Study of Key Enablers of Industry 4.0 Practices Implementation Using ISM-Fuzzy MICMAC Approach

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Abstract

Industry 4.0 (I4) has rapidly gained its importance across manufacturing industries over the globe. It can be seen as the fourth up-gradation of the Industry sector, which is competent to influencing entire business processes mainly at the designing, production and delivery stages. Accordingly, the key objective of this research is to identify the key enablers of I4 practices that facilitate its adoption across the Indian manufacturing industries. This study captures a unique set of ten key enablers with the help of existing literature. Further, Interpretive Structural Modeling (ISM)-fuzzy MICMAC was used to assess the interrelationship among key enablers and also compute a structural hierarchy. The primary result indicates that 'Supportive government policies' have a critical impact in implementing I4 practices from Indian perspective. This study may help policymakers and practitioners in the implementation of I4 practices in the Indian perspective for sustainable business development.

Keywords:
Industry 4.0, Key enablers, Interpretive Structural Modeling (ISM), Fuzzy MICMAC

1. Introduction

Industry 4.0 (I4) is basically as German concept introduced by Prof. Hanover Messe in 2011 for the first time and its roadmap was released in 2013. This concept has been adopted by the industries across value chain networks and production systems by the digitization of entire process structure to analyze the data in a more effective manner (Chen and Xing, 2015). For creating a novel paradigm in business practices, managers of industries have been adopting several emerging technologies which includes 3D printing, Internet of Things (IoT), Big Data Analytics (BDA) and I4 (Almada-Lobo, 2016). Currently, I4 is at the nascent stage especially in underdeveloped countries like India and it requires a firm discussion for its implementation in business processes (Hofmann and Rüsch, 2017; Luthra and Mangla, 2018).

I4 assists the managers to handle complex industry systems easily by making a proper network-based user-friendly system based on devices, entities and Information and Communication Technologies (ICT) (Müller et al., 2017). I4 plays a vital role in merging the domain of ICT to implement the IoT and related digital communication practices for an intelligent and digitized environment (Luthra and Mangla, 2018). Currently, most of the organizations are searching their way in I4 field and mainly dependent on ad hoc system. Therefore, the need arises to create a strategy based framework of I4 practices implementation by recognizing and analyzing key enablers. The present research article has the following objectives:

i. To identify key enablers of I4 practices implementation;
ii. To analyze the identified key enablers in the Indian perspective to create a strategy based framework of I4 practices implementation.

The present work aims to recognize and investigate key enablers of I4 practices implementation. Interpretive Structural Modeling (ISM) is utilized to establish a structural hierarchy of key I4 enabler practices implementation from Indian perspective. It is further observed that many researchers integrate ISM with MICMAC analysis so as to compute the driving and dependence power of included variables; however, it is also observed that MICMAC analysis often fails to identify the hidden relationship among the variables. So it is further advised to integrate fuzzy set theory with MICMAC analysis. Therefore, ISM-Fuzzy MICMAC has been identified as a suitable approach (Sindhu et al., 2016) for analyzing key enablers of I4 practices implementation from Indian perspective. This will later help in computing the intensities of I4 enablers.

Further, the paper is organized as a review of literature in section 2, methodology in section 3, data collection and results in section 4, findings along with study implications in section 5 and conclusions with the limitations and future scope of research are provided in Section 6.

2. Literature Review

For the literature review, we used several keywords, including – Drivers/Key Factors/Enablers of I4 practices implementation. These keywords were searched in the database, given as – Google Scholar; Google, Scopus; EBSCO Host; Web of Science (WoS) and PROQUEST, etc. as suggested by (Yadav et al. 2016) 10 key enablers of I4 practices implementation are identified from literature resource and inputs received from the experts. The list of identified drivers is given in Table 1 as shown below.

Table 1- Identification of key enablers of I4 practices implementation

Drivers	Brief Description	Sources
Understanding benefits of I4 practices	There is a lack of understanding of I4 utilization at both research and practice levels.	Luthra and Mangla (2018)
Research & development on I4 adoption	The foremost reason for this is a lack of focused research to address different aspects of I4 adoption.	Hermann et al. (2016); Luthra and Mangla (2018)
Management support and commitment towards I4 practices	I4 practices could not possible without management support and commitment.	Shamim et al. (2017); Luthra and Mangla (2018)
Supportive government policies towards I4	There is a lack of government policies in I4 for most of the economies	BRICS Business Council (2017); Luthra and Mangla (2018)
Change management	Industries need to improve their capabilities for accepting immediate changes in their processes as well as decisions.	de Sousa Jabbour et al. (2018)
Training and development programs	Training and development programs for employees and staff are useful in understanding and	Lin et al. (2017); Luthra et al. (2019)

	implementing I4.	
Developing infrastructure, digital technologies, and networks	IT-based infrastructure and new technologies are essential for I4 adoption.	Pfohl et al. (2017)
Adoption of innovative business models	Business organizations must upgrade themselves in terms of usage of innovative business models to reap benefits.	Stock and Seliger (2016)
Integration of technologies and data	Industries need to integrate various advanced technologies such as IoT, Cloud computing and exchange formats.	Lasi et al. (2014); Mangla et al. (2019)
Trust building between organization and inter organizations	Trust building between organization and inter organizations is important in accepting the I4 concept.	Pfohl et al. (2017); Yadav et al. (2019)

Luthra and Mangla (2018) indicated in their study that "Understanding benefits of I4 practices", "Management support and commitment towards I4 practices" and "Research & development on I4 adoption" are the most critical enablers that help in improving I4 adoption. Various researchers across the globe have reported that digitization activities and introducing smart factory components within the system strongly influences the adoption rate of I4. Many researchers further indicated that regular execution of training and development programs and adoption of change management leads to a positive impact in improving organizational performance (Lin et al. 2017). It is reported in various performance improvement studies that the adoption of innovative business models and integration of technologies and data helps in better execution of organizational activities (Stock and Seliger 2016). Developing infrastructure, digital technologies and networks often play a vital role in attainment of organizational goals by synchronising a correct mix of processes and optimizing the entire structure (Pfohl et al. 2017). Further, it is also captured by various researchers that scheduled training and development programs keep the employees updated with the adopted methodologies and accordingly it helps in improving individual performances. Many organizations failed to adopt I4 due to a lack of management support and a strong commitment towards its adoption. Various studies in literature also reported that the management is often unaware of the benefits of I4 practices so it is though required to clearly capture the insights to portray the improvement in organizational and financial performance (Hermann et al. 2016). It also helps the organization to build their brand image which assists them in competing at an international platform.

3. Methodology

This study intends to use a combination of ISM and fuzzy MICMAC analysis to analyze the identified key enablers in the Indian perspective to develop a policy framework of I4 practices implementation. The details are provided below.

3.1 Interpretive Structural Modeling

Prof. J. Warfield in 1974 introduced the ISM approach for understanding the complex industry system that requires establishing the linkage among a large number of variables. It may also be considered as a systematic approach required for developing a structural hierarchy of the variables existing in a complex system. ISM for the present study can be developed with the help of the following steps (Luthra et al., 2011).

- Identification of key enablers for I4 implementation.
- The setting of pairwise relationships between key enablers based on a Structural Self-Interaction Matrix (SSIM)
- Construct a final reachability matrix from an initial reachability matrix based on transitivity rule.
- Obtaining different levels from the final reachability matrix.
- Construct a digraph by eliminating the transitivity and convert it into a model by substituting defined variable nodes with actual statements.
- Check the conceptual inconsistency of the developed model and make the required modifications.

3.2 Fuzzy MICMAC

Matriced'Impacts croises-multipication applique' and classment (MICMAC) analysis is extremely helpful in computing the driving and dependent power of enablers through the enablers included within the problem structure. However, it is critical to note that the relationship among the included variables cannot be the same; hence, it is possible that some variables might be strongly related while some might have a weak linkage. To overcome such a situation, ISM has been integrated with fuzzy MICMAC. For executing the fuzzy MICMAC approach, following steps are considered (Khan and Haleem, 2015).

- Obtain the binary direct relationship matrix and convert into fuzzy direct relationship matrix
- To stabilize the fuzzy direct relationship matrix to achieve Fuzzy MICMAC stabilized matrix
- Divide enablers into different categories based upon the driving and dependence power

4. Data Analysis And Results

For data collection, an expert panel including 5 decision-makers (two academicians and three industry experts) was selected. All the selected industry experts have a minimum of 10 years of industry experience of handling advanced manufacturing systems and holds strong exposure towards the adoption of new methodologies. Similarly, the academic experts have a minimum Ph.D. degree and were involved in various live consultancy projects of industries. To capture the required data for the above-mentioned hybrid approach, a brainstorming session was conducted to seek their opinions on the level of significance of enablers in I4 implementation from Indian perspective. Further, a contextual relationship between enablers has been set by brainstorming. To estimate the relationship between two variables (i and j), VAXO analysis was conducted.
V- Enabler i will help to achieve enabler j; **A-** Enabler j will help to achieve enabler i;
X- i and j help to achieve each other; and **O-** i and j have no relation with each other.
According to the VAXO analysis, the SSIM has been developed (Table 2).

Table 2- SSIM matrix for key enablers of I4 practices implementation

S. No.	Key Enablers of I4 practices implementation	10	9	8	7	6	5	4	3	2
1	Understanding benefits of I4 practices	X	A	V	A	A	A	A	A	A
2	Research & development on I4 adoption	V	V	V	V	V	V	A	V	-
3	Management support and commitment towards I4 practices	V	V	V	V	V	V	A	-	-
4	Supportive government policies towards I4	V	V	V	V	V	V	-	-	-
5	Change management	V	X	V	X	X	-	-	-	-
6	Training and development programs	V	O	V	O	-	-	-	-	-
7	Developing infrastructure, digital technologies and networks	V	X	V	-	-	-	-	-	-
8	Adoption of innovative business models	A	A	-	-	-	-	-	-	-
9	Integration of technologies and data	V	-	-	-	-	-	-	-	-
10	Trust building between organisation and inter organisations	-	-	-	-	-	-	-	-	-

The binary initial reachability matrix is computed by substituting different values for the relations captured through SSIM. Accordingly, the binary values are obtained by the different set of rules. If, (i, j) value is represented V then the (i, j) value within the reachability matrix will be allotted as 1 and (j, i) value will be 0. Similarly, if (i,j) value is represented by A then the (i,j) value within the reachability matrix will be allotted as 0 and (j,i) value turns to be 1. However, if (i,j) value is represented by X then the (i,j) value within the reachability matrix will be allotted as 1 and (j,i) value turns to be 1. Subsequently, if (i,j) value is represented by O then the (i,j) value within the reachability matrix will be allotted as 0 and (j,i) value turns out to be 0. The final reachability matrix constructed by incorporating the transitivity that occurred within the system. The concept of transitivity is basically a mutual relationship obtained during relative inter-relation among the two variables with the other variable. The final reachability matrix for key enablers of I4 practices implementation has been shown in Table 3.

Table 3- Final Reachability matrix for key enablers of I4 practices implementation

S. No.	Key Enablers of I4 practices implementation	1	2	3	4	5	6	7	8	9	10
1	Understanding benefits of I4 practices	1	0	0	0	0	0	0	1	0	1

2	Research & development on I4 adoption	1	1	1	0	1	1	1	1	1	1
3	Management support and commitment towards I4 practices	1	0	1	0	1	1	1	1	1	1
4	Supportive government policies towards I4	1	1	1	1	1	1	1	1	1	1
5	Change management	1	0	0	0	1	1	1	1	1	1
6	Training and development programs	1	0	0	0	1	1	1*	1	1*	1
7	Developing infrastructure, digital technologies and networks	1	0	0	0	1	1*	1	1	1	1
8	Adoption of innovative business models	0	0	0	0	0	0	0	1	0	0
9	Integration of technologies and data	1	0	0	0	1	1*	1	1	1	1
10	Trust building between organisation and inter organisations	1	0	0	0	0	0	0	1	0	1

*After incorporating transitivity

To obtain the level partitioning, various iterations are conducted by using three important terminologies namely; reachability set, antecedent set, and intersection set. The reachability set for a specific enabler indicates who effectively it helps in achieving the other enablers. However, the antecedent for a specific enabler indicates who effectively it is achieved with the help of the other enablers. Similarly, the intersection of both these sets for all the enablers helps in computing the intersection set. The situation where the reachability set and the intersection set are exactly identical for the selected enablers, then it is allotted as level 1st and it captures the top level of structural hierarchy (Luthra et al., 2011). This process will continue until the identification of each level. The final level of each enabler is portrayed in Table 4.

Table 4- Final Level Partitioning for key enablers of I4 practices implementation

S. No.	Key Enablers of I4 practices implementation	Level in ISM hierarchy
1	Understanding benefits of I4 practices	II
2	Research & development on I4 adoption	V
3	Management support and commitment towards I4 practices	IV
4	Supportive government policies towards I4	VI
5	Change management	III
6	Training and development programs	III
7	Developing infrastructure, digital technologies and networks	III
8	Adoption of innovative business models	I
9	Integration of technologies and data	III
10	Trust building between organisation and inter organisations	II

From Table 4, the structural model has been constructed by separating transitivity's links. ISM based hierarchical model for enablers of I4 practices implementation in the Indian context has been shown in Figure 1.

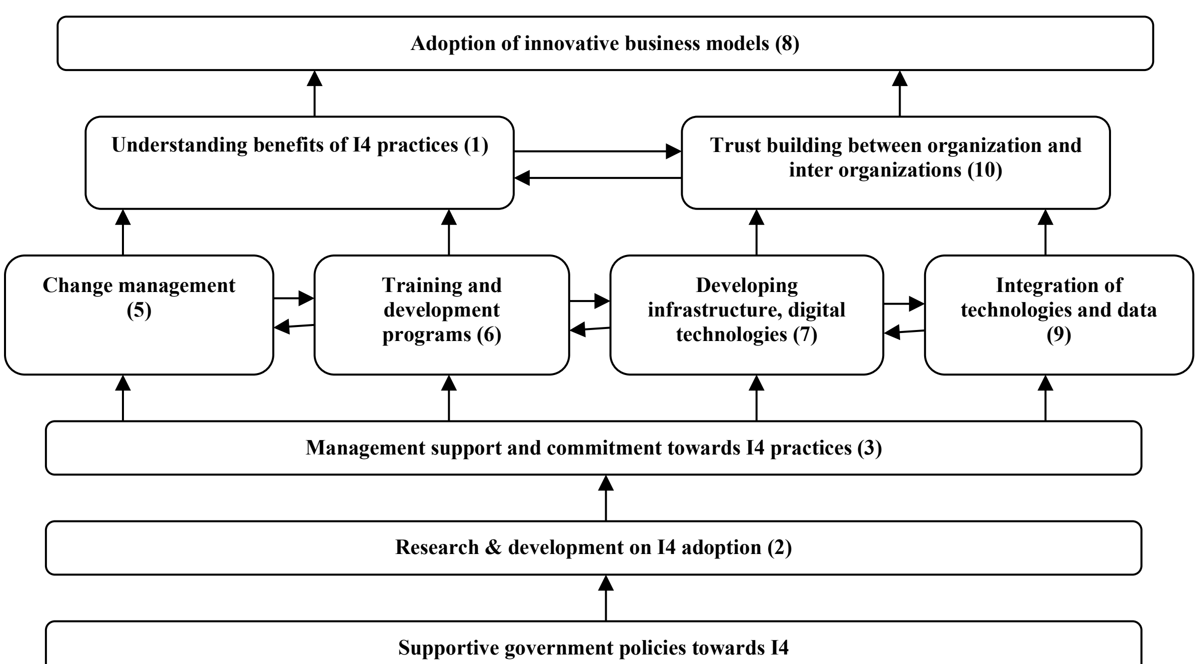

Figure. 1 ISM based hierarchical model for enablers of I4 practices implementation

"Adoption of innovative business models" is at the dependent top-level position and "Supportive government policies towards I4 is at the independent bottom level position enablers of I4 practices implementation in the Indian context.

Fuzzy concepts allow analyzing the possibility of reachability on 0-1 scale converted from triangular fuzzy number (No=0; Extremely Poor = 0.1; Poor = 0.3; Fair = 0.5; Good = 0.7; Very Good = 0.9; Excellent = 1). Based on an initial reachability matrix, the binary relationship matrix is constructed, which is further converted into Fuzzy Direct Relationship Matrix (FDRM) for key enablers of I4 practices implementation. Matrix multiplication plays a critical role in the fuzzy MICMAC analysis as it helps in stabilizing the previous reachability matrix and accordingly assists in developing the fuzzy stabilized matrix (Khan and Haleem, 2015). The fuzzy stabilized matrix for key enablers of I4 practices implementation is portrayed through Table 5.

Table 5- Fuzzy stabilized matrix for key enablers of I4 practices implementation

S. No	Key Enablers of I4 practices implementation	1	2	3	4	5	6	7	8	9	10	Driving Power
1	Understanding benefits of I4 practices	0	0	0	0	0	0	0	0.7	0	0.9	1.6
2	Research & development on I4 adoption	0.3	0	0.7	0	0.5	0.5	0.5	0.1	0.5	0.3	4.9
3	Management support and commitment towards I4 practices	0.5	0	0	0	0.7	0.7	0.7	0.3	0.7	0.5	4.9
4	Supportive government policies towards I4	0.1	0.7	0.5	0	0.3	0.3	0.3	0	0.3	0.1	4.9
5	Change management	0.7	0	0	0	0	0.9	0.9	0.5	0.9	0.7	5.7
6	Training and development programs	0.7	0	0	0	0.9	0	0	0.5	0	0.7	5.7
7	Developing infrastructure, digital technologies and networks	0.7	0	0	0	0.9	0	0	0.5	0.9	0.7	5.7
8	Adoption of innovative business models	0	0	0	0	0	0	0	0	0	0	0
9	Integration of technologies and data	0.7	0	0	0	0.9	0	0.9	0.5	0	0.7	5.7
10	Trust building between organisation and inter organisations	0.9	0	0	0	0	0	0	0.7	0	0	1.6
Dependence Power		5.8	0	0	0	5.7	5.7	5.7	6.3	5.7	5.8	40.7

Fuzzy MICMAC analysis (Figure 2) highlights the key enablers of I4 practices implementation into four categories with respect to their influence on I4 adoption.

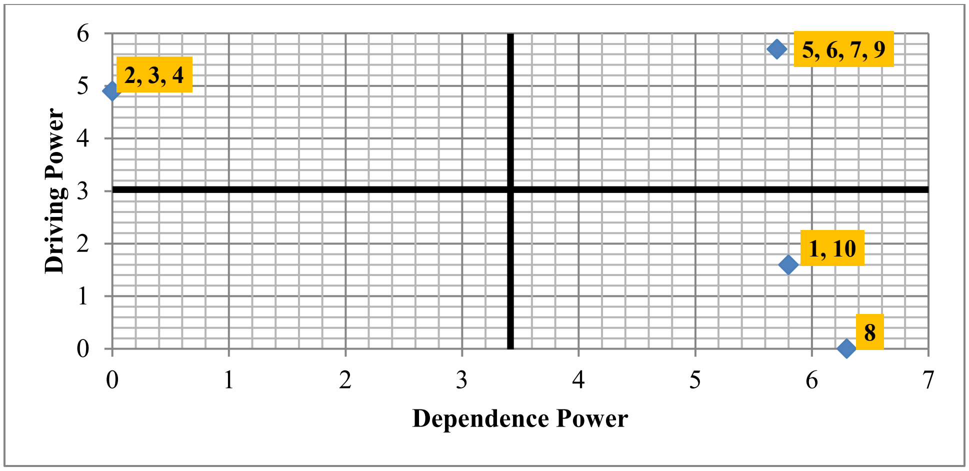

Figure- 2 Fuzzy MICMAC for enablers of I4 practices implementation

The four regions are discussed as under:
Autonomous region: Enablers observed among this region holds low driving and dependence power. Hence, it is assumed that they do not affect the adoption process and can be ignored or neglected.
Dependent region: Enablers observed among this region holds less driving power and high dependence. These enablers hold the top position in the structural model.
Linkage region: Enablers observed among this region holds high driving and dependence power. They establish a linkage between driving and dependence enablers.
Driver region: Enablers observed among this region holds less dependence and high driving power. These enablers hold the bottom of the structural hierarchy.

5. Discussion

The objectives defined for the present study are achieved by utilizing an integrated ISM-fuzzy MICMAC approach. In the initial phase, the structural hierarchy development of I4 enablers is accomplished through ISM approach. The results reveal that the supportive government policies towards I4 adoption actuate the system for adoption of I4. Further, it promotes research and development on I4 adoption and also requires management support and commitment towards I4 adoption. These three enablers are most critical for I4 adoption as it lies at the bottom of the hierarchy and helps other enablers to get executed in an effective manner. It is very essential that these enablers are penetrated in the system effectively. Luthra and Mangla (2018) also highlighted that appropriate usage of government policies and strong management engagement helps in the adoption of I4. Further, change management, training and development programs, developing infrastructure and digital technologies, and integration of technologies and data exist in the middle of the structural hierarchy. It helps in binding the input and output variables. Hermann et al. (2016) emphasized on digitization of activities and processes within the system structure. They also indicated the importance of training and development programs in improving organizational performance. Later, in the subsequent level, understanding the benefits of I4 practices and trust-building between the organization and inter organizations are emerged which play a critical role in the successful adoption of I4. Finally, it supports the adoption of innovative business models that flourishes the organizational structure and helps in standardizing the system environment. Appropriate execution of such initiatives helps the organizations to withstand against the global competition. Khan and Haleem (2015) also discussed that adopting innovative business models helps in smoothing the system processes which ultimately improves the organizational performance. Later on, fuzzy MICMAC analysis was conducted to compute the driving and dependence power of the selected I4 enablers. All the enablers (Enabler 2, 3, 4) existing in the bottom of the ISM model fall in the fourth quadrant and is termed as driving enablers which actuates the entire system. These enablers have high driving power but their dependence power is very low. Similarly, the enablers (Enabler 1, 8, 10) observed at the top of the ISM model are dependent enablers with low driving and high dependent power. These enablers are observed in the second quadrant among the cluster. However, the enablers (Enabler 5, 6, 7, 9) existing in the middle of the hierarchy and termed as linkage enablers and it helps in binding the driving and dependent enablers.

5.1 Study Implications

The present study offers various implications for researchers and practitioners as defined below:

- This study identifies a unique set of 10 I4 enablers that helps in its adoption process.
- Many studies in the literature have portrayed several enabler sets, but no study could guide how these enablers can act as a roadmap in successfully adopting I4. This study develops a structural hierarchy which will be extremely beneficial for the practitioners to execute the adoption process effectively.
- The enabler set portrayed in various studies is extracted through the research articles reported in the existing literature. However, this study verifies the set of enablers through the experts for better assurance of their applicability.
- It is enormously critical to adopt all the enablers simultaneously, hence, the ISM model developed in this study would assist the researchers and practitioners to assess the execution stage of each enabler and also plan the corrective strategies accordingly.
- The driving and dependence power of enablers will also aid the practitioners to assess the importance of each enabler. So that the management decisions and financial planning can be done hassle-free.

6. Conclusion

The main aim of the research was to study key enablers of I4 practices implementation to develop a policy framework of I4 practices implementation. Initially, ten key enablers of I4 practices implementation were identified through literature support. After that, contextual relationships between identified key enablers were evaluated through experts' inputs to develop a hierarchy of key enablers of I4 practices implementation from Indian perspective. Finally, fuzzy MICMAC analysis was used to categorize key enablers based upon their driving and dependence powers. "Adoption of innovative business models" is at the top level position and "Supportive government policies towards I4 is at the independent bottom level position enablers of I4 practices implementation in the Indian context. In fuzzy MICMAC analysis results, three enablers were identified as dependent enablers. Dependent enablers are weak drivers but strongly dependent on other enablers. These enablers represent desired objectives for the implementation of I4 practices. Four enablers were reported as linkage enablers. Three enablers were identified as the driver or key enablers to develop a policy framework of I4 practices implementation. Initially, Practitioners and policymakers must focus on these three enablers to improve other enablers. Practitioners and policymakers may be benefited in analyzing the enabler in I4 practices implementation.
Biasing of expert's opinions may be the limitation of this study. In future Structural Equation Modeling (SEM) may be used to test and validate the model of this study. It is also recommended that researchers can also conduct a large scale survey by strengthening the data set and increasing the number of enablers for obtaining better results. It is difficult to adopt all the enablers simultaneously; hence, the structural model developed will provide a roadmap to the practitioners for successfully executing the required objectives. It is also advised to utilize other structural mapping approaches such as DEMATEL, fuzzy cognitive maps, and analytical network process to validate the results obtained in the present study. More such studies will strongly help the practitioners and industry personals to improve their organizational performance and achieve the defined organizational goals more effectively. It is also recommended that if the defined enablers are successfully penetrated within the organization then it would be much easier for them to expand their business and compete at the international markets.

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Biographies

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Gunjan Yadav is currently working as Assistant Professor of Production Engineering at Veermata Jijabai Technological Institute (VJTI), Mumbai (India). He is having more than 10 years of Teaching, Training, Consultancy, Research experience. He has completed his Ph.D. in Mechanical Engineering from Sardar Vallabhbhai National Institute of Technology (SVNIT), Surat. He is serving as reviewer to renowned International Journals such as Journal of Cleaner Production (Elsevier), Production Planning and Control (Taylor & Francis), Transportation Research: Part A (Elsevier), International Journal of Production Research (Taylor & Francis) and many more. Presently his h-index is 8 and i-10 index is 8. He has contributed 40+ papers at National/International level at various journals (SCI/Scopus indexed), seminars and conferences. He has chaired sessions at International/National conferences and delivered invited talks in various NITs and government funded institutions. He is presently associated with various societies which include Institution of Engineers (India), Indian Institution of Industrial Engineering (IIIE), Indian Society of Technical Education (ISTE), Operation Research Society of India (ORSI). He regularly conducts training programs and guides research scholars on areas such as Sustainable Manufacturing, Lean Six Sigma, QMS, GT, Renewable Energy Management, Quality and Productivity Improvement etc. He may be contacted at – gunjanyadav86@gmail.com

Anil Kumar is a Lecturer in area of Operations, Supply Chain and Business Analytics at Centre for Supply Chain Improvement, the University of Derby, U.K. For the last eight years, he has been associated with teaching and research. He earned his PhD in Management Science from Indian Institute of Information Technology and Management, Gwalior, India. He did graduation in Mathematics (Hons) and MSc in Mathematics from Kururksheta University, India. He earned Master of Business Administration (MBA) and qualified National Eligibility Test (NET), June 2011. Anil has contributed over 40+ research papers in international referred & national journals.

Anthony Anosike is a Senior Lecturer in area of Operations and Supply Chain Management at Centre for Supply Chain Improvement at University of Derby, U.K. He earned his PhD in Modelling and Simulation of Dynamically Integrated Manufacturing Systems from University of Exeter, U.K. He is working in the areas of Supply Chain Sustainability, Supply Chain Resilience, Food Supply Chain, Lean and Agile manufacturing, Theory of Constraints (ToC), Systems Thinking, Systematic Innovation (TRIZ), Business Process Management, Applications of Industry 4.0 Technologies in Supply Chain such as Internet of Things (IoT), Blockchain and Big Data etc.

Sachin Kumar Mangla is a lecturer of Knowledge Management and Business Decision-making, in Plymouth Business School, University of Plymouth, Plymouth, United Kingdom. He is working in the field of Green Supply Chain; Circular Economy and Sustainability; Cross Disciplinary Research in Supply and Operations Management; Knowledge Management based Decision-Making; Industry 4.0; Risk Management; Simulation; Optimisation; Reverse Logistics; Renewable Energy; Empirical research. He did his doctorate (specialization Operations and Supply Chain Management) from Indian Institute of Technology (IIT), Roorkee. He loves to write research papers and projects. He has published/presented several papers in repute (ABS and ABDC indexed) international/national journals. He has an h-index 24, i10-index 32 and Google Scholar Citations of more than 2000. He has received 2017 Most Cited Paper Award for his paper entitled "Risk analysis in green chain using fuzzy AHP approach: a case study". Recently, he has edited a book "Sustainable Procurement in Supply Chain Operations" published under CRC Press (Taylor & Francis Group). He is also currently editing several special issues in Production Planning & Control: The Management of Operations; Resources, Recycling and Conservation; Annals of Operations Research; Management of Environmental Quality; Journal of Resource Policy and Journal of Enterprise Information Management.

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