and improve the industry's overall performance.
	B09	Lack of government support	The absence of a legal framework and regulatory issues further exacerbate the challenges by causing confusion and uncertainty in the minds of the stakeholders. Additionally, outdated laws and complex systems make it difficult for industries to comply with regulations and hamper the adoption of new technologies.
External	B10	Lack of financial support	The lack of financial support, including tax benefits, funds, or investments, is a significant challenge to implementing Industry 4.0 in Indian automobile industries. The high initial investment cost is an essential factor that impedes the application of Industry 4.0, and the need for more financial incentives exacerbates the problem.
	B11	Lack of customer awareness	Customers need to be made aware of the intelligent features and products that Industry 4.0 can provide to the automobile industry. This lack of understanding results in customers not demanding these smart products, leading to lower motivation among the manufacturers to invest in them.
	B12	Recession due to the COVID-19	The COVID-19 pandemic has caused a recession in many countries, which has led to financial constraints and uncertainty in the automobile industry. This has made it difficult for automobile manufacturers to invest in new technologies and implement Industry 4.0 initiatives.
	B13	Concern for data security	It is a significant concern for stakeholders worried about data breaches, data theft, and the misuse of sensitive information. There needs to be more trust in the security of connected systems and awareness of security measures and protocols.
Apprehensive	B14	Fear of loss of employment	Employees resist adopting new technologies, fearing that machines or robots might replace them. This fear leads to a lack of enthusiasm for re-skilling and up-skilling necessary for implementing Industry 4.0.
	B15	Uncertainty about financial benefits	Companies only invest in new technologies if they understand the potential financial returns, costs, and risks. A proper cost-benefit analysis makes it easier to justify the investment required to implement Industry 4.0.
	B16	Change in work organization	The current products and processes must be more labour-intensive for Industry 4.0 implementation. The emergence of new business models, such as product-service systems (PSS), requires significant organisational structure and business process changes.
	B17	Absence of IT and R&D department	The lack of IT expertise can limit the capability to develop and maintain the IT infrastructure necessary for Industry 4.0 implementation. Similarly, the need for an R&D department can limit the ability to research and develop new technologies.
Prospective	B18	Lack of research and collaboration with academia	The lack of research and collaboration with academia limits the availability of new ideas, technologies, and processes that could benefit the industry. It also limits access to specialised knowledge and expertise that could lead to breakthroughs.
	B19	High initial cost	The high initial investment cost for implementing Industry 4.0 technologies and processes is a significant barrier for the Indian automobile industry, especially for smaller businesses.
	B20	Low maturity levels of I4.0 tools	The low maturity of technologies, such as IoT sensors, cloud computing, and artificial intelligence, makes it difficult for Indian automobile industries to adopt Industry 4.0 and realise its benefits.

Table 4. Frequency of occurrence of challenges in implementing Industry 4.0 in the Indian automobile industry in past research works

Sources	B01	B02	B03	B04	B05	B06	B07	B08	B09	B10	B11	B12	B13	B14	B15	B16	B17	B18	B19	B20
[23]	•	•	•			•		•		•			•		•		•	•		•
[11]	•	•		•	•	•		•	•	•			•		•	•	•		•	•
[24]	•	•	•	•		•	•	•	•				•	•		•			•	
[25]	•	•	•	•	•	•	•	•	•	•	•		•		•	•	•	•		
[26]	•	•				•	•						•	•		•	•		•	
[27]	•	•		•		•		•		•			•		•	•	•	•	•	•
[28]	•	•	•		•	•				•			•			•				•
[29]		•	•	•	•			•		•			•		•	•				
[30]	•				•		•				•		•						•	
[31]	•	•			•	•	•	•	•				•		•					•
[32]	•	•					•	•					•			•			•	
[33]		•	•			•									•	•				
[34]	•	•	•	•	•		•	•		•				•	•	•	•	•	•	
[1]	•		•	•		•	•	•		•	•	•	•	•		•	•	•		
[35]	•	•	•	•	•	•	•	•	•						•	•			•	

[36]		•	•	•	•	•			•	•					•				•	
[37]	•	•	•	•	•	•		•		•	•						•		•	•
[38]		•	•			•	•			•	•				•		•	•	•	•
[39]	•	•	•	•	•	•		•		•			•	•	•	•			•	•
[40]	•	•	•	•	•	•	•	•	•	•			•		•	•			•	
[41]		•	•		•	•				•						•		•	•	
[42]	•	•	•			•			•	•		•	•		•	•	•	•		•
[43]			•	•	•							•		•		•				
[44]		•	•		•	•			•					•	•	•		•		•
[45]	•	•		•		•							•	•	•	•				
[46]	•	•	•	•	•	•	•	•	•				•	•	•	•	•		•	•
[47]	•	•	•	•	•	•	•				•	•		•	•	•			•	
[48]	•	•			•	•		•					•	•	•	•			•	
[13]	•	•	•		•				•		•		•	•		•	•		•	
[49]			•	•		•							•		•	•		•	•	
[50]	•	•	•	•	•	•	•		•				•	•	•	•	•	•	•	
[51]	•	•		•		•	•	•					•	•		•			•	•
[52]		•	•	•		•		•	•		•		•		•	•			•	

The challenges affecting the application of Industry 4.0 in the Indian automobile industries, categorised into four categories, are described in Table 3. The frequency of occurrences in past research works (before March 2022) assessing the challenges of Industry 4.0 implementation in various countries and industries is shown in Table 4.

3. RESEARCH FRAMEWORK

Implementing Industry 4.0 tools in the Indian automobile industry has its challenges. Identifying the interdependency between them and the significance level of each challenge is necessary to address these challenges. This study aims to identify the challenges in implementing Industry 4.0 in the Indian automobile industry and prioritise them by analysing the responses obtained from a questionnaire survey of experts from OEMs, supplier industries, and academia using the fuzzy-DEMATEL method.

The research methodology, as shown in Figure 1, involved the following steps:

(1) Identification and selection of challenges through Machine Learning text analysis (LDA algorithm), followed by selecting challenges from the database and refining through Delphi-based consensus building: The initial step of the study was to conduct a literature review of the challenges faced by the Indian automobile industry in implementing Industry 4.0.

(2) Collection of data through Questionnaire-based Survey: Based on the selected challenges after the Delphi method, a questionnaire was developed to survey experts from OEMs, supplier industries, and academia. Experts were asked to rate the influence of one challenge over others in implementing Industry 4.0 in the Indian automobile industry.

(3) Data analysis using Fuzzy-DEMATEL technique: The data obtained from the questionnaire survey were analysed using the fuzzy-DEMATEL method. The fuzzy-DEMATEL approach is a decision-making method that can determine the interdependency between challenges and the cause-effect analysis of the challenges.

The expected outcomes of this study are to identify the challenges faced by the Indian automobile industry in implementing Industry 4.0, prioritise them based on their significance, and determine the interdependency and cause-effect relationship between challenges. This study can help develop a comprehensive strategy to address the challenges. The study will be helpful for policymakers, industry experts, and academics working in the field of Industry 4.0 in the Indian automobile industry.

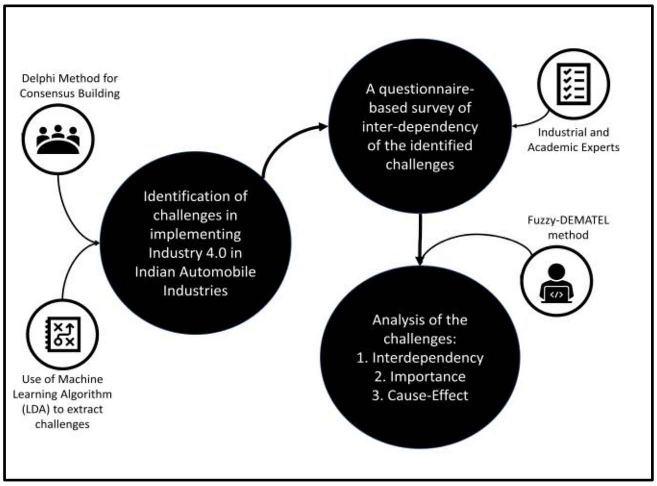

Figure 1. The research framework of the current study

3.1 Questionnaire-based survey

A questionnaire was developed to survey experts on the influence of challenges in implementing Industry 4.0 in the Indian automobile industry. The questionnaire included challenges identified through LDA analysis and the Delphi method with Industry 4.0 experts. Experts from OEMs, supplier industries, and academia were asked to rate the influence of one challenge over others using a 5-point Likert scale. Triangular fuzzy values were assigned to each code to reduce the vagueness, ambiguity, and distortion in responses, as shown in Table 5.

Table 5. Scoring of responses by participants

Lingual Term	Responder's Code	Triangular Fuzzy Number
No influence	A	(0, 0, 0.25)
Very low influence	B	(0, 0.25, 0.5)
Moderate influence	C	(0.25, 0.5, 0.75)
High influence	D	(0.5, 0.75, 1.0)
Very high influence	E	(0.75, 1.0, 1.0)

The triangular membership functions (graphically shown in Figure 2) corresponding to the 5-point Likert scale are:

$$\mu_A(x;0,0,0.25) = \max\left(\left(\frac{0.25-x}{0.25}\right),0\right) \quad (1)$$
$$0 \leq x \leq 0.25$$

$$\mu_B(x;0,0.25,0.5) = \max\left(\min\left(\frac{x}{0.25},\frac{0.5-x}{0.25}\right),0\right) \quad (2)$$
$$0 \leq x \leq 0.5$$

$$\mu_C(x;0.25,0.5,0.75) = \max\left(\min\left(\frac{x-0.25}{0.25},\frac{0.75-x}{0.25}\right),0\right) \quad (3)$$
$$0.25 \leq x \leq 0.75$$

$$\mu_D(x;0.5,0.75,1.0) = \max\left(\min\left(\frac{x-0.5}{0.25},\frac{1.0-x}{0.25}\right),0\right) \quad (4)$$
$$0.5 \leq x \leq 1.0$$

$$\mu_c(x;0.75,1.0,1.0) = \max\left(\left(\frac{x-0.75}{0.25}\right),0\right) \quad (5)$$
$$0.75 \leq x \leq 1.0$$

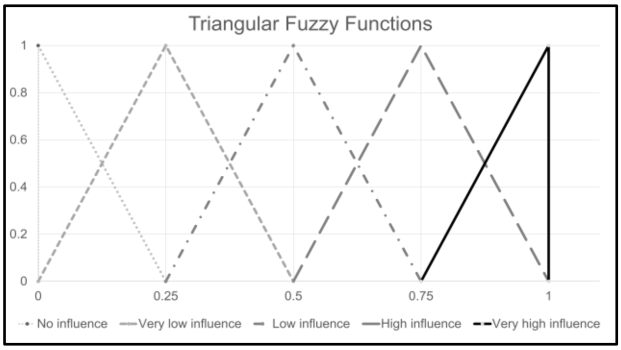

Figure 2. Triangular membership functions are used to represent the response of the experts

3.2 Data collection

The selection of experts for this study followed a deliberate and systematic approach to ensure expertise diversity and sector representation within the Indian automobile industry. The snowball sampling method, a widely recognised technique in qualitative research, was used to identify and recruit individuals with significant knowledge and experience relevant to Industry 4.0 implementation in the Indian automobile sector. Initially, key informants possessing expertise in the field were identified based on their publications, professional affiliations, and contributions to the industry. These key informants were then asked to recommend additional experts known to them who could provide valuable insights into the challenges of Industry 4.0 adoption. Through this iterative process, we expanded our network and ultimately recruited a diverse panel of 17 experts comprising representatives from OEMs, supplier industries, and academia. It was ensured that the sample size meets the criteria of fuzzy-DEMATEL analysis [53, 54] and is proportionally representative of focus groups, with three experts from OEMs, eight experts from supplier industries, and six experts from academia, as shown in Table 6. Careful consideration was given to the composition of the expert panel, with efforts made to include individuals representing each sector proportionally. By recruiting experts from diverse backgrounds and sectors, we aimed to capture a comprehensive range of perspectives and insights into the challenges of implementing Industry 4.0 across different industry segments. The expertise and qualifications of each expert were verified through their professional affiliations, publications, and contributions to the field, ensuring that they possessed the requisite knowledge and experience to provide meaningful input for the study. The survey questionnaire was designed based on the challenges identified through the LDA analysis and selected by the Delphi method involving Industry 4.0 experts. The language used in the questionnaire was ensured to be easy to understand for the participants. Participants had enough time to complete the survey, which was carried out using a web-based platform. The responses from the participants, which were personal and identifiable, were kept anonymous and confidential.

Table 6. Demographics of experts

Industrial Experts	OEMs	Deputy General Manager	2	3
		Floor Manager	1	
	Suppliers	Owners	1	8
		Managers	4	
		Supervisor	2	
		Operator	1	
	Academicians			6
	Total			**17**

3.3 Fuzzy-DEMATEL technique

The fuzzy-DEMATEL technique is a multi-criteria decision-making (MCDM) framework that evaluates and scores complex relationships between variables. This method's key advantage is its ability to analyse cause-and-effect linkages. The original Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique was developed by the Science and Human Affairs Programme at the Battelle Memorial Institute of Geneva between 1972 and 1976 [14]. Since then, it has gained popularity among researchers, with various studies utilising it in some variation and combination with other MCDM methods [55, 56]. The DEMATEL technique transforms the relationship between the causes and consequences of criteria into a precise system structural model. The mathematics behind the fuzzy-DEMATEL technique is described in greater detail below.

3.3.1 Average response matrix

The average of the fuzzy set values of all the responses was taken using Eq. (6) for further calculations.

$$a_{ij}^* = \frac{\sum a_{ijk}}{n}$$
$$b_{ij}^* = \frac{\sum b_{ijk}}{n} \quad (6)$$
$$c_{ij}^* = \frac{\sum c_{ijk}}{n}$$

where, (a, b, c) is the fuzzy triangular set corresponding to the response by participant k on the influence of barrier i on barrier j, n is the total number of participants in the survey.

Corresponding Python code:

```
>>   for k in range (0, n)
>>       X_a=((X_a*k)+(X_aijk))/(k+1)
>>       X_b=((X_b*k)+(X_bijk))/(k+1)
>>       X_c=((X_c*k)+(X_cijk))/(k+1)
>>       k=k+1
```

3.3.2 Normalised average response matrix

The average response matrix was normalised using Eq. (7), as shown below:

$$a_i^N = \frac{a_i^*}{max\ (\sum c_i^*)}$$
$$b_i^N = \frac{b_i^*}{max\ (\sum c_i^*)} \quad (7)$$
$$c_i^N = \frac{c_i^*}{max\ (\sum c_i^*)}$$

Corresponding Python code:

```
>>    NR_a=X_a/numpy.max(numpy.sum(X_c, axis=1))
>>    NR_b=X_b/numpy.max(numpy.sum(X_c,axis=1))
>>    NR_c=X_c/numpy.max(numpy.sum(X_c, axis=1))
```

3.3.3 Total relation matrix

The Total Relation Matrix is calculated using Eq. (8), where I denote an Identity Matrix.

$$a_i^T = a_i^N \times (I - a_i^N)^{-1}$$
$$b_i^T = b_i^N \times (I - b_i^N)^{-1} \quad (8)$$
$$c_i^T = c_i^N \times (I - c_i^N)^{-1}$$

Corresponding Python Code:

```
>>    T_a=numpy.matmul (NR_a,
      numpy.linalg.inv(numpy.identity(len(dataset))-NR_a))
>>    T_b=numpy.matmul (NR_b,
      numpy.linalg.inv(numpy.identity(len(dataset))-NR_b))
>>    T_c=numpy.matmul (NR_c,
      numpy.linalg.inv(numpy.identity(len(dataset))-NR_c))
```

The variable ‘dataset’ stores the matrix size, which must be the same as the normalised response matrix.

3.3.4 Defuzzified total relation matrix

The fuzzy values from the Total Relation Matrix are de-fuzzified into crisp values using the Eqs. (9)-(12).

$$a_i^n = \frac{a_i^T - min\ (a_i^T)}{\partial}$$
$$b_i^n = \frac{b_i^T - min\ (a_i^T)}{\partial} \quad (9)$$
$$c_i^n = \frac{c_i^T - min\ (a_i^T)}{\partial}$$

where,

$$\partial = (c_i^T) - min\ (a_i^T) \quad (10)$$

The upper and lower limit of the total relation matrix is found using the following:

$$u_i = \frac{c_i^n}{1 + c_i^n - a_i^n}$$
$$l_i = \frac{b_i^n}{1 + b_i^n - a_i^n} \quad (11)$$

The de-fuzzified value (d) corresponding to the fuzzy value (a^T, b^T, c^T), is found using Eq. (12).

$$d_i = \frac{l_i(1 - l_i) + u_i{}^2}{1 - l_i + u_i} \quad (12)$$

Corresponding Python Code:

```
>>    delta=np.max(T_c)-np.min(T_a)
>>    N_a=(T_a-np.min(T_a))/delta
>>    N_b=(T_b-np.min(T_a))/delta
>>    N_c=(T_c-np.min(T_a))/delta
>>    uplim=N_c/(1+N_c-N_a)
>>    lowlim=N_b/(1+N_b-N_a)
>>    di=(lowlim*(1-lowlim)+(uplim*uplim))/(1-lowlim+uplim)
```

3.3.5 Threshold value

A threshold level *t* was set to filter out the negligible values from matrix *d* to explain the interrelation among challenges while keeping the complexity of the problem at a manageable level. Those challenges whose effect in the matrix *d* is greater than the threshold value are chosen for further analysis [57].

$$t = mean\ (d_i) \quad (13)$$

The de-fuzzified matrix is then filtered using the threshold value:

$$d_i = d_i \text{ if } d_i > t$$
$$= 0 \text{ if } d_i < t \quad (14)$$

Corresponding Python Code:

```
>>    threshold=np.mean(di)
>>    for i in range(0, len(dataset)):
>>        for j in range(0, len(dataset)):
>>            if di[i][j]<=threshold:
>>                di[i][j]=0
```

3.3.6 Importance and interdependency

The importance and interdependency of challenges are calculated based on the row-wise (D) and column-wise (R) sum of the de-fuzzified total relation matrix, as shown in Eqs. (15)-(18).

$$D = \sum_{i=0}^{m} d_{ij} \quad (15)$$

$$R = \sum_{j=0}^{m} d_{ij} \quad (16)$$

The importance of the challenges is calculated by adding the row-wise sum and column-wise sum of the de-fuzzified total relation matrix. The relationship value is calculated by subtracting the row-wise sum and column-wise sum of the de-fuzzified total relation matrix.

$$Importance = D + R \quad (17)$$

$$Relation = D - R \quad (18)$$

Corresponding Python Code:

```
>>    D=np.sum(di, axis=1)
>>    R=np.sum(di, axis=0)
>>    Importance=D+R
>>    Relation=D-R
```

The Importance value is used to calculate the fuzzy-DEMATEL weight of the challenges, ultimately giving the rank of the challenges. At the same time, the Relation value is used to draw the cause-effect chart.

3.3.7 Fuzzy-DEMATEL weight

The fuzzy-DEMATEL weight is calculated using the Eq. (19):

$$Weight_i = \frac{(Importance)_i}{\sum(Importance)} \quad (19)$$

Corresponding Python Code:

```
>>      Weight=Importance/np.sum(Importance)
```

4. RESULT AND DISCUSSION

The analysis of the opinions of 17 experts, including OEMs, supplier industries, and academia, revealed significant differences in their perspectives and rankings of the challenges. These differences were further explored using the fuzzy-DEMATEL method, which provided insights into how each group viewed the challenges differently. This section elaborates on the findings of the analysis: the ranking of the challenges, the cause-effect relation among the challenges, the reliability of the data collected and the sensitivity analysis of the responses.

4.1 Ranking of challenges

The overall ranking of challenges more commonly reported in academic research deviated significantly from individual opinions at some points. On closer observations, it was found that experts from similar domains have similar views of challenges and perspectives based on their field. Hence, the data collected was segregated into OEMs, supplier industries and academia. The ranking of challenges, as shown in Table 7, obtained by the fuzzy-DEMATEL analysis, shows that although the experts from these sectors view the challenges differently due to their different perspectives, there is some degree of coincidence in their view.

Experts from OEMs consider the outdated infrastructure, high initial cost, uncertainty about financial gains, and lack of strategy and standards to follow as the most critical challenges. OEMs are primarily responsible for designing and producing vehicles. They are in a position to understand better the technological aspects of Industry 4.0 and its potential benefits [58]. Therefore, they focus more on the challenges of implementing the actual tools and technologies, such as dealing with outdated infrastructure, high initial costs, uncertainty about financial gains, and lack of strategy and standards [51]. They already know about Industry 4.0 but need help incorporating it into their operations [25].

In contrast, the experts from supplier industries view the absence of IT and R&D departments in their sector, lack of strategy and standards, uncertainty about financial gains, low maturity levels of Industry 4.0 tools, and lack of research and collaboration with academia as the most significant challenges. This difference in opinion is because experts from supplier industries who provide components and services to OEMs have a different perspective. They have limited exposure to Industry 4.0 tools and technologies, which can result in a lack of awareness. Suppliers face challenges in adapting their processes and capabilities to meet the requirements of Industry 4.0 [59]. Hence, their focus is more on challenges such as the absence of IT and R&D departments, low maturity levels of Industry 4.0 tools, lack of strategy and standards, and the need for research collaboration with academia [38, 60]. These challenges indicate a need for capacity building and support to enhance their understanding and implementation of Industry 4.0 [49].

The academicians, on the other hand, view the lack of financial aid, lack of government support, changes in work organisation, and poor infrastructure as the most challenging parameters. The academic experts bring a policy-oriented perspective to the discussion. Their views highlight the need for government support, financial aid, and changes in work organisation [61]. Academia is often crucial in policy-making, research, and knowledge dissemination. They have identified these challenges based on their understanding of the broader industry landscape, the impact of policies and regulations, and the potential socio-economic implications [62]. Their focus on policy-related challenges suggests creating an enabling environment and providing the necessary resources to drive Industry 4.0 implementation in the Indian automobile industry [46].

Table 7. Ranking of challenges by OEMs, suppliers, and academia experts

Code	Challenge	OEMs	Suppliers	Academicians
B01	Outdated infrastructure and machinery	1	7	4
B02	Lack of strategy and standards	4	2	8
B03	Lack of knowledge/awareness	10	12	13
B04	The reluctance of top management	16	10	11
B05	No support from employees and stakeholders	18	9	7
B06	Lack of skilled workers	8	15	20
B07	Poor internet connectivity	20	19	6
B08	Inability to collect and identify data	11	16	12
B09	Lack of government support	7	8	2
B10	Lack of financial support	13	11	1
B11	Lack of customer awareness	17	18	5
B12	Recession due to the COVID-19 pandemic	9	13	15
B13	Concern for data security	15	17	19
B14	Fear of loss of employment	19	20	14
B15	Uncertainty about financial benefits	3	3	17
B16	Change in work organization	14	6	3
B17	Absence of IT and R&D department	6	1	9
B18	Lack of research and collaboration with academia	5	5	16
B19	High initial cost	2	14	10
B20	Low maturity levels of I4.0 tools	12	4	18

These diverse perspectives underscore the multifaceted nature of implementing Industry 4.0 and highlight the importance of collaboration and coordination among different stakeholders to address the challenges effectively and drive the successful adoption of Industry 4.0 in the Indian automobile industry.

4.2 Cause-Effect analysis

The causal relationship from the fuzzy-DEMATEL analysis, as shown in Table 8, gives a more detailed view of the challenges.

Table 8. Relation and importance of challenges per the OEMs, suppliers, and academia experts

OEMs		Suppliers		Academicians	
First Quadrant (High Importance and High Relation)					
B1	B8	B17	B16	B10	B11
B19		B20	B12	B9	B5
B15		B2	B10	B16	
B2		B9		B1	
B18		B1		B7	
Second Quadrant (Low Importance and High Relation)					
B13	B20	B19	B8	B19	B2
B14	B11	B7		B8	B15
B7		B11		B17	B12
B16		B14		B13	
Third Quadrant (Low Importance and Low Relation)					
B10		B13		B4	B20
B5		B6		B6	B18
B4				B3	B14
Fourth Quadrant (High Importance and Low Relation)					
B6	B17	B3	B15		
B9		B18			
B3		B5			
B12		B4			

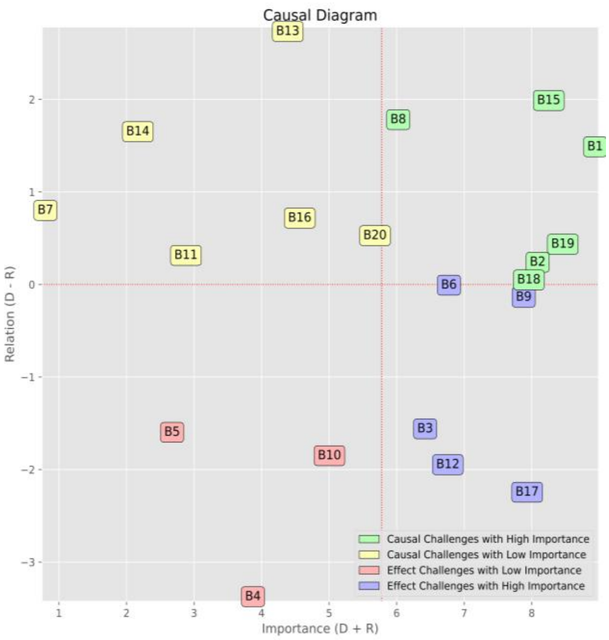

Figure 3. Causal diagram of response from experts from OEMs

From the perspective of experts from OEMs, as shown in Figure 3, outdated infrastructure (B1), a high initial cost of investment (B19), uncertainty about financial gains (B15), lack of strategy and standards (B2), lack of research and collaboration with academia (B18); and the inability to identify or collect data (B8) are the challenges in the first quadrant. These challenges are seen as highly important and highly related to other challenges. Such challenges are termed 'causes' and need policymakers' attention to ease the implementation of Industry 4.0. in Indian automobile industries [63]. In the second quadrant, concern for data security (B13), fear of loss of employment (B14), change in work organisation (B16), low level of maturity of I4.0 tools (B20), lack of awareness among customers (B11); and poor internet connectivity (B7) indicate challenges with relatively lower importance but are highly related to other challenges, thus are termed as "dependent challenges". The challenges with low priority and relatively lower relation with different challenges, shown in the third quadrant, are termed as 'independent challenges', and they are no support from employees or stakeholders (B5), lack of financial support (B10), and the reluctance of top management (B4). Lastly, in the fourth quadrant are the challenges with high importance but low relation with other challenges. Such challenges are termed 'effects' and cannot be resolved directly [63]. As per OEM experts, such challenges are lack of skilled workforce (B6), lack of government support (B9), lack of knowledge and awareness (B3), recession due to the COVID-19 pandemic (B12), and absence of IT and R&D department (B17).

To mitigate the lack of skilled workforce (B6), OEMs can invest in workforce development programs, collaborate with educational institutions to tailor curricula to industry needs and implement apprenticeship or training programs. Additionally, forming partnerships with government agencies and educational institutions can help address the absence of IT and R&D departments (B17) by facilitating knowledge exchange, funding research initiatives, and providing access to technological resources. Furthermore, advocating for policy reforms and incentives from the government can help alleviate challenges related to lack of government support (B9), fostering an environment conducive to innovation and investment in Industry 4.0 technologies. While challenges such as the COVID-19 pandemic-induced recession (B12) require broader economic measures and recovery strategies, OEMs can mitigate its impact by diversifying revenue streams, adopting lean manufacturing practices, and embracing digital transformation to enhance operational efficiency and resilience.

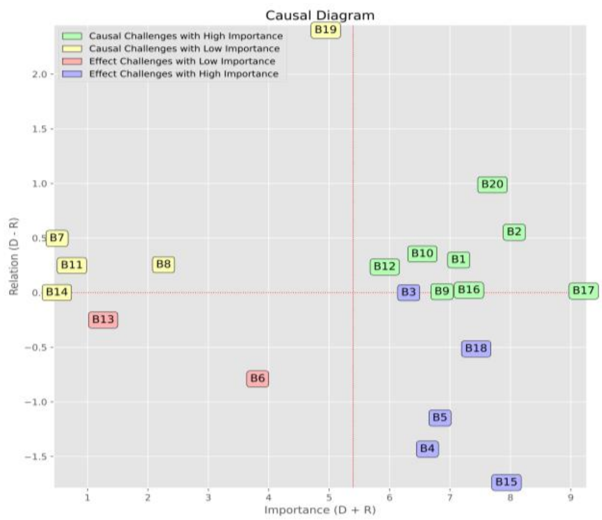

Figure 4. Causal diagram of response from experts from supplier industries

Similarly, Figure 4 shows that according to experts from supplier industries, the absence of an IT and R&D department (B17), low level of maturity of I4.0 tools (B20), lack of strategy and standards (B2), lack of government support (B9); outdated infrastructure (B1); change in work organisation (B16); recession due to COVID-19 pandemic (B12); and lack of financial support (B10) are 'causes'. The high initial cost of investment (B19), poor internet connectivity (B7), lack of awareness among customers (B11), inability to identify or collect data (B8), and fear of loss of employment (B14) are the 'dependent challenges'. The independent challenges concern data security (B13) and a lack of skilled workforce (B6). The 'effect' challenges are lack of knowledge and awareness (B3), lack of research and collaboration with academia (B18), uncertainty about financial gains (B15), no support from employees or stakeholders (B5), and the reluctance of top management (B4).

To combat the lack of knowledge and awareness (B3), supplier industries can invest in educational campaigns, training programs, and knowledge-sharing platforms to disseminate information about Industry 4.0 technologies and their benefits. Moreover, establishing partnerships with research institutions and academia (B18) can facilitate collaborative research projects, technology transfer, and skill development initiatives, enhancing innovation and competitiveness. Addressing uncertainty about financial gains (B15) involves conducting cost-benefit analyses, risk assessments, and scenario planning to evaluate potential returns on investment and develop robust business cases for Industry 4.0 adoption. Additionally, fostering a supportive organisational culture, providing incentives, and involving employees and stakeholders in decision-making processes can mitigate challenges related to lack of support (B5) and the reluctance of top management (B4).

Figure 5 shows the causal diagram of the response from experts from academia. The challenges in the first quadrant (causes) are lack of financial support (B10), lack of government support (B9), change in work organisation (B16), outdated infrastructure (B1), poor internet connectivity (B7), lack of awareness among customers (B11); and no support from employees or stakeholders (B5). The challenges in the second quadrant (dependent challenges) are the high initial cost of investment (B19), inability to identify or collect data (B8), absence of an IT and R&D department (B17), concern for data security (B13); lack of strategy and standards (B2); uncertainty about financial benefits (B15); and recession due to COVID-19 pandemic (B12). The challenges in the third quadrant (independent challenges) are the reluctance of top management (B4), lack of skilled workforce (B6), lack of knowledge and awareness (B3), low level of maturity of I4.0 tools (B20), lack of research and collaboration with academia (B18); and fear of loss of employment (B14). Interestingly, no challenges were found under the 'effect' category from the academicians' responses.

The result suggests that policymakers must prioritise addressing the challenges in the first quadrant to ensure the successful implementation of Industry 4.0 in the Indian automobile industry. Experts from OEMs view that this can be achieved by investing in infrastructure, providing financial support and incentives, promoting collaboration with academia, and investing in upskilling the workforce to meet the demands of Industry 4.0. Experts from supplier industries opined that this could be achieved by investing in infrastructure, promoting collaboration with academia, providing financial support and incentives, and upskilling the workforce to meet the demands of Industry 4.0. The response from experts from academia suggests that challenges related to lack of support and awareness from various stakeholders, poor infrastructure, and inadequate connectivity are identified as significant causes that need to be addressed to implement Industry 4.0 in the Indian automobile industry.

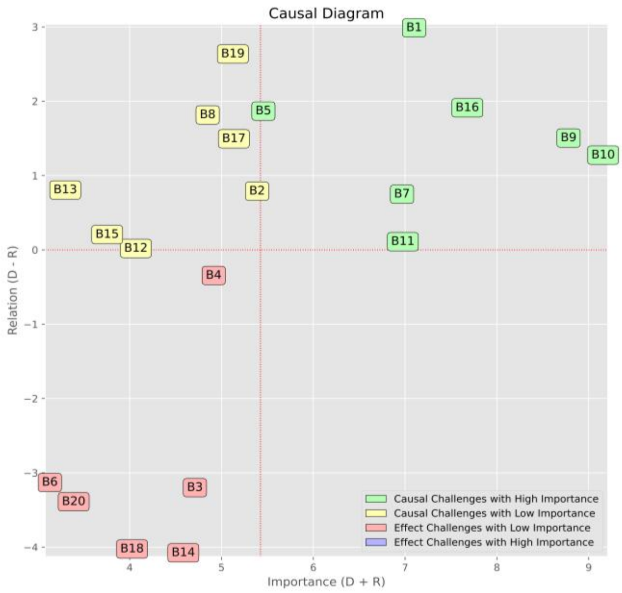

Figure 5. Causal diagram of response from experts from academia

4.3 Reliability test

Table 9. Cronbach's Alpha value if the response from a particular participant is dropped

P_i	Cronbach's Alpha Value (if Participant P_i is Dropped)
P1	0.839
P2	0.843
P3	0.844
P4	0.835
P5	0.834
P6	0.834
P7	0.84
P8	0.845
P9	0.83
P10	0.843
P11	0.848
P12	0.839
P13	0.837
P14	0.851
P15	0.837
P16	0.851
P17	0.834

Cronbach's Alpha coefficient is used to measure the level of reliability of data provided in a questionnaire-based survey. Cronbach developed it to measure the reliability of psychometry [64]. According to Bujang et al. [65], for a questionnaire-based survey with 20 items (challenges, as in this case), the minimum number of participants required to achieve a Cronbach's Alpha value of 0.85 (for excellent reliability) is 16. In this study, the reliability of the data collected through the questionnaire-based survey was measured through Cronbach's Alpha Value (α). It was found to be 0.848, indicating high reliability [66]. The Cronbach's Alpha value in a case where the response from a particular participant is dropped is shown in Table 9. From Table 9, it is evident that the reliability of the survey data does not change significantly on the removal of any particular participant, and each participant's response is reliable to almost the same degree.

4.4 Sensitivity analysis

The sensitivity analysis evaluated the robustness of the results obtained through the fuzzy-DEMATEL method. It involved removing the participant's response and assessing the impact of this change on the final results. The percentage change in fuzzy-DEMATEL weights of challenges when a participant's responses were removed is shown in Table 10. The percentage changes in fuzzy-DEMATEL weights of challenges when a participant's response is removed range from 3.55% to 7.85%, which indicates that no single participant's response has a significant impact on the final results. The fact that the changes are relatively small suggests that the results are stable and reliable. It further strengthens the validity of the results obtained through the fuzzy-DEMATEL method. It reinforces the importance of the challenges identified in the study for implementing Industry 4.0 in the Indian automobile industry.

Table 10. Sensitivity Analysis

Participant P_i	The Percentage Change in Fuzzy-DEMATEL Weight When Participant P_i's Response is Removed
P1	4.64
P2	3.55
P3	4.31
P4	7.85
P5	4.87
P6	4.71
P7	5.18
P8	4.98
P9	4.06
P10	5.73
P11	6.92
P12	5.13
P13	4.63
P14	5.84
P15	6.36
P16	4.07
P17	7.43

5. IMPLICATIONS

The findings of this study can help policymakers and industrialists build strategies to solve the problems of implementing Industry 4.0 in the Indian automobile sector. This investigation of the Indian automobile sector provides several managerial insights and theoretical consequences.

5.1 Managerial implications

The findings of this study have several managerial implications in the Indian automobile sector:

(1) Collaborative Approach: The results highlight the importance of a collaborative approach among policymakers, industry players, and academic institutions. OEMs and supplier industries should actively partner with academia to enhance their understanding of Industry 4.0 tools, standards, and best practices [67]. Collaboration with academia can also facilitate research and development efforts, enabling the industry to stay at the forefront of technological advancements [68]. Successful collaborative projects such as between Siemens and BMW [69] and Volkswagen and Amazon Web Services (AWS) [70] are a few case examples of this approach.

(2) Infrastructure Investment: Managers need to prioritise investments in infrastructure to address challenges such as outdated machinery and poor internet connectivity. Upgrading infrastructure can create a solid foundation for implementing Industry 4.0 technologies and ensure smooth integration with existing operations.

(3) Financial Support: Lack of financial support emerged as a significant challenge across all expert groups. Managers should advocate for government initiatives and policies that provide financial incentives and support for Industry 4.0 implementation. It can help alleviate the high initial costs associated with adopting new technologies and encourage greater participation from the industry.

(4) Upskilling the Workforce: All expert groups identified the shortage of skilled workers as challenging. Managers should focus on upskilling their workforce to meet the demands of Industry 4.0. It can be achieved through training programs, partnerships with educational institutions, and creating a culture of continuous learning within the organisation. The OEMs should take capacity-building and hand-holding initiatives for their concerned supplier industries to help them overcome the challenges.

(5) Standardisation and Strategy: OEM experts and supplier industries identified the lack of strategy and standards as critical challenges. Automobile industries should invest in developing clear implementation strategies and guidelines for Industry 4.0 adoption. Emphasising the importance of standardisation can enable interoperability and seamless integration of different technologies and processes.

(6) Data Security and Organizational Transformation: Concerns related to data security and organisational transformation were highlighted as dependent challenges by supplier industries. Industries should prioritise developing robust data security protocols and strategies to address these concerns. Additionally, they should proactively manage organisational change and provide necessary support and training to employees to ensure a smooth transition to Industry 4.0. Firstly, for data security, industries should adopt a multi-layered approach that includes encryption, access controls, and regular security audits to safeguard sensitive information. Implementing industry standards such as ISO 27001 [71] can provide a robust framework for managing data security risks. Organisations should prioritise employee training and awareness programs to promote a culture of data security throughout the company. Companies can follow Kotter's 8-Step Change Model [72] or Prosci's ADKAR model [73] to manage change effectively for organisational transformation. It's essential to involve employees in the transformation process, communicate openly about the changes, and provide adequate support and resources to facilitate a smooth transition.

(7) Government Advocacy: Industries should actively engage policymakers to advocate for supportive policies and regulations promoting the adoption of Industry 4.0. This includes incentives, funding schemes, and a conducive regulatory environment encouraging innovation and collaboration.

5.2 Theoretical implications

The findings of this study have several theoretical implications for policymakers and academicians in implementing Industry 4.0 in the Indian automobile industry.

(1) Holistic Approach: The results highlight the need for policymakers to adopt a holistic approach that considers multiple dimensions of Industry 4.0 implementation. Policymakers should focus not only on technological aspects but also on social, organisational, and policy-related challenges. This holistic perspective can help formulate comprehensive strategies and policies that address stakeholders' diverse challenges.

(2) Stakeholder Collaboration: The study emphasises the importance of collaboration among stakeholders, including policymakers, industry players, and academia. Policymakers should actively promote and facilitate collaborations to bridge the gap between industry and academia. This can foster knowledge sharing, research and development, and the co-creation of innovative solutions that cater to the specific needs of the Indian automobile industry.

(3) Financial Support and Incentives: More financial support emerged as a significant challenge in implementing Industry 4.0. Policymakers should explore various mechanisms to provide financial support and incentives to industrialists, particularly small and medium-sized enterprises (SMEs), to overcome the barriers associated with the high initial costs of adopting Industry 4.0 technologies. This can include grants, subsidies, tax incentives, and funding programs tailored explicitly for Industry 4.0 implementation.

(4) Policy Framework: Policymakers are crucial in establishing a supportive policy framework that encourages the adoption of Industry 4.0. They should develop policies and regulations addressing data security, privacy, intellectual property rights, and interoperability concerns. A clear and conducive policy framework can provide a favourable environment for industrialists to embrace Industry 4.0 technologies with confidence.

(5) Skills Development and Education: Policymakers should prioritise initiatives to foster skills development and education to meet the changing demands of Industry 4.0. This includes collaborating with educational institutions to design relevant curricula, promoting lifelong learning programs, and providing training opportunities for the existing workforce. By nurturing a skilled and adaptable workforce, policymakers can facilitate a smooth transition to Industry 4.0 and ensure the industry's long-term sustainability.

(6) Regional Disparities: Policymakers should recognise regional disparities regarding Industry 4.0 readiness and challenges. They should form policies and support mechanisms to address the specific needs and challenges of different regions within India. This can help promote balanced growth and ensure that the benefits of Industry 4.0 are equitably distributed across the country.

6. CONCLUSION

In conclusion, this research aimed to identify and analyse the challenges faced by the Indian automobile industry in implementing Industry 4.0. The findings shed light on the industry's internal, external, apprehensive, and prospective difficulties. Through a comprehensive analysis of expert opinions and applying the fuzzy-DEMATEL method, the study provided valuable insights into these challenges' ranking and causal relationships.

The paper successfully achieved its three research objectives stated in the introduction. It identified the challenges in implementing Industry 4.0 tools in the Indian automobile industries (RO1). It structured the identified challenges to find their interdependency and causal relationship power (RO2). Lastly, it presented the managerial and theoretical implications of the result obtained (RO3). The most critical challenges identified in this study revolve around outdated infrastructure and machinery, absence of strategy and standards, lack of knowledge/awareness, reluctance of top management, and inadequate support from employees and OEMs/supplier industries. These challenges underscore the pressing need for concerted efforts to modernise infrastructure, establish clear strategies and standards, enhance awareness and education initiatives, foster leadership buy-in, and promote collaboration across all stakeholders.

The findings offer valuable implications for both industries and policymakers. While this study contributes valuable insights, it has limitations. Firstly, the study's sample size may not have represented the entire Indian automobile industry. The study included experts from OEMs, supplier industries, and academia, but other stakeholders, such as policymakers and consumers, were excluded. Additionally, the study relied on the participants' subjective opinions, and their views may have been influenced by their personal biases and experiences. Another potential limitation is that the study focused solely on the challenges faced in implementing Industry 4.0 in the Indian automobile industry and did not consider the potential benefits and opportunities that Industry 4.0 could bring. Finally, the study should have regarded the regional differences within India, as certain regions may have different readiness levels and challenges in implementing Industry 4.0.

Future research can investigate the potential benefits and opportunities that Industry 4.0 could bring to the Indian automobile industry. It can involve analysing case studies of thriving Industry 4.0 implementations in other countries and exploring how these strategies could be adapted to the Indian context. Further research can be done to examine the potential regional differences in the challenges faced in implementing Industry 4.0 in the Indian automobile industry. This could involve conducting a more extensive survey of stakeholders in different regions of India to identify each region's unique challenges and opportunities. Another research area could be exploring strategies for addressing the challenges identified in this study. For example, future research could investigate how policymakers could provide support to address challenges related to infrastructure and funding or how companies could collaborate with academia to address challenges related to research and development. Researchers could also investigate the potential impact of Industry 4.0 on various stakeholders, such as employees, consumers, and the broader society. For employees, it could entail examining how automation and digitalisation may reshape job roles, skills requirements, and workplace dynamics. Consumer-focused research could explore how Industry 4.0 technologies might influence product offerings, customer experiences, and market dynamics. Societal implications could encompass economic, environmental, and social factors, such as job displacement, sustainability, and ethical implications of automation and data-driven decision-making. It can involve exploring how Industry 4.0 could change the nature of work in the Indian automobile industry or analysing the potential environmental impacts of increased automation and digitalisation. By addressing the identified challenges and implementing appropriate strategies, the Indian automobile industry can successfully embrace Industry 4.0, enhance its competitiveness, and contribute to the country's economic growth and technological advancement.

DECLARATIONS

The authors declare that they have no conflict of interest.

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