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INDUSTRY 4.0 ADOPTION FRAMEWORK IN MSMES USING A HYBRID FUZZY AHP-TOPSIS APPROACH

Yogesh Upadhyay
Faisal Talib[1]
Syed Ali Zaheen
Mohd. Saifuddin Ansari

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A B S T R A C T

This work presents an outline for adopting industry 4.0 enabling technologies, and appropriate strategies are prioritized to implement them. A hybrid fuzzy Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) approaches are applied to achieve the objectives. The enabling technologies and strategies were identified based on the literature review and expert's opinions, a total of 26 enabling technologies and eight strategies were identified. Later fuzzy AHP technique is used to rank the enablers and TOPSIS is applied to order the implementation strategies. From 26 enablers, a total of ten enabling technologies were found to be the most effective. Artificial intelligence (AI), top management commitment and support, virtual reality, and enterprise resource planning (ERP) systems were the top-ranked enablers in the list, whereas edge computing was the least effective enabler. Among the strategies, lean manufacturing, green supply chain and logistics, and integrated and smart manufacturing systems were the top priorities in implementing industry 4.0, while recruiting and managing talents was the least important strategy in the study. The findings from this framework will provide a deep insight to the managers and practitioners of MSMEs to adopt the industry 4.0 technologies in their organizations

1. INTRODUCTION

The new era of the industrial revolution, often regarded as Industry 4.0, was first introduced by Hanover Messe in 2011, and its roadmap was framed in 2013. Today this concept is followed by various industries globally (Luthra et al., 2020). Industry 4.0 is influenced by various technological developments, particularly the Internet of things (IoT) which also includes the concept of a cyber-physical system (CPS) (Jimeno-Morenilla et al., 2021). The fourth industrial revolution penetrates the competitive market and generates high customer demands. Considering the market scenario, digital technologies motivate new digital solutions, for example, embedded products based on IoT technologies. As more companies adopt digitalization and IoT concepts, Micro, Small and Medium Enterprises (MSMEs) face significant competition and

[1] Corresponding author: Faisal Talib
Email: ftalib77@gmail.com

lag in fulfilling customer demand(Da Silva et al., 2020). The contribution of MSMEs is 36% of India's total export, and it gives around 387.18 lakhs of employment while the employment (Ministry of Micro, Small & Medium Enterprises, 2020). Despite such significant contribution, the MSMEs still follow the traditional manufacturing culture that depends on outdated manufacturing cycles compared to heavy industries, and they still lack to yield the full advantage of the Industrial revolution(Jimeno-Morenilla et al., 2021). To overcome this, many countries, including India, have started local programs to increase industry developmentand implementation of industry 4.0 technologies(Devi K, Paranitharan and Agniveesh A, 2020). During the time of COVID-19, the MSMEs were severely affected, and their progress was fallen drastically. To support MSMEs, the government launched Collateral free automatic Loans and six reforms under the Atmanirbhar Bharat Abhiyaan (Self-Reliant) and Make in India to recuperate the MSMEs. However, to successfully implement industry 4.0 in Indian MSMEs, the right enabling technologies and proper strategies are needed.

Different researchers have performed different work on the industry explaining the importance of industry 4.0 in Industries. The first step in initiating industry 4.0 was the Cyber-Physical System (CPS), which uses sensors and actuators(Rojko, 2017).CPS and service innovation trends were investigated in industry 4.0, which stated that these could generate useful data using big data technologies(Lee, Bagheri and Kao, 2015). By using CPS, the factories can organize and control themselves without much human involvement(Lee, Bagheri and Kao, 2015). These factories are called Smart factories(Shrouf, Ordieres and Miragliotta, 2014). The sensors are usually embedded in the system and controlled by the chain of the network; this concept is known as the Internet of things (IoT)(Manglani et al. 2019). IoT is regarded as the enabler of intelligence and context-aware services development in industries(Rathore et al., 2018). The IoT services produce real-time data that helps in monitoring and giving services to customers. However, managing such huge data is a tough task. To overcome this, Big data analytics plays an important role as an industry 4.0 enabler (Santos et al., 2017; Li, Tan and Chaudhry, 2019). Today Big data, IoT is not limited to the manufacturing sector, but they are revolutionizing the Health sector, Entertainment, Agriculture, etc. as well(Hajjaji et al., 2021).

Jimeno-Morenillaet al.(2021)presented a study on traditional manufacturing sectors such as footwear, clothing, furniture, etc. He highlighted the significant changes that have occurred in the traditional sectors in the past few years. He discussed Additive manufacturing Product customization, AI, Robots, and Cloud Computing as the main technological enablers to drive these changes. He further stated that AI and Cloud computing still need more effort to penetrate the traditional market. Industry 4.0 has fused traditional industries with digitalization (Calabrese et al., 2020), and it aims to connect people using networks and services and enables remote use of computers and robotics to reduce human effort (Devi K et al., 2020). Industry 4.0 is improving the manufacturing processes and affecting the supply chain (Dallasega et al. 2018; Zimon et al., 2022; Wozniak et al., 2022). Blockchain also has a significant role in bringing supply chain digitalization (Wamba and Queiroz, 2020). Esmaeilianet al.(2020)found blockchain technology as an enabler for effectively implementing sustainability.
Along with innovations, digitalization is also reshaping labor (Ghobakhloo, 2020). Dalenogareet al.,(2018)considered the adoption of industry 4.0 technologies and stated that labor claims are the side effects of industry 4.0. The side effects claimed by Dalenogareet al.(2018) were obvious as the automation due to Industry4.0 significantly affects labor, but the bigger picture of gain due to technologies is significantly high. Somohano-Rodríguez et al. (2020)showed that industry 4.0 has a crucial impact on the performance of SMEs which have already followed innovation strategies.

Industry 4.0 also has a crucial impact on the supply chain(Szozda, 2017). The relationship between manufacturing suppliers and customers utilizing smart technologies creates transparency in all manufacturing stages (Ghadge et al., 2020). Adopting Industry 4.0 has a key effect on order demands and transport logistics(Ripanti and Tjahjono, 2019; Winkelhaus and Grosse, 2020)also highlighted the concept of logistics with the increase in demand for goods; he also described how industry 4.0 affects the logistics system. Besides the supply chain and logistics, industry 4.0 is also affected by lean manufacturing(Mrugalska and Wyrwicka, 2017). Rosin et al., (2020) discussed how the technologies of industry 4.0 helped the implementation process of Lean. His result showed that industry4.0 showed a significant effect on just in time and Jidoka, whereas people and teamwork were hardly affected.

From the above literature, it was concluded that many researchers identified different enablers for industry 4.0 and their applications. Few researchers also use different techniques to identify the key enablers. A few researchers also proposed a framework for implementing these enablers. However, most of the work is focused on large enterprises, The study on MSMEs was given relatively less importance. Also, a combined study is not yet undertaken that prioritizes the industry 4.0 enablers and their implementation strategies in the MSMEs. In order to bridge this gap, this work identified the key enablers of Industry 4.0 and ranked them using the Fuzzy AHP technique, and later the weights of enablers were used to prioritize the implementation strategies.

Hence, the key objectives of this paper are as follows:

1. To identify and select the enablers of Industry 4.0 implementation in Indian MSMEs through literature review and expert's opinion;
2. To prioritize and rank the selected enablers using Fuzzy AHP;
3. To identify and prioritize implementation strategies in Indian MSMEs using TOPSIS; and
4. To propose a framework for Industry 4.0 adoption and suggest implications to managers and decision-makers of Indian MSMEs.

The rest of the study is ordered as follows: Section 2 represents the literature review on the industry 4.0 enabling technologies and implementing strategies with the overview of Indian MSMEs. Section 3 describes the research methodology with a complete explanation of Fuzzy AHP and TOPSIS techniques. Section 4 displayed the result and discussed its outcomes. Finally, the study is concluded in section 5 with the future scope.

2.0 LITERATURE REVIEW

To accomplish the above objectives, an extensive literature review was conducted to identify the enabling technologies and the implementation strategies. The literature was considered from the year 2001 onwards. The enablers and strategies were identified based on the literature and experts' opinions from academia and industry professionals. Most of the literature was searched using databases like Web of Science, SCOPUS, Google Scholar, JSTOR, and ProQuest to extract relevant articles. The search keywords used were-Industry 4.0, MSMEs, fuzzy AHP, TOPSIS, and industry 4.0 enablers and strategies.

2.1 Overview of MSMEs

Micro, Small and Medium Enterprises are considered the key component to economic growth. These are administered by the MSMED (Micro Small & Medium Enterprise Development) Act 2006 (Virk and Negi, 2019). The MSMEs sector plays an important role in filling the gap between the urban and rural status, dropping poverty, and generating employment opportunities. According to the National sample survey (NSS) the MSMEs have created 11.10 crore jobs with the highest employment in manufacturing and trade (Ministry of Micro, Small & Medium Enterprises, 2020). The MSMEs' contribution to GDP may rise from 29% to 50%, according to the union minister (Subramanian et al., 2021). Indian MSMEs must implement an appropriate framework that generates more opportunities and robust the business infrastructure for economic development(Singh, 2019). In the current scenario, MSMEs face operational and technological challenges. The major challenge faced by the MSMEs is to match the quality and price with large enterprises(Konur et al., 2021). The MSMEs have to face toughcompetition from large domestic firms and multinational corporations with advanced production and technology methods, skilled workers, and a range of products. Incompetent marketing strategies and poor management are other factors that lead to poor quality and inefficiency. Another major factor that has increased competitiveness in Indian MSMEs is Globalization. The MSMEs do not have adequate knowledge of technologies and proper infrastructure to stand up with MNCs(Singh, 2019).Influence of the market scenario and internet usage force the MSMEs to update their traditional processes to improve the services and demand(Haleem et al., 2012). It is a fact that IT tools can improve the business infrastructure, but for MSMEs, it is hard to adapt due to expense. The adoption merely depends on the Top management and knowledge of the technology(Zheng et al., 2004).

2.2 Enablers of Industry 4.0

The enabling technologies are not easy to select when it comes to adoption in the industry. Calabrese et al. (2021)also stated in their study that the adoption rate depends on the firm's size. Many enabling technologies are identified from the literature. Due to progressing development in this evolving nature of industry 4.0, every researcher has identified the key technologies in its way. Krishnan et al. (2021)identified ten enablers that include top management interest in implementing industry 4.0, future viability, Government policies to support smart factories, competitive global advantage, ability to address environmental challenges, Customized customer requirements, Digital and integrated process capabilities, financial performance, etc. Raji et al.,(2021)recognized the Internet of Things IoT, Cyber-physical systems (CPS), Big Data Analytics as enabling technologies. In addition, sensors, robots, algorithms, Networks, Skills, AI, innovations, Simulated, Networks, monitors, Actuators, etc., were identified in the study by Murugaiyan and Ramasamy (2021). The identical enabling technologies were acknowledged in the work of Jain and Ajmera (2020), where he used Total Interpretive Structural Modelling methodology (TISM) to estimate the relationship between these factors in Indian manufacturing industries.

After analyzing the enabling technologies from different papers, the final enablers were identified from the literature and the expert's opinion. The identified enabling factors were grouped into main categories i.e. Big Data, IoT, Digitalization, Technological, and Management-related enablers. A deeper understanding of the technologies and their interrelationship is crucial to adopt these features in the industries successfully.

The Internet of things, which is defined as the technology that connects every object with the help of a smart sensor network over the internet(Gubbi et al., 2013). Today technologies such as RFID have changed the logistics and supply chain system(Elbasani et al., 2020). IoT shows a remarkable response when it is connected to Cloud computing services, which can be defined as remote access to the services over the internet (Aazam et al., 2016). The data collected by IoT devices is used by Big data analytics techniques to generate useful output(Gokalp et al., 2017). Machine learning, as the name suggests is the process of making machines think and work accordingly. The accuracy of the machine depends on the quality and amount of data that is made input to the machines, and they respond accordingly(Brik et al., 2019). When the data is flying over the internet, the chances of threat increase, so cybersecurity is vital, which ensures that the information is secure and private.

Another aspect that led to the fourth industrial revolution is Digitalization. Virtualreality, Drones, 3D Printing, Artificial intelligence (AI), and Digital twins are all the components that lie in the domain of digitalization. Although AI is usually connected to the aspect of big data and machine learning, due to its huge impact in the digitalizing industry with robots, apple Siri, self-driving cars, etc., it is considered a sub-category enabler under Digitalization. Virtual reality is another aspect that triggers digitalization; it can be defined as interacting with a pseudo 3d environment. It is widely used in the gaming industry, automobile industry, etc. (Guttentag, 2010). Another similar technology is Digital twins, which is defined as the technology that can be used to simulate real-life scenarios in the lab and predict their results(Santos et al., 2020). Another enabler in technology is product and service innovation; it ensures that the product has a new feature, whereas service innovation deals with improving marketing strategies and performance. Today giants like HP, Apple, Rolls-Royce, etc., are fusing these concepts to advance customer value and brand preference(Shelton, 2015).

Technology has seen a huge development due to innovation and developments. Autonomous robots which use AI are taking technology to another level. However, Hardware and software compatibility is important when it comes to integrating the software comments in the hardware, the performance of the system is defined by its hardware and software compatibility(Igor, Bohuslava and Martin, 2016). Further, technology is influenced by technological infrastructure or IT services. The devices with the software's technologies come with the protocols for transmitting data defined by the technological infrastructure(Moktadir et al., 2018), this not only maintains privacy but also improves customer satisfaction(Steinmueller, 1996). Customer satisfaction is also determined by another enabler, i.e., Customize customer requirements. It gives freedom to the customer to propose their idea in the product and services(Krishnan et al., 2021).The managerial factors are crucial when implementing industry 4.0. the first component is Enterprise resource planning (ERP), which combines all the business processes to increase the efficiency in the enterprise(Muscatello, Small and Chen, 2003). Further, the efficiency is monitored by a change management program which shows the possibility of risk and shows the strategy to eliminate risk and display progress. This analysis is managed by the Big data management department, they ensure that the data used in the analysis is of high quality and produce effective results(Zhang et al., 2015). Further, in the role of managerial factors, Top management commitment and support Customer relationship management (CRM) play an important role in making good customer experiences make use of strategies and technologies to manage and analyze customers to give the best user experience(Marnewick and Labuschagne, 2005; Devi K, Paranitharan and Agniveesh A, 2020), whereas Top management commitment and support make sure to ensure employees job satisfaction and promise to the customer for getting quality experience(Rodgers, Hunter and Rogers, 1993; Ahire and O'Shaughnessy, 1998).

The identified enablers arranged in the categories are shown in Table 1.

Table 1. Enabling technologies of Industry 4.0.

Main Category	Sub-category
Big Data Analytics	Cyber Security
	Real-time data
	Machine learning
	Cloud computing services (CCS
	Edge computing
IoT	RFID Technologies
	Smart Sensor Network
	Cyber-Physical Systems (CPS
	CIoT
	Real-time information
	E-logistics
Digitalization	Virtual reality
	Drones
	3D Printing
	Artificial intelligence (AI)
	Digital twins
Technological	Product and service innovation
	Hardware and software compatibility
	Technological infrastructure
	Autonomous Robots
	Customize customer requirement
Management	Enterprise Resource Planning (ERP) System
	Customer Relationship Management (CRM)
	Change management Program
	Top management commitment and support
	Big Data management

To accommodate the barriers, there is always a need to formulate strategies to implement these enablers. The following section follows the study of enablers and their identification through literature review and expert's opinion.

2.3 Strategies to implement industry 4.0.

Popkova (2019)tried to establish the relationship between economic knowledge and industry 4.0. He uses the correlation method to analyze this fact. His results show that the economy and industry 4.0 are dependable processes, any knowledge of the economy is the foundation for implementing industry 4.0. Amoozad Mahdiraji et al., (2020)identified strategies such as Human resource management, improving information systems strategies, work organization and design, new business model development, and operation optimization. He uses BWM and TODIM-IVIF methods to rank the strategies. He further added that the strategies are essential in achieving the desired goal. When implementing new technologies, there are some barriers that we must overcome. Da Silva et al.(2020)did an empirical study and found that Government financial, Technology Organizational are some of the barriers to industry 4.0. Kumar et al.(2020)also researched the barriers to the adoption of industry 4.0 using PCA-Fuzzy AHP-K means. He found that IT infrastructure and Management support are the major barriers to implementing industry 4.0. Chauhan et al.(2021)stated internal and external barriers to digitization that affect industry 4.0 implementation. To support the argument, he proposed a research hypothesis and developed a model. The model is tested on different manufacturing industries using Analysis of moment structure (AMOS). His results showed that the barriers in the industries adversely affect digitalization and thus, implementation of Industry 4.0 can improve operational performance. To implement the enablers of Industry 4.0, proper strategies are needed. The proposed strategies are described in Table 2.

Table 2. Proposed strategies

Strategies / Alternatives	Description	References
Recruit and manage talents (A1)	Training the present employees with the modern skills to match up with the latest technologies and trends. This also involves handling the interdisciplinary departments to produce effective results.	(Zhou, Liu and Zhou, 2016; Erdogan et al., 2018; Ghobakhloo, 2018; Amoozad Mahdiraji et al., 2020)
Planning and control (A2)	A proper business plan is needed to achieve the desired goals in the organization. The priorities are set up to improve operational effectiveness.	(Zhou, Liu and Zhou, 2016; Erdogan et al., 2018; Ghobakhloo, 2018)
Using integrated and smart manufacturing systems (A3)	The technologies including 3d printing, automation, robotics are integrated into one manufacturing unite to meet the manufacturing demands and when these technologies are combined with intelligent manufacturing like AR, VR, and IoT the process becomes more efficient.	(Zhou, Liu and Zhou, 2016; Ghobakhloo, 2018; Türkeş et al., 2019)
Eliminating boundaries between physical world and digital world (A4)	The Internet plays an important role in eliminating the boundaries between the physical and digital world. The Augmented reality (AR) and Virtual reality (VR) plays an important role in this strategy.	(Zhou, Liu and Zhou, 2016; Türkeş et al., 2019)
Increasing awareness among people (A5)	To make use of technologies successfully it is important to display the product features so that the people know how to make use of the technologies. People should be aware of the new technologies and their applications that can benefit them, this will raise the demand too	Self-proposed, Expert's opinion
Retrofitting the old machinery (A6)	The old machines in the production unit should be updated with the latest technologies like Automation, Robots, sensors etc.	(Guerreiro et al., 2018; Türkeş et al., 2019; Hassan Al-Maeeni et al., 2020)
Green supply chain & logistics (A7)	When implementing new technologies, environmental factors are taken into account. A green supply chain applies supply chain in such a way that it also integrates environmental concerns and organizational activities. Logistics plays a crucial role in supply chain operations. It condenses the environmental and energy footprint of freight distribution.	(Franchetti, Elahi and Ghose 2019; Chiarini, Belvedere and Grando, 2020; De Giovanni and Cariola, 2020)
Lean manufacturing (A8)	Lean manufacturing focuses on reducing waste and maximizing profit in an operation. In industry 4.0, lean is a vital tool to gain a higher level of operational performance and productivity.	(Mrugalska and Wyrwicka, 2017; Ghobakhloo and Fathi, 2019; Chiarini, Belvedere and Grando, 2020; Cagnetti et al., 2021)

3. RESEARCH METHODOLOGY

The study uses two techniques Fuzzy-AHP and TOPSIS. The fuzzy AHP is used to rank the enablers of industry 4.0 in the MSMEs. Further, the strategies to implement them are ranked using the TOPSIS technique. The methodology flowchart is shown in Figure 1.

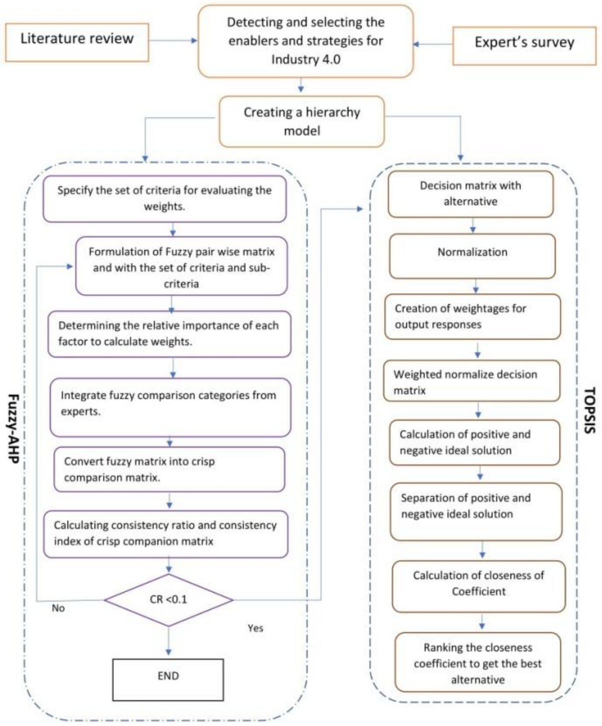

Figure 1. Methodology flowchart of FUZZY-AHP-TOPSIS

In the first phase, the enablers are identified using an expert survey. Total 38 enabling technologies are selected from the literature review. Further, using a 5-point liker scale, these enablers are filtered by expert opinion, and 26 enablers were selected. The mean deviation was calculated to get the influencing enablers. The mean and standard deviation was calculated as 3, and the factors which lie beyond this value are considered significant. The mean and standard deviation of selected enablers are shown in Table 3, and the experts' profile is shown in Table4; The complete hierarchy chart is shown in Figure 2.

In the second phase, the Fuzzy AHP is used to calculate the weight to get the importance of each enabler. The Questionnaires were filled by industry experts and academic professors. Each respondent was asked to do the relative ranking of the enabling categories based on goal and the sub-criteria based on the respective enabling category. Further pairwise matrix is developed based on the relative ranking.

Table 3. Mean standard deviation of the selected enablers.

Selected Enablers	**Mean standard deviation**
Cyber Security	3.1
Real-time data	4.0
Machine learning	3.5
cloud computing services (CCS	3.7
Edge computing	3.8
RFID Technologies	4.2
Smart Sensor Network	3.1
Cyber-Physical Systems (CPS	3.4
CIoT	3.6
Real-time information	4.1
E-logistics	3.5
Virtual reality	3.5
Drones	4.0
3D Printing	3.1
Artificial intelligence (AI)	3.8
Digital twins	3.4
Product and service innovation	3.6
Hardware and software compatibility	3.9
Technological infrastructure	3.5
Autonomous Robots	3.6
Customize customer requirement	3.2
Enterprise Resource Planning (ERP) System	4.2
Customer Relationship Management (CRM)	3.5
Change management Program	3.8
Top management commitment and Support	3.9
Big Data management	4.3

Table 4. Profile of the Respondent

Profile of the Respondent (n=22)		
Gender	**No of respondent**	**Percentage**
Male	15	68
Female	7	32
Age		
Below 25	2	9
25-35	10	45
45-55	8	36
Above 55	2	9
Qualification		
Graduate	4	18
PhD	10	45
Professionals	8	36
work experience		
<2 years	4	18
2-5 years	8	36
5-10 years	7	32
>10 years	3	14

In the final phase, TOPSIS is used to prioritize the strategies for implementing industry 4. A total of eight strategies were proposed based on the literature study. In the questioner, the respondents were asked to rate and allot a value to the strategy corresponding to each sub-category. The value is used to calculate the closeness coefficient for each enabling sub-category.

The closeness coefficient provides the distance of the strategy from its ideal condition by calculating its worst and best value. The obtained closeness coefficient was used to prioritize the strategy. The higher value signifies better strategy relatively.

3.1 Fuzzy analytical hierarchy process

The AHP method is a multicriteria decision method established to solve the problem by distributing it into solutions and grouping them, then ordering them in a hierarchical framework (Kahraman, Cebeci and Ulukan, 2003). Additionally, Fuzzy logic is applied to divide the AHP scale into a fuzzy triangle scale to get the priorities. The fuzzy AHP method can be divided into the following steps-

Step-1: First problem goal and hierarchical framework is formed.

Step-2: Linguistic variables are constructed to define the relative importance of one indicator concerning each enabler. The indicators are shown in table 5.

Step-3: Pairwise matrix is constructed based on the expert's opinion. The fuzzy pairwise matrix is based on Eq (1).

$$X = \begin{matrix} x_{11} & x_{12} & .. & x_{1n} \\ 1/x_{12} & x_{22} & .. & x_{2n} \\ : & : & : & : \\ 1/x_{1n} & 1/x_{2n} & .. & x_{nn} \end{matrix} \quad (1)$$

Step-4: The fuzzy pairwise matrix was constructed for each category and subcategory of the enablers based on the expert's review.

Step-5: After making a pairwise matrix, the consistency of the individual fuzzy matrix is checked to authenticate the decisions of experts. To did this, the matrix is DE fuzzified by allocating a crisp numeric value in the place of TFNs. If the TFN number is represented by T=(l,m,u) then the DE fuzzified will be obtained by Eq (2).

$$T_{crisp} = \frac{l+4m+u}{6} \quad (2)$$

After de-fuzzifying the matrix, it is being normalized, which is achieved by dividing each element of a column by the sum of all the elements as shown in Eq (3).

$$x_{ij} = \frac{x_{ij}}{\sum_{j=1}^{n} x_{ij}} \forall i, j x_{ij} \in X \quad (3)$$

Here n represents the criteria selected for comparison. The eigenvectors wi corresponding to row i, represents the weight which is calculated by Eq (4).

$$w_i = \frac{\sum_{j=1}^{n} x_{ij}}{n} \quad (4)$$

The$\sum_{j=1}^{n} x_{ij}$in the equation signifies the sum of all the elements in row I of the normalized pairwise matrix. After this the largest eigenvalue λ_max is calculated, using Eq(5).

$$\lambda_{max} = \sum_{i=1}^{n} [(\sum_{j=1}^{n} x_{ij}) \times w_i] \quad (5)$$

The consistency ratio (CI) and consistency ratio are calculated using Eq(6) and Eq (7).

$$CI = \frac{\lambda_{max}}{n-1} \quad (6)$$

$$CR = \frac{CI}{RI} \quad (7)$$

The (Random index) RI used for calculating the consistency ratio is taken from Table 6.

Table 5. Linguistic variables and equivalent Numerical Crisp values and TFNs.

Linguistic value	TFNs
Equally important	(1,1,1)
Equally important to moderately more important	(1,2,3)
Moderately more important	(1,3,5)
Moderately more important to strongly more important	(3,4,5)
Strongly more important	(3,5,7)
Strongly to very strongly more important	(5,6,7)
very strongly more important	(5,7,9)
very strongly to extremely more important	(7,8,9)
Extremely more important	(7,9,9)

Table 6. Random index

Matrix	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

3.2 Technique for order performance by similarity to ideal solution (TOPSIS)

TOPSIS was developed by Hwang and Yoon, (1994) it is used to solve multi-criteria decision making (MCDM) problems and choose the best alternative by calculating the shortest distance to positive ideal solution(A+) and longest distance from negative ideal solution(A-). The maximum functionality is governed by a positive ideal solution and vice versa. The steps of TOPSIS are as follows:

Step-1: Formation of decision matrix based on the expert's opinion.

Step-2: The decision matrix is normalized using Eq. (8)

$$N = \left| \frac{g_j(a_i)}{\sqrt{\sum_{i-1}^{m} [g_j(a_i)]^2}} \right| \quad (8)$$

Where gi is the deterministic value of alternative i for criterion j.

Step-3: The weighted normalized matrix is calculated by multiplying the normalized decision matrix with the corresponding weight. The same is given by Eq (9).

$$Nij = W_j \times N_{ij}^{`} \quad (9)$$

Step-4: The positive ideal solution and negative ideal solution are identified.

For a positive ideal solution'

$$A^{+} = (N_1^{+}, N_2^{+}, \dots N_n^{+}) = \{(maxN_{ij} \mid j \in I), (minN_{ij} \mid j \in I)\} \quad (10)$$

For negative-

$$A^{-} = (N_1^{-}, N_2^{-}, \dots N_n^{-}) = \{(minN_{ij} \mid j \in I), (maxN_{ij} \mid j \in I)\} \quad (11)$$

Where I is associated with benefit criteria and J with the cost criteria.i=1,…,m; j=1,…,n

Step-5: Calculation of Euclidean distance of each alternative from the ideal solutions.

$$D_i^{+} = \sqrt{\left(\sum_{j=-1}^{n} \left(N_{ij} - N_j^{+}\right)^2\right)} \quad , i = 1,2,..m \quad (12)$$

$$D_i^{-} = \sqrt{\left(\sum_{j=-1}^{n} \left(N_{ij} - N_j^{-}\right)^2\right)} \quad , i = 1,2,..m \quad (13)$$

Step-6: After Euclidean distance, the closeness coefficient if the ith alternative is calculated using eq.14.

$$C_i = \frac{D_i^{-}}{D_i^{+} + D_i^{-}} \quad , i = 1,2, \dots, m \quad (14)$$

Where 0≤C_i≤1

Step-7: Based on the value of Ci the ranking of alternatives is done to select the best one.

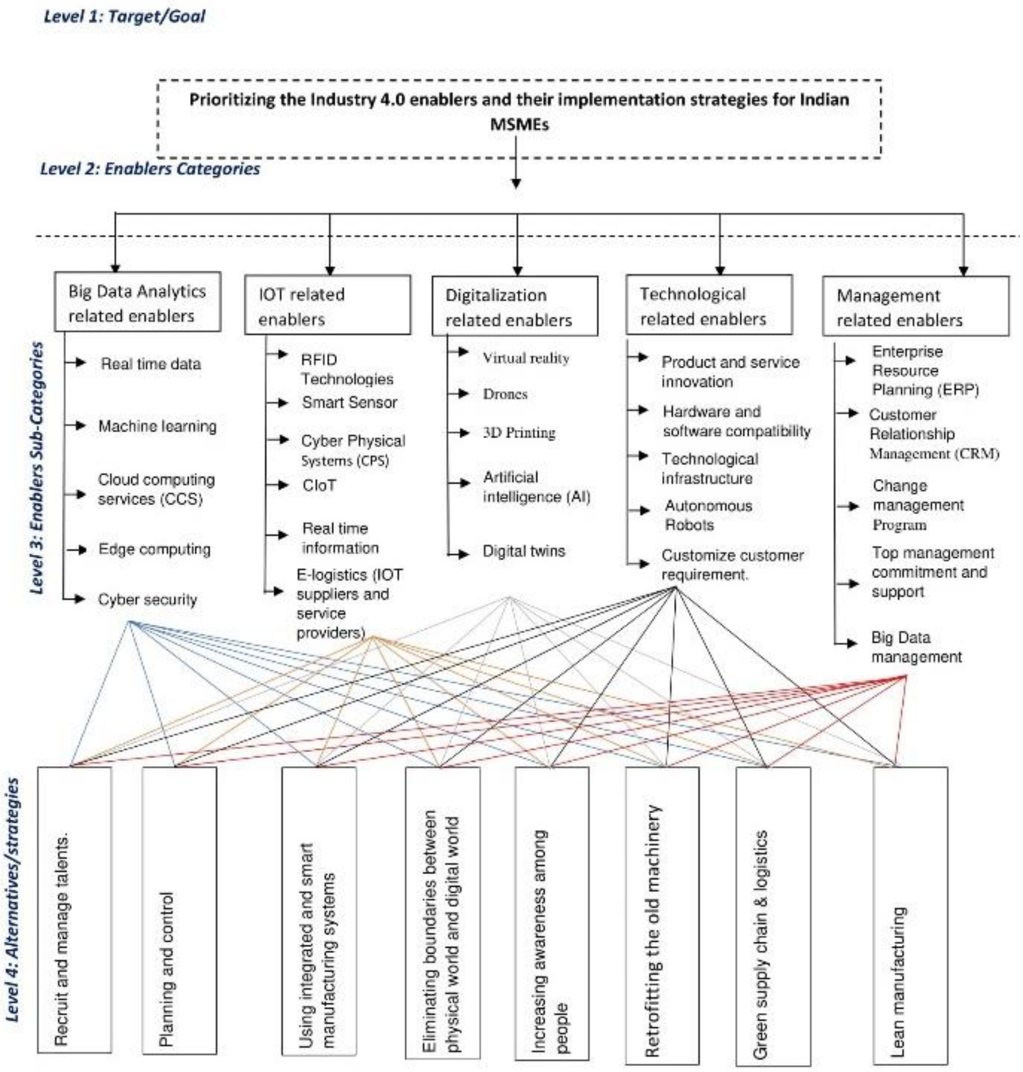

Figure 2. Hierarchy model of Industry 4.0

The above stated methods were used to select the enablers and strategies. The following section discussed the obtained results and their implications.

4. RESULTS AND DISCUSSION

4.1 Results

The integrated fuzzy AHP-TOPSIS approach was used to prioritize the strategies in selecting the enabling technology and their implementation strategy.

Based on the questionnaire prepared (as discussed in section 3), a total of 26 enablers are identified. Further, these selected enablers were grouped to form different categories. Further, the experts were asked to rank these enabling technologies. The list of enabling technologies is shown in Table1.

In the second phase, the comparison pairwise matrix is constructed based on the expert's opinion. Later the matrix is de-fuzzified as shown in Tables 7-12.

The final ranking of the enablers was done based on the global weights. The value of the global weight of the enablers is calculated by multiplying by category weight and sub-category weight. The global weights and the ranking are shown in Table 13. The comparison of the enablers according to their global weight is also shown in Figure 3. The main category and the sub-categories weight are shown in Tables 7-12.

Table 7. Pairwise matrix of Main enablers category.

Enablers	Big Data Analytics	IOT	Digitalization	Technological	Management	Criteria Weight
Big Data Analytics	1.00	0.26	0.13	0.56	0.17	0.04
IOT	4.00	1.00	0.42	2.00	0.56	0.17
Digitalization	8.00	3.00	1.00	6.00	2.00	0.43
Technological	2.00	0.56	0.17	1.00	0.21	0.08
Management	6.00	2.00	0.56	5.00	1.00	0.29

Table 8. Pairwise matrix of enablers sub-categories of Big Data Analytics related enablers.

Big Data Analytics	1. Cyber Security	2. Real-time data	3. Machine learning	4. cloud computing services (CCS	5. Edge computing	Criteria Weight (NW)
1. Cyber Security	1.00	0.17	0.56	0.26	2.00	0.08
2. Real time data	5.00	1.00	4.00	2.00	8.00	0.45
3. Machine learning	2.00	0.26	1.00	0.56	4.00	0.15
4. cloud computing services (CCS	3.00	0.56	2.00	1.00	6.00	0.27
5. Edge computing	0.56	0.13	0.26	0.17	1.00	0.05

Table 9. Pairwise matrix of enablers sub-categories of IOT related enablers

IOT related enablers	RFID Technologies	Smart Sensor Network	Cyber Physical Systems (CPS	CIoT	Real time information	E-logistics	Criteria Weight
RFID Technologies	1.00	2.00	5.00	6.00	0.56	3.00	0.25
Smart Sensor Network	0.56	1.00	4.00	5.00	0.42	3.00	0.18
Cyber Physical Systems (CPS	0.21	0.26	1.00	2.00	0.21	0.42	0.06
CIoT	0.17	0.21	0.56	1.00	0.13	0.26	0.04
Real time information	2.00	3.00	5.00	8.00	1.00	5.00	0.36
E-logistics	0.42	0.42	3.00	4.00	0.21	1.00	0.12

Table 10. Pairwise matrix of enablers sub-categories of Digitalization related enablers

Digitalization Related enablers	Virtual reality	Drones	3D Printing	Artificial intelligence (AI)	Digital twins	Criteria Weight (NW)
Virtual reality	1.00	2.00	6.00	0.56	4.00	0.27
Drones	0.56	1.00	4.00	0.26	3.00	0.16
3D Printing	0.17	0.26	1.00	0.13	0.42	0.04
Artificial intelligence (AI)	2.00	4.00	8.00	1.00	6.00	0.45
Digital twins	0.26	0.42	3.00	0.17	1.00	0.08

Table 11. Pairwise matrix of enablers sub-categories of technological related enablers

Technological related enablers	1. Product and service innovation	2. Hardware and software compatibility	3. Technological infrastructure	4. Autonomous Robots	5. Customize customer requirements	Criteria Weight (NW)
1. Product and service innovation	1.00	3.00	0.42	5.00	0.56	0.19
2. Hardware and software compatibility	0.42	1.00	0.21	3.00	0.26	0.09
3. Technological infrastructure	3.00	5.00	1.00	8.00	2.00	0.41
4. Autonomous Robots	0.21	0.42	0.13	1.00	0.21	0.04
5. Customize customer requirement	2.00	4.00	0.56	5.00	1.00	0.26

Table 12. Pairwise matrix of enablers sub-categories of Management related enablers

Management related enablers	1. Enterprise Resource Planning (ERP) System	Customer Relationship Management (CR)	3. Change management Program	4. Top management commitment and	5. Big Data management	Criteria Weight (NW)
1. Enterprise Resource Planning (ERP) System	1.00	5.00	4.00	0.56	3.00	0.28
2. Customer Relationship Management (CRM)	0.21	1.00	0.42	0.13	0.21	0.04
3. Change management Program	0.26	3.00	1.00	0.15	0.42	0.08
4. Top management commitment and	2.00	8.00	7.00	1.00	4.00	0.45
5. Big Data management	0.42	5.00	3.00	0.26	1.00	0.16

Table 13. Ranking and global weights of the enabling technologies.

Main Category	Main category weight (Wm)	Sub-category	Sub-category weight (Ws)	Global Weight Wg=WmxWs	Rank
Big Data Analytics related enablers	0.044	Cyber Security	0.08	0.004	24
		Real time data	0.45	0.020	14
		Machine learning	0.15	0.007	21
		cloud computing services (CCS	0.27	0.012	19
		Edge computing	0.05	0.002	26
IOT related enablers	0.169	RFID Technologies	0.25	0.042	8
		Smart Sensor Network	0.18	0.030	11
		Cyber Physical Systems (CPS	0.06	0.010	20
		CIoT	0.04	0.006	23
		Real time information	0.36	0.061	6
		E-logistics	0.12	0.020	13
Digitalization related enablers	0.426	Virtual reality	0.27	0.115	3
		Drones	0.16	0.067	5
		3D Printing	0.04	0.018	16
		Artificial intelligence (AI)	0.45	0.191	1
		Digital twins	0.08	0.034	9
Technological related enablers	0.076	Product and service innovation	0.19	0.015	17
		Hardware and software compatibility	0.09	0.007	22
		Technological infrastructure	0.41	0.031	10
		Autonomous Robots	0.04	0.003	25
		Customize customer requirement	0.26	0.020	15

Management related enablers	0.286	Enterprise Resource Planning (ERP) System	0.28	0.079	4
		Customer Relationship Management (CRM)	0.04	0.012	18
		Change management Program	0.08	0.022	12
		Top management commitment and support	0.45	0.128	2
		Big Data management	0.16	0.044	7

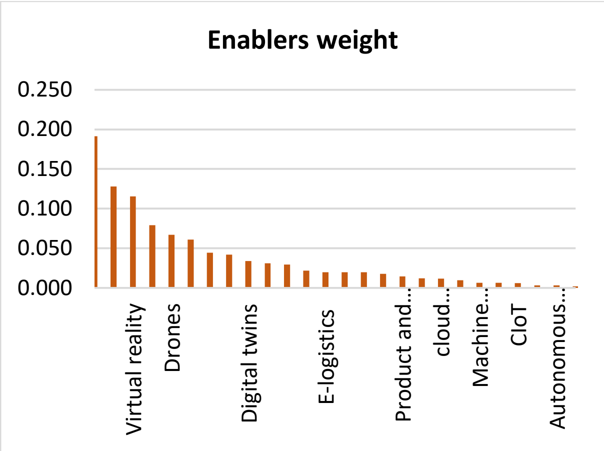

Figure 3. Comparison of the enablers according to their wights

In the third phase, TOPSIS is applied to prioritize the strategy of industry 4.0. The experts were asked to rate the strategy, and based on the expert's response, the input value of the TOPSISanalysis is framed corresponding to the enablers' weight calculated from Fuzzy AHP. The input values of the TOPSIS analysis are shown in Table 14. After this, the matrix is normalized using Eq.(8) and Eq.(9). The normalized matrix is illustrated in Table 15. After this using Eq.(10) and eq.(11), the positive and negative ideal solutions are calculated.

Table14. TOPSIS Analysis input values

Sub-category	**Sub-category weight (Ws)**	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**
Cyber Security	0.08	6	6	6	6	6	6	6	6
Real-time data	0.45	7	7	7	6	6	7	7	8
Machine learning	0.15	6	7	6	6	6	6	6	7
cloud computing services (CCS	0.27	5	5	5	5	5	5	5	5
Edge computing	0.05	6	6	5	6	6	6	6	7
RFID Technologies	0.25	6	7	7	7	7	7	7	7
Smart Sensor Network	0.18	6	6	6	6	6	6	7	7
Cyber-Physical Systems (CPS	0.06	7	6	6	7	7	7	6	6
CIoT	0.04	6	6	6	6	7	6	7	7
Real-time information	0.36	7	6	8	7	8	7	7	7
E-logistics	0.12	7	7	7	8	8	8	7	8
Virtual reality	0.27	7	6	6	7	7	7	7	7
Drones	0.16	6	6	6	6	7	7	7	6
3D Printing	0.04	6	6	6	7	7	6	6	6
Artificial intelligence (AI)	0.45	7	7	7	7	7	7	7	7
Digital twins	0.08	7	6	6	6	7	7	6	7
Product and service innovation	0.19	6	6	6	6	6	6	6	5
Hardware and software compatibility	0.09	6	7	7	7	7	7	6	6
Technological infrastructure	0.41	7	7	7	7	7	7	6	6
Autonomous Robots	0.04	7	6	8	8	8	7	7	7
Customize customer requirement	0.26	6	6	7	6	6	7	6	6
Enterprise Resource Planning (ERP) System	0.28	6	7	7	6	7	7	7	6
Customer Relationship Management (CRM)	0.04	7	7	7	7	7	6	6	6
Change management Program	0.08	7	7	7	6	7	7	7	7
Top management commitment and support	0.45	7	8	7	7	7	8	6	7
Big Data management	0.16	6	6	6	7	6	6	6	6

Table 15. Normalized matrix

Sub-category	A1	A2	A3	A4	A5	A6	A7	A8		A+	A-
Cyber Security	0.028876	0.028074	0.028876	0.027272	0.028876	0.028074	0.028074	0.028876	+	0.028876	0.027272
Real time data	0.156902	0.172995	0.156902	0.152879	0.14081	0.160926	0.156902	0.181041	+	0.181041	0.14
Machine learning	0.051212	0.056902	0.052634	0.054057	0.054057	0.052634	0.048367	0.058325	+	0.058325	0.048367
cloud computing services (CCS	0.089379	1.606111	1.778195	1.716877	1.550728	1.716877	1.900829	1.962146	+	1.962146	0.089379
Edge computing	0.014922	0.01673	0.01447	0.017183	0.016278	0.015826	0.015826	0.017635	+	0.017635	0.01447
RFID Technologies	0.082879	0.087242	0.087242	0.091604	0.089423	0.085061	0.087242	0.091604	+	0.091604	0.082879
Smart Sensor Network	0.062035	0.058682	0.060359	0.058682	0.062035	0.062035	0.067065	0.065389	+	0.067065	0.058682
Cyber Physical Systems (CPS	0.020741	0.020209	0.020209	0.022868	0.020741	0.021273	0.019677	0.020209	+	0.022868	0.019677
CIoT	0.012576	0.012227	0.012227	0.012227	0.013624	0.012227	0.014672	0.015022	+	0.015022	0.012227
Real time information	0.126942	0.114852	0.136009	0.132987	0.136009	0.120897	0.132987	0.117875	+	0.136009	0.114852
E-logistics	0.03807	0.037142	0.039927	0.046427	0.045499	0.045499	0.040856	0.042713	-	0.037142	0.046427
Virtual reality	0.096251	0.084513	0.08686	0.096251	0.100946	0.103293	0.098598	0.098598	+	0.103293	0.084513
Drones	0.05263	0.051168	0.051168	0.05263	0.062864	0.061402	0.058478	0.054092	+	0.062864	0.051168
3D Printing	0.014996	0.014185	0.014591	0.016212	0.016212	0.013375	0.01378	0.015401	+	0.016212	0.013375
Artificial intelligence (AI)	0.158108	0.169677	0.165821	0.154252	0.150396	0.154252	0.158108	0.158108	+	0.169677	0.150396
Digital twins	0.071243	0.067681	0.062338	0.067681	0.071243	0.071243	0.0659	0.069462	+	0.071243	0.062338
Product and service innovation	0.07278	0.07278	0.070865	0.067034	0.07278	0.067034	0.065119	0.057458	+	0.07278	0.057458
Hardware and software compatibility	0.028946	0.03047	0.031993	0.033517	0.031231	0.03047	0.028946	0.028946	+	0.033517	0.028946
Technological infrastructure	0.153206	0.145733	0.14947	0.14947	0.153206	0.145733	0.134523	0.134523	+	0.153206	0.134523
Autonomous Robots	0.015265	0.013135	0.01633	0.01704	0.01704	0.01491	0.01491	0.015265	+	0.01704	0.013135
Customize customer requirement	0.087339	0.089835	0.099816	0.09233	0.087339	0.102312	0.094826	0.089835	+	0.102312	0.087339
Enterprise Resource Planning (ERP) System	0.092436	0.102166	0.104598	0.092436	0.102166	0.102166	0.094868	0.092436	+	0.104598	0.092436
Customer Relationship Management (CRM)	0.015125	0.015125	0.015503	0.016638	0.014747	0.014369	0.014369	0.014369	+	0.016638	0.014369
Change management Program	0.026757	0.026105	0.028715	0.024147	0.028063	0.028063	0.02741	0.02741	+	0.028715	0.024147
Top management commitment and support	0.161353	0.16502	0.161353	0.161353	0.154018	0.176021	0.13935	0.146684	+	0.176021	0.13935
Big Data management	0.052365	0.052365	0.052365	0.061885	0.055538	0.058712	0.052365	0.052365	+	0.061885	0.052365

The alternative (strategy) ranking is done using Eqs. (12-14). The ranking is shown in Table 16. The ideal alternative (strategy) is chosen based on the shortest distance to the positive ideal solution and the longest distance to the negative ideal solution. The graphical comparison of the strategy weights is shown in Figure 4. The following strategies are as follows in declining weight order: Lean manufacturing, green supply chain & logistics, using integrated and smart manufacturing systems, eliminating boundaries between the physical world and digital world, replacing old production units with new ones, Planning and control, increasing awareness among people, Recruit and manage talents.

Table 16. Ranking of the strategies.

Alternatives	Di+	Di-	Ci	Rank
Recruit and manage talents	1.88	0.19	0.090	8
Planning and control	0.40	1.53	0.791	6
Using integrated and smart manufacturing systems	0.27	1.70	0.864	3
Eliminating boundaries between physical world and digital world	0.32	1.64	0.837	4
Increasing awareness among people	0.46	1.47	0.761	7
Replacing old production unit with new one	0.32	1.64	0.836	5
Green supply chain & logistics	0.22	1.82	0.893	2
Lean manufacturing	0.21	1.88	0.901	1

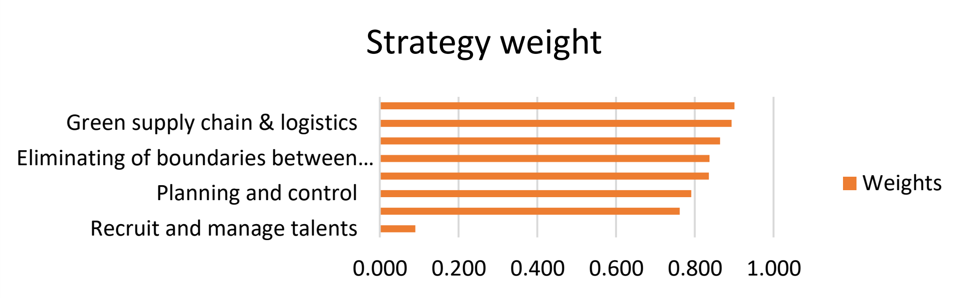

Figure 4. Strategy weight

The next section will discuss the results obtained. The top 10 effective enabling technologies were chosen as per the position obtained from the Fuzzy AHP. Later strategies are described according to their rank obtained by TOPSIS.

4.2 Discussion

The ranking of the enablers and the implementing strategies have successfully been achieved through the Fuzzy AHP-TOPSIS approach. There were 26 enabling technologies identified through expert judgments; weights of these enablers were calculated through the fuzzy AHP and gave the relative ranking while TOPSIS was used to rank the strategies.

After analyzing the ranking of the 26 enabling technologies through Fuzzy AHP, it was concluded that only the top ten technologies have significant weightage among all enabling technologies. It should be further noted that the remaining technologies have a critical role in their way and cannot be neglected in the initiating fourth industrial revolution, but only these ten technologies have shown worth relative to other enabling technologies. The ten technologies identified according to their rank are Artificial intelligence (AI), Top management commitment and Support, Virtual reality, Enterprise Resource Planning (ERP) systems, Drones, Real-time information, Big Data management, RFID Technologies, Digital twins, and Technological infrastructure.

Artificial intelligence (AI) was identified as the best enabler for industry 4.0., which is no surprise considering its huge applications in the industry and accuracy. The adoption of AI by MSMEs will not only helps in making operations productive but also stand out from the competitive markets. Peres et al.(2020)also stated that AI and Machine learning have a major impact as industry 4.0 technology. After artificial intelligence, priority should be given to Top management commitment and support. It plays an important role in employee empowerment and fulfillment in the industry. It also emphasizes Quality Management to give value to the customer. Devi, K. et al. (2020)also identified Top-Level Management involvement as the highest driving power and significance in implementing Industry 4.0. When it comes to customer satisfaction, virtual reality down the list is the next priority. Today Virtual reality (VR) plays an important role in almost every sector of industry, whether it is the automotive industry in testing prototypes or in healthcare to practice on dummy bodies. Virtual reality makes it too simple and ultimately increases customer satisfaction, thus growing demands in MSMEs.A study by Coates (2000) also stated VR is the quality revolution in the manufacturing and performance of the product. A recent study by Javaid et al.(2020) also stated that VR technology was seen to be an outstanding technology for communication in a time like COVID.

Implementing AI and VR will no doubt increase the demand and productivity, but great demand motivates the need for strong resources and planning, and that is fulfilled by the next enabling technology, i.e., Enterprise Resource Planning (ERP) System. The ERP system is more of a software technology that connects different departments of the company to synchronize the data and share it with each department, for example, the sales and purchase department can easily share the data with the order management and accounts departments it does not only make information readily available but makes the company run efficiently. A recent study by Akyurt et al.(2020)stated that the technologies like Big data and Cloud computing are making a great contribution to improving ERP software capabilities and achieving business intelligence. This argument is supported by Gërvalla and Ternai, (2019). In his study, he found that ERP, along with industry 4.0 technologies system, improves decision-making capabilities in the companies in real-time.

The next enabler on the priority list is Drones. The DIY hobby is now an emerging technology that has penetrated most aspects of industrial applications, whether it is drone delivery or data collection devices for industry. Industry 4.0 has projected drones as a sensing devices with flying as its inbuilt feature. They are used in photography, 3D mapping, shipping, remote sensing, agriculture application, space applications, etc. It has influenced almost every industrial aspect. They are also used in warehouse management to save labor costs (Fernández-Caramés et al., 2019). The drones have made real-time data collection so easy(Ayamga, Akaba and Nyaaba, 2021), and real-time information is our next importance when it comes to data collection. Real-time information utilizes the data and customer behavior over the internet and gives them the best user experience. The importance of real-time information is also illustrated by Javaid et al.(2020) where he described how real-time data generated useful information that became a helping hand during the time of COVID-19. This collection of data is achieved by the various embedded sensors devices (also known as IoT devices) that produce huge amounts of data, known as big data(Sowe et al., 2014). This huge amount of data will be wasted if not managed, and this brings us to the next priority in the row, i.e., Big Data management. The rapid advancement in data size from IoT devices and information services motivates the industry to develop new data analysis techniques. It was concluded by Devi K et al., (2020) that Big data is one of the driving enablers in the Industry 4.0 implementation. The next enabler is RFID (radio-frequency identification) Technology, it uses tags with digitally encoded data, and the data is captured by the radio waves. The captured data is stored in the database. Employment of RFID technologies in the MSMEs will help in improving accuracy and reliability in supply chain and production line efficiency (Angeles, 2005).

The concept of RFID has been emphasized as being used as microchip implants. This concept is although in research due to its controversy because of security aspects. Nonetheless, it will make promising improvements in the future(Fram et al., 2020). When the ideas are proposed, it generates the need for prototypes and testing. The succeeding enabler, i.e., Digital twins, plays a crucial role in fulfilling this prerequisite. These are the virtual copies of the physical device that practices simulations before real devices are manufactured. Fuller et al.(2020) described the digital twin as an emerging technology in industry 4.0. He also mentioned that the digital twins merged the concept of AI, IoT, and Big data to accomplish the desired results. It used different models to simulate real-world problems. It usually gathers real-time data using IoT devices, and big data tools play an important role in analysis (Wang and Luo, 2021). The twins provide feedback that can be useful in modifying the product before it is manufactured. The implementation of Digital twins in MSMEs will increase productivity and reduce product wastage, thus increasing profit. The next and last enabler, according to its importance, is technological infrastructure. Onat and Bayar (2010)indicated that Information and communication technologies infrastructure significantly contributes to industry 4.0 adoption. Oesterreich and Teuteberg (2016) also mentioned that information and communication technologies in Industry 4.0 are the best tool to link the gap between conventional and modern manufacturing technologies. The IT technologies give desired results when they have united with the technologies like robotics in manufacturing units and AI for real-time data (Sharma et al., 2020).

The least impactful enabling technologies identified are Autonomous robots and Edge computing. Autonomous robots are emerging technology that uses sensors and smart IoT networks to function. Autonomous robots are regarded as the future of productivity and growth in the manufacturing sector(Rüßmann et al., 2015), Bekey (2005)described autonomous robots as"Intelligent machines are capable of performing tasks in the real world by themselves, without explicit human control". Despite the advantages, they have limitations and drawbacks too(Kiru, 2016). The major limitation of autonomous robots is a disability in differentiating between right and wrong and social emotions(Sharkey, 2013).In another study by Arkin (2009) autonomous robots have created a thoughtful ethical, legal, and technical alarm, another drawback is the human replacement (Decker, 2000). Autonomous robots still need more research before full adoption by the MSMEs. Considering the limited investment of MSMEs, it will not be economical to adopt these limitations. However, they can adopt semi-autonomous robots with skilled labor involvement. The next least impactful technology is edge computing which process time-sensitive data and advanced response(Shi and Dustdar, 2016). Though Edge computing has many benefits, it also offers numerous technical and nontechnical challenges (Satyanarayanan, 2017). The technical side includes software mechanisms and algorithms, which require more research, whereas the non-technical side includes the involvement of Top-level management to create business models for effective implementation. Considering edge computing in its way of development, it makes it the last choice for MSMEs to adopt.

After enabling technologies, the strategies were prioritized using TOPSIS. The weights of the strategies are displayed in figure 4. As per the position, the strategy is as follows; Lean manufacturing, green supply chain & logistics, using integrated and smart manufacturing systems, eliminating boundaries between the physical world and digital world, Planning and control, increasing awareness among people, Recruiting and managing talents.

The first strategy that was found was Lean manufacturing. Lean manufacturing refers to reducing waste in the production system and response times from suppliers and to customers. No doubt implementing the industry 4.0 technologies will improve efficiency and make the process robust. To meet the demands, industries should be ready with the proper management system to meet customer demands. Saxby et al. (2020) also stated Lean is supportive of Industry 4.0. The second strategy in implementing industry 4.0 is a green supply chain & logistics. The green supply chain improves the environmental performance of the process(Vachon and Klassen, 2006). It is also responsible for reducing lead time, thus increasing the efficiency of the supply chain(Dües, Tan and Lim, 2013).On the other hand, Green logistics is contributing towards unified progress along with sustainable manufacturing(Bag et al., 2021). Together this strategy will be a productive step in implementing industry 4.0.

The third strategy, according to the rank, is using integrated and smart manufacturing systems. Integrated manufacturing involves the concept of modern technologies like 3D printing and automation along with digital infrastructure. According to Paszkiewiczet al.(2020), this technique increases production efficiency as well as cuts production time, decreases costs, and intensifies flexibility. On the other hand, in Smart manufacturing, the technologies such as AI, Cyber-physical systems, IoT, etc., are implemented in the manufacturing unit to monitor and analyze the machine's real-time data and improve performance. A study conducted by Kamble et al.(2020) on MSMEs showed that smart manufacturing could provide inexpensive paybacks of improved costs, time, flexibility, quality, and optimized productivity, and also it contributes to the overall performance of the organization. The fourth priority is to eliminate boundaries between the physical world and the digital world. A study by Frank et al.(2019) expressed this strategy as an important driver to support Industry4.0.

The fifth priority is Retrofitting the old machinery. It uses the latest technology of industry 4.0 in the older system to increase efficiency and output(Hassan Al-Maeeni et al., 2020).Di Carlo et al.(2021) showed that retrofitting old machinery improves safety and maintenance performance. The sixth priority in implementing industry 4.0 is Planning and control. It can bring a significant improvement to manufacturing systems(Usuga Cadavid et al., 2020).To implement and smooth working of the industry 4.0 technologies, a proper planning and control framework is needed for the proper utilization of these tools(Tsai and Lu, 2018).

Increasing awareness among people and Recruiting and Managing talents were found to be the least important strategy in implementing industry 4.0. A study conducted by Parunget al.(2018) also suggested that raising public awareness and conducting training are the least impactful strategies. However, both strategies play an important role in their way, but they were given the least importance according to the weights obtained.

5.0 CONCLUSION

The study aimed to prioritize the enabling technologies of industry 4.0 and the strategies to implement them in Indian micro, small and medium enterprises utilizing the Hybrid fuzzy AHP-TOPSIS approach. The Indian MSMEs still lack the precise framework and strategies to implement the new technologies of the fourth industrial revolution. From the literature and experts' views, a total of 26 enablers were recognized. Out of 26 enablers, Artificial intelligence (AI) was identified as the best technology whereas edge computing was ranked last. It should be noted that poor ranking does not imply that edge computing should not be considered a good enabling technology for industry 4.0. It is just relatively less important than other enabling technologies. Later eight strategies were investigated from the literature and prioritized with the help of the TOPSIS technique. The major findings of the work are as follows-

1. The Hybrid FuzzyAHP-TOPSIS technique was found to be an effective technique in developing a framework for industry 4.0 implementation.
2. Total 10 effective enabling technologies were selected based on their ranking.
3. AI was found to be the best enabling technology, whereas Edge computing was the least effective.
4. Eight strategies were identified through literature and prioritized using TOPSIS.
5. Lean manufacturing was identified as the top strategy based on priority, whereas Recruiting and managinging talents was found to be the least operative strategy.

5.1 Theoretical implications

The current study proposes a framework for industry 4.0 implementation. Previously many studies focused on the industry 4.0 enablers and their importance in sustainability(Chauhan, Singh and Luthra, 2021) and their implementations (Rajput and Singh, 2019). However, these studies have not considered the industry 4.0 enabling technology and its strategy as a combined approach. The main theoretical implication of this work is to create a systematic framework of the enabling technologies and their strategies to implement industry 4.0 in the industries. This study considers both enablers and sub-categories of enablers which gives more precise results with the Fuzzy AHP approach. The proposed framework suggests that AI is a crucial tool in industry 4.0 technologies and can penetrate most aspects of industries to increase efficiency and productivity. The concept of Lean manufacturing is found to be the top strategy for implementing industry 4.0 in MSME.

5.2 Practical implications

The results obtained in the work provide a framework to MSMEs for analyzing the techniques of industry 4.0 and implementing them according to proposed strategies. Considering so many enabling technologies of industry 4.0, there is always uncertainty while selecting and choosing the right one. Managers and decision-makers of MSMEs can make use of the proposed outline to focus on the enabling technologies that have a significant effect on industry 4.0 implementation. The framework has ranked different enabling technologies which were identified from the literature. The results also suggest that companies should first emphasize the top ten enabling technologies to successfully implement industry 4.0 in enterprises. It is also advised to the managers and practitioners of MSMEs to adopt the least impactful technologies in the last stage if necessary. Later, they should follow the proposed strategies to get effective results.

5.3 Future scope

In this work, the main focus was on MSMEs, further comparative analysis with regard to large enterprises can improve the results. The findings can propose new models that can help in bridging the challenges faced by the MSMEs from Large enterprises. Another scope of this study is to discretize the study to the different states of India, this can help to get more insights into the companies and improve accordingly. Another motivation of the study is to broaden the size of respondents. The respondents were considered from India only, the overseas respondents from different parts of the world can robust the study and generate more precise results.

References:

Aazam, M., Huh, E. N., St-Hilaire, M., Lung, C. H., & Lambadaris, I. (2016). Cloud of Things: Integration of IoT with Cloud Computing. *Studies in Systems, Decision and Control, 3*6, 77-94. doi: 10.1007/978-3-319-22168-7_4

Ahire, S. L., & O'shaughnessy, K. C. (1998). The role of top management commitment in quality management: an empirical analysis of the auto parts industry. *International Journal of Quality Science, 3*(1), 5-37.. doi: 10.1108/13598539810196868.

Akyurt, İ. Z., Kuvvetli, Y., & Deveci, M. (2020). Enterprise resource planning in the age of industry 4.0: A general overview. *Logistics 4.0*, 178-185.. doi: 10.1201/9780429327636-21

Angeles, R. (2005). RFID technologies: supply-chain applications and implementation issues. *Information systems management, 22*(1), 51-65.. doi: 10.1201/1078/44912.22.1.20051201/85739.7

Arkin, R. (2009). G*overning lethal behavior in autonomous robots.* CRC press. doi: 10.1201/9781420085952

Ayamga, M., Akaba, S., & Nyaaba, A. A. (2021). Multifaceted applicability of drones: A review. *Technological Forecasting and Social Change, 16*7, 120677. doi: 10.1016/J.TECHFORE.2021.120677

Bag, S., Yadav, G., Dhamija, P., & Kataria, K. K. (2021). Key resources for industry 4.0 adoption and its effect on sustainable production and circular economy: An empirical study. *Journal of Cleaner Production, 281*, 125233. doi: 10.1016/J.JCLEPRO.2020.125233

Bekey, G. A. (2005). *Autonomous robots: from biological inspiration to implementation and control.* MIT press.

Brik, B., Bettayeb, B., Sahnoun, M. H., & Duval, F. (2019). Towards predicting system disruption in industry 4.0: Machine learning-based approach. *Procedia computer science, 151*, 667-674.

Cagnetti, C., Gallo, T., Silvestri, C., & Ruggieri, A. (2021). Lean production and Industry 4.0: Strategy/management or technique/implementation? A systematic literature review. *Procedia Computer Science, 180*, 404-413.. doi: 10.1016/J.PROCS.2021.01.256

Calabrese, A., Dora, M., Levialdi Ghiron, N., & Tiburzi, L. (2022). Industry's 4.0 transformation process: how to start, where to aim, what to be aware of. *Production Planning & Control, 3*3(5), 492-512. doi: 10.1080/09537287.2020.1830315

Calabrese, A., Levialdi Ghiron, N., & Tiburzi, L. (2021). 'Evolutions' and 'revolutions' in manufacturers' implementation of industry 4.0: a literature review, a multiple case study, and a conceptual framework. *Production Planning & Control, 3*2(3), 213-227. doi: 10.1080/09537287.2020.1719715

Di Carlo, F., Mazzuto, G., Bevilacqua, M., & Ciarapica, F. E. (2021). Retrofitting a process plant in an industry 4.0 perspective for improving safety and maintenance performance. *Sustainability, 13*(2), 646. doi: 10.3390/su13020646

Chauhan, C., Singh, A., & Luthra, S. (2021). Barriers to industry 4.0 adoption and its performance implications: An empirical investigation of emerging economy. *Journal of Cleaner Production, 285*, 124809. doi: 10.1016/j.jclepro.2020.124809

Chiarini, A., Belvedere, V., & Grando, A. (2020). Industry 4.0 strategies and technological developments. An exploratory research from Italian manufacturing companies. *Production Planning & Control, 31*(16), 1385-1398. doi: 10.1080/09537287.2019.1710304

Coates, J. F. (2000). Manufacturing in the 21st Century. *International Journal of Manufacturing Technology and Management, 1*(1), 42-58. doi: 10.1504/IJMTM.2000.001328

Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. I*nternational Journal of production economics, 204*, 383-394. doi: 10.1016/j.ijpe.2018.08.019

Dallasega, P., Rauch, E., & Linder, C. (2018). Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review. *Computers in industry, 99*, 205-225. doi: 10.1016/j.compind.2018.03.039

Decker, M. (2000). Replacing human beings by robots. How to tackle that perspective by technology assessment. In *Vision Assessment: Shaping Technology in 21st Century Society: Towards a Repertoire for Technology Assessment* (pp. 149-166). Berlin, Heidelberg: Springer Berlin Heidelberg.. doi: 10.1007/978-3-642-59702-2_7

Devi K, S., Paranitharan, K. P., & Agniveesh A, I. (2021). Interpretive framework by analysing the enablers for implementation of Industry 4.0: an ISM approach. Total Quality Management & Business Excellence, 32(13-14), 1494-1514. doi: 10.1080/14783363.2020.1735933

Dües, C. M., Tan, K. H., & Lim, M. (2013). Green as the new Lean: how to use Lean practices as a catalyst to greening your supply chain. *Journal of cleaner production, 40*, 93-100. doi: 10.1016/J.JCLEPRO.2011.12.023

Elbasani, E., Siriporn, P., & Choi, J. S. (2020). A Survey on RFID in Industry 4.0. *Internet of Things for Industry 4.0: Design, Challenges and Solutions*, 1-16. doi: 10.1007/978-3-030-32530-5_1

Erdogan, M., Ozkan, B., Karasan, A., & Kaya, I. (2018). Selecting the best strategy for industry 4.0 applications with a case study. In *Industrial Engineering in the Industry 4.0 Era: Selected papers from the Global Joint Conference on Industrial Engineering and Its Application Areas, GJCIE 2017, July 20–21, Vienna, Austria* (pp. 109-119). Springer International Publishing. doi: 10.1007/978-3-319-71225-3_10

Esmaeilian, B., Sarkis, J., Lewis, K., & Behdad, S. (2020). Blockchain for the future of sustainable supply chain management in Industry 4.0. *Resources, Conservation and Recycling*, *163*, 105064. doi: 10.1016/j.resconrec.2020.105064

Fernández-Caramés, T. M., Blanco-Novoa, O., Froiz-Míguez, I., & Fraga-Lamas, P. (2019). Towards an autonomous industry 4.0 warehouse: A UAV and blockchain-based system for inventory and traceability applications in big data-driven supply chain management. *Sensors*, *19*(10), 2394. doi: 10.3390/S19102394

Fram, B. R., Rivlin, M., & Beredjiklian, P. K. (2020). On emerging technology: What to know when your patient has a microchip in his hand. *The Journal of hand surgery*, *45*(7), 645-649.. doi: 10.1016/J.JHSA.2020.01.008

Franchetti, M. J., Elahi, B., & Ghose, S. (2016). Green supply chain, logistics, and transportation. In *Green and Lean Management* (pp. 1-16). Cham: Springer International Publishing. doi: 10.1007/978-3-319-44909-8

Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International journal of production economics*, *210*, 15-26. doi: 10.1016/J.IJPE.2019.01.004

Fuller, A., Fan, Z., Day, C., & Barlow, C. (2020). Digital twin: Enabling technologies, challenges and open research. *IEEE access*, *8*, 108952-108971. doi: 10.1109/ACCESS.2020.2998358

Gani, A., Asjad, M., & Talib, F. (2021). Prioritization and Ranking of indicators of sustainable manufacturing in Indian MSMEs using fuzzy AHP approach. *Materials Today: Proceedings*, *46*, 6631-6637. doi: 10.1016/j.matpr.2021.04.101

Gërvalla, M., & Ternai, K. (2019). The Impact of Industry 4.0 to the ERP Approach. *SEFBIS Journal*, (13).

Ghadge, A. et al. (2020) 'The impact of Industry 4.0 implementation on supply chains', Journal of Manufacturing Technology Management, 31(4), pp. 669–686. doi: 10.1108/JMTM-10-2019-0368

Ghobakhloo, M. (2018). The future of manufacturing industry: a strategic roadmap toward Industry 4.0. *Journal of manufacturing technology management*, *29*(6), 910-936. doi: 10.1108/JMTM-02-2018-0057

Ghobakhloo, M. (2020). Industry 4.0, digitization, and opportunities for sustainability. *Journal of cleaner production*, *252*, 119869. doi: 10.1016/j.jclepro.2019.119869

Ghobakhloo, M., & Fathi, M. (2019). Corporate survival in Industry 4.0 era: the enabling role of lean-digitized manufacturing. *Journal of Manufacturing Technology Management*, *31*(1), 1-30. doi: 10.1108/JMTM-11-2018-0417

De Giovanni, P., & Cariola, A. (2021). Process innovation through industry 4.0 technologies, lean practices and green supply chains. *Research in Transportation Economics*, *90*, 100869. doi: 10.1016/J.RETREC.2020.100869

Gokalp, M. O., Kayabay, K., Akyol, M. A., Eren, P. E., & Koçyiğit, A. (2016, December). Big data for industry 4.0: A conceptual framework. In *2016 international conference on computational science and computational intelligence (CSCI)* (pp. 431-434). IEEE. doi: 10.1109/CSCI.2016.0088

Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future generation computer systems*, *29*(7), 1645-1660.. doi: 10.1016/J.FUTURE.2013.01.010

Guerreiro, B. V., Lins, R. G., Sun, J., & Schmitt, R. (2018). Definition of Smart Retrofitting: First steps for a company to deploy aspects of Industry 4.0. In *Advances in Manufacturing* (pp. 161-170). Springer International Publishing. doi: 10.1007/978-3-319-68619-6_16

Guttentag, D. A. (2010). Virtual reality: Applications and implications for tourism. *Tourism management*, *31*(5), 637-651. doi: 10.1016/J.TOURMAN.2009.07.003

Hajjaji, Y., Boulila, W., Farah, I. R., Romdhani, I., & Hussain, A. (2021). Big data and IoT-based applications in smart environments: A systematic review. *Computer Science Review*, *39*, 100318.. doi: 10.1016/J.COSREV.2020.100318

Haleem, A., Sushil, Qadri, M. A., & Kumar, S. (2012). Analysis of critical success factors of world-class manufacturing practices: an application of interpretative structural modelling and interpretative ranking process. *Production Planning & Control*, *23*(10-11), 722-73.. doi: 10.1080/09537287.2011.642134

Hassan Al-Maeeni, S. S., Kuhnhen, C., Engel, B., & Schiller, M. (2020) Smart retrofitting of machine tools in the context of industry 4.0. *Procedia CIRP*, *88*, 369-374. doi: 10.1016/J.PROCIR.2020.05.064

IIgor, H., Bohuslava, J., & Martin, J. (2016, June). Proposal of communication standardization of industrial networks in Industry 4.0. In *2016 IEEE 20th Jubilee International Conference on Intelligent Engineering Systems (INES)* (pp. 119-124). IEEE. doi: 10.1109/INES.2016.7555105

Jain, V., & Ajmera, P. (2021). Modelling the enablers of industry 4.0 in the Indian manufacturing industry. *International Journal of Productivity and Performance Management*, *70*(6), 1233-1262. doi: 10.1108/IJPPM-07-2019-0317

Javaid, M., Haleem, A., Vaishya, R., Bahl, S., Suman, R., & Vaish, A. (2020). Industry 4.0 technologies and their applications in fighting COVID-19 pandemic. *Diabetes & Metabolic Syndrome: Clinical Research & Reviews*, *14*(4), 419-422. doi: 10.1016/J.DSX.2020.04.032

Jimeno-Morenilla, A., Azariadis, P., Molina-Carmona, R., Kyratzi, S., & Moulianitis, V. (2021). Technology enablers for the implementation of Industry 4.0 to traditional manufacturing sectors: A review. *Computers in Industry*, *125*, 103390, p. 103390. doi: 10.1016/j.compind.2020.103390

Kamble, S. S., Gunasekaran, A., Ghadge, A., & Raut, R. (2020). A performance measurement system for industry 4.0 enabled smart manufacturing system in SMMEs-A review and empirical investigation. *International journal of production economics*, *229*, 107853. doi: 10.1016/J.IJPE.2020.107853

Kiru, M. U. (2016). A critical review of the challenges, threats, and drawbacks of humanoid and autonomous robots. *International journal of technology & engineering*, *4*(3), 135-150. doi: 10.21013/jte.v4.n3.p2

Konur, S., Lan, Y., Thakker, D., Morkyani, G., Polovina, N., & Sharp, J. (2021). Towards design and implementation of Industry 4.0 for food manufacturing. *Neural Computing and Applications*, 1-13. doi: 10.1007/s00521-021-05726-z

Krishnan, S., Gupta, S., Kaliyan, M., Kumar, V., & Garza-Reyes, J. A. (2021). Assessing the key enablers for Industry 4.0 adoption using MICMAC analysis: a case study. *International Journal of Productivity and Performance Management*, *70*(5), 1049-1071. doi: 10.1108/IJPPM-02-2020-0053

Kumar, S., Suhaib, M., & Asjad, M. (2021). Narrowing the barriers to Industry 4.0 practices through PCA-Fuzzy AHP-K means. *Journal of Advances in Management Research*, *18*(2), 200-226. doi: 10.1108/JAMR-06-2020-0098

Lai, Y. J., Liu, T. Y., & Hwang, C. L. (1994). Topsis for MODM. *European journal of operational research*, *76*(3), 486-500. doi: 10.1016/0377-2217(94)90282-8

Lee, J., Bagheri, B., & Kao, H. A. (2015). A cyber-physical systems architecture for industry 4.0-based manufacturing systems. *Manufacturing letters*, *3*, 18-23. doi: 10.1016/j.mfglet.2014.12.001

Li, G., Tan, J. and Chaudhry, S. S. (2019) 'Industry 4.0 and big data innovations', Enterprise Information Systems, 13(2), pp. 145–147. doi: 10.1080/17517575.2018.1554190

Luthra, S., Yadav, G., Kumar, A., Anosike, T., Mangla, S., & Garg, D. (2020) 'Study of key enablers of industry 4.0 practices implementation using ISM-Fuzzy MICMAC approach', Proceedings of the International Conference on Industrial Engineering and Operations Management, 0(March), pp. 241-251.

Amoozad Mahdiraji, H., Kazimieras Zavadskas, E., Skare, M., Rajabi Kafshgar, F. Z., & Arab, A. (2020). Evaluating strategies for implementing industry 4.0: a hybrid expert oriented approach of BWM and interval valued intuitionistic fuzzy TODIM. *Economic research-Ekonomska istraživanja*, *33*(1), 1600-1620. doi: 10.1080/1331677X.2020.1753090

Manglani, H., Hodge, G. L., & Oxenham, W. (2019). Application of the internet of things in the textile industry. *Textile Progress*, *51*(3), 225-297. doi: 10.1080/00405167.2020.1763701

Marnewick, C., & Labuschagne, L. (2005). A conceptual model for enterprise resource planning (ERP). *Information management & computer security*, *13*(2), 144-155.. doi: 10.1108/09685220510589325

Moktadir, M. A., Ali, S. M., Kusi-Sarpong, S., & Shaikh, M. A. A. (2018). Assessing challenges for implementing Industry 4.0: Implications for process safety and environmental protection. *Process safety and environmental protection*, *117*, 730-741. doi: 10.1016/J.PSEP.2018.04.020

Mrugalska, B., & Wyrwicka, M. K. (2017). Towards lean production in industry 4.0. *Procedia engineering*, *182*, 466-473. doi: 10.1016/J.PROENG.2017.03.135

Murugaiyan, P., & Ramasamy, P. (2021). Analyzing interrelated enablers of industry 4.0 for implementation in present industrial scenario. *Management Research Review*, *44*(9), 1241-1262. doi: 10.1108/MRR-08-2020-0499

Muscatello, J. R., Small, M. H., & Chen, I. J. (2003). Implementing enterprise resource planning (ERP) systems in small and midsize manufacturing firms. *International Journal of Operations & Production Management*, *23*(8), 850-871.. doi: 10.1108/01443570310486329/FULL/HTML

OOesterreich, T. D., & Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in industry*, *83*, 121-139. doi: 10.1016/J.COMPIND.2016.09.006

Onat, N., & Bayar, H. (2010). The sustainability indicators of power production systems. *Renewable and Sustainable Energy Reviews*, *14*(9), 3108-3115. doi: 10.1016/J.RSER.2010.07.022

Usuga Cadavid, J. P., Lamouri, S., Grabot, B., Pellerin, R., & Fortin, A. (2020). Machine learning applied in production planning and control: a state-of-the-art in the era of industry 4.0. *Journal of Intelligent Manufacturing*, *31*, 1531-1558. doi: 10.1007/s10845-019-01531-7

Parung, G. A., Hidayanto, A. N., Sandhyaduhita, P. I., Ulo, K. L. M., & Phusavat, K. (2018). Barriers and strategies of open government data adoption using fuzzy AHP-TOPSIS: A case of Indonesia. *Transforming Government: People, Process and Policy*, *12*(3/4), 210-243. doi: 10.1108/TG-09-2017-0055

Paszkiewicz, A., Bolanowski, M., Budzik, G., Przeszłowski, Ł., & Oleksy, M. (2020). Process of creating an integrated design and manufacturing environment as part of the structure of industry 4.0. *Processes*, *8*(9), 1019. doi: 10.3390/PR8091019

Peres, R. S., Jia, X., Lee, J., Sun, K., Colombo, A. W., & Barata, J. (2020). Industrial artificial intelligence in industry 4.0-systematic review, challenges and outlook. *IEEE Access*, *8*, 220121-220139. doi: 10.1109/ACCESS.2020.3042874

Popkova, E. G. (2019). Preconditions of formation and development of industry 4.0 in the conditions of knowledge economy. *Industry 4.0: Industrial Revolution of the 21st Century*, 65-72. doi: 10.1007/978-3-319-94310-7_6

Raji, I. O., Shevtshenko, E., Rossi, T., & Strozzi, F. (2021). Industry 4.0 technologies as enablers of lean and agile supply chain strategies: an exploratory investigation. *The International Journal of Logistics Management*, *32*(4), 1150-1189. doi: 10.1108/IJLM-04-2020-0157

Rajput, S., & Singh, S. P. (2018). Identifying Industry 4.0 IoT enablers by integrated PCA-ISM-DEMATEL approach. *Management Decision*, *57*(8), 1784-1817. doi: 10.1108/MD-04-2018-0378

Rathore, M. M., Paul, A., Hong, W. H., Seo, H., Awan, I., & Saeed, S. (2018). Exploiting IoT and big data analytics: Defining smart digital city using real-time urban data. *Sustainable cities and society*, *40*, 600-610. doi: 10.1016/J.SCS.2017.12.022

Reports and Publications | Ministry of Micro, Small & Medium Enterprises (no date). Available at: https://msme.gov.in/documents/reports-and-publications (Accessed: 24 July 2021)

Ripanti, E. F., & Tjahjono, B. (2019). Unveiling the potentials of circular economy values in logistics and supply chain management. *The International Journal of Logistics Management*, *30*(3), 723-742. doi: 10.1108/IJLM-04-2018-0109

Rodgers, R., Hunter, J. E., & Rogers, D. L. (1993). Influence of top management commitment on management program success. *Journal of applied psychology*, *78*(1), 151-155. doi: 10.1037/0021-9010.78.1.151

Rojko, A. (2017). Industry 4.0 concept: Background and overview. *International journal of interactive mobile technologies*, *11*(5). doi: 10.3991/ijim.v11i5.7072

Rosin, F., Forget, P., Lamouri, S., & Pellerin, R. (2020). Impacts of Industry 4.0 technologies on Lean principles. *International Journal of Production Research*, *58*(6), 1644-1661. doi: 10.1080/00207543.2019.1672902

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015). Industry 4.0: The future of productivity and growth in manufacturing industries. *Boston consulting group*, *9*(1), 54-89.

Santos, C. H. D., De Queiroz, J. A., Leal, F., & Montevechi, J. A. B. (2022). Use of simulation in the industry 4.0 context: Creation of a Digital Twin to optimise decision making on non-automated process. *Journal of Simulation*, *16*(3), 284-297. doi: 10.1080/17477778.2020.1811172

Santos, M. Y., Oliveira e Sá, J., Costa, C., Galvão, J., Andrade, C., Martinho, B., ... & Costa, E. (2017). A big data analytics architecture for industry 4.0. In *Recent Advances in Information Systems and Technologies: Volume 2 5* (pp. 175-184). Springer International Publishing. doi: 10.1007/978-3-319-56538-5_19

Satyanarayanan, M. (2017). The emergence of edge computing. *Computer*, *50*(1), 30-39. doi: 10.1109/MC.2017.9

Saxby, R., Cano-Kourouklis, M., & Viza, E. (2020). An initial assessment of Lean Management methods for Industry 4.0. *The TQM Journal*, *32*(4), 587-601. doi: 10.1108/TQM-12-2019-0298

Sharkey, N. E. (2012). The evitability of autonomous robot warfare. *International Review of the Red Cross*, *94*(886), 787-799. doi: 10.1017/S1816383112000732

Sharma, R., Jabbour, C. J. C., & Lopes de Sousa Jabbour, A. B. (2021). Sustainable manufacturing and industry 4.0: what we know and what we don't. *Journal of Enterprise Information Management*, *34*(1), 230-266. doi: 10.1108/JEIM-01-2020-0024

Shelton, R. (2009). Integrating product and service innovation. *Research-Technology Management*, *52*(3), 38-44. doi: 10.1080/08956308.2009.11657567

Shi, W., & Dustdar, S. (2016). The promise of edge computing. *Computer*, *49*(5), 78-81.1. doi: 10.1109/MC.2016.145

Shrouf, F., Ordieres, J., & Miragliotta, G. (2014). Smart Factories in INdustry 4.0: a review of the concept and of Energy Management approaches in Porduction based on the Internet of Things. In *IEEE International conference on Industrial, Engineering and Engineering Management* (pp. 697-701). doi: 10.1109/IEEM.2014.7058728

Da Silva, V. L., Kovaleski, J. L., Pagani, R. N., Silva, J. D. M., & Corsi, A. (2020). Implementation of Industry 4.0 concept in companies: Empirical evidences. *International Journal of Computer Integrated Manufacturing*, *33*(4), 325-342.. doi: 10.1080/0951192X.2019.1699258

Singh, R. R. (2019). Present Status of MSMEs in India : Challenges and Opportunities, 3085(06), 1267–1271.

Somohano-Rodríguez, F. M., Madrid-Guijarro, A., & López-Fernández, J. M. (2022). Does Industry 4.0 really matter for SME innovation?. *Journal of Small Business Management*, *60*(4), 1001-1028. doi: 10.1080/00472778.2020.1780728

Sowe, S. K., Kimata, T., Dong, M., & Zettsu, K. (2014, July). Managing heterogeneous sensor data on a big data platform: IoT services for data-intensive science. In *2014 IEEE 38th international computer software and applications conference workshops* (pp. 295-300). IEEE.0. doi: 10.1109/COMPSACW.2014.52

Steinmueller, W. E. (1996). Technological infrastructure in information technology industries. In *Technological infrastructure policy: An international perspective* (pp. 117-139). Dordrecht: Springer Netherlands. doi: 10.1007/978-94-015-8739-6_5

Subramanian, G., Patil, B. T., & Gardas, B. B. (2021). Evaluation of enablers of cloud technology to boost industry 4.0 adoption in the manufacturing micro, small and medium enterprises. *Journal of Modelling in Management*, *16*(3), 944-962. doi: 10.1108/JM2-08-2020-0207

Szozda, N. (2017). Industry 4.0 and its impact on the functioning of supply chains. *Logforum*, *13*(4), 401–414. doi: 10.17270/J.LOG.2017.4.2

Talib, F., K Josaiman, S., & Faisal, M. N. (2021). An integrated AHP and ISO14000, ISO26000 based approach for improving sustainability in supply chains. *International Journal of Quality & Reliability Management*, *38*(6), 1301-1327.. doi: 10.1108/IJQRM-04-2020-0129

Tsai, W. H., & Lu, Y. H. (2018). A framework of production planning and control with carbon tax under industry 4.0. *Sustainability*, *10*(9), 3221. doi: 10.3390/SU10093221

Türkeș, M. C., Oncioiu, I., Aslam, H. D., Marin-Pantelescu, A., Topor, D. I., & Căpușneanu, S. (2019). Drivers and barriers in using industry 4.0: a perspective of SMEs in Romania. *Processes*, *7*(3), 153. doi: 10.3390/pr7030153

Vachon, S., & Klassen, R. D. (2006). Extending green practices across the supply chain: the impact of upstream and downstream integration. *International journal of operations & Production Management*, *26*(7), 795-821. doi: 10.1108/01443570610672248

Virk, S. K., & Negi, P. (2019). An overview of MSME sector in India with special reference to the state of Uttarakhand. *International Journal of Trend in Scientific Research and Development*, *3*(2), 891-896. doi: 10.31142/ijtsrd21520

Wamba, S. F., & Queiroz, M. M. (2022). Industry 4.0 and the supply chain digitalisation: a blockchain diffusion perspective. *Production Planning & Control*, *33*(2-3), 193-210. doi: 10.1080/09537287.2020.1810756

Wang, P., & Luo, M. (2021). A digital twin-based big data virtual and real fusion learning reference framework supported by industrial internet towards smart manufacturing. *Journal of manufacturing systems*, *58*, 16-32. doi: 10.1016/J.JMSY.2020.11.012

What is Big Data Analytics and Why is it Important? (no date). Available at: https://searchbusinessanalytics.techtarget.com/definition/big-data-analytics (Accessed: 10 December 2020)

Winkelhaus, S., & Grosse, E. H. (2020). Logistics 4.0: a systematic review towards a new logistics system. *International Journal of Production Research*, *58*(1), 18-43. doi: 10.1080/00207543.2019.1612964

Wozniak, J., Budzik, G., Przeszlowski, L., Fudali, P., Dziubek, T., & Paszkiewicz, A. (2022). Analysis of the quality of products manufactured with the application of additive manufacturing technologies with the possibility of applying the industry 4. 0 conception. *International Journal for Quality Research*, *16*(3), 831–850. https://doi.org/10.24874/IJQR16.03-12

Zimon, D., Urbaniak, M., Madzík, P., & Prokopiuk, I. (2022). Supply chain quality management (Scqm) literature review and model proposal in the era of industry 4. 0. *International Journal for Quality Research*, *16*(4), 1283–1296. https://doi.org/10.24874/IJQR16.04-21

Zhang, H., Chen, G., Ooi, B. C., Tan, K. L., & Zhang, M. (2015). In-memory big data management and processing: A survey. *IEEE Transactions on Knowledge and Data Engineering*, *27*(7), 1920-1948. doi: 10.1109/TKDE.2015.2427795

Zheng, J., Caldwell, N., Harland, C., Powell, P., Woerndl, M., & Xu, S. (2004). Small firms and e-business: cautiousness, contingency and cost-benefit. *Journal of Purchasing and Supply Management*, *10*(1), 27-39. doi: 10.1016/J.PURSUP.2003.11.004

Zhou, K., Liu, T., & Zhou, L. (2015, August). Industry 4.0: Towards future industrial opportunities and challenges. In *2015 12th International conference on fuzzy systems and knowledge discovery (FSKD)* (pp. 2147-2152). IEEE. doi: 10.1109/FSKD.2015.7382284

Yogesh Upadhyay
Department of Mechanical Engineering
Zakir Husain College of Engineering & Technology
Faculty of Engineering & Technology
Aligarh Muslim University
Aligarh
India
yogeshupadhyay35@gmail.com
ORCID 0000-0002-6577-4192

Faisal Talib
Department of Mechanical Engineering
Zakir Husain College of Engineering & Technology
Faculty of Engineering & Technology
Aligarh Muslim University
Aligarh
India
ftalib77@gmail.com
ORCID 0000-0002-3982-3798

Syed Ali Zaheen
Department of Mechanical Engineering
Zakir Husain College of Engineering & Technology
Faculty of Engineering & Technology
Aligarh Muslim University
Aligarh
India
s.alizaheen@gmail.com
ORCID 0000-0002-0576-9826

Mohd. Siaffuddin Ansari
Department of Mechanical Engineering
Zakir Husain College of Engineering & Technology
Faculty of Engineering & Technology
Aligarh Muslim University
Aligarh
India
saifuddinansari11@gmail.com
ORCID 0000-0002-7992-3208