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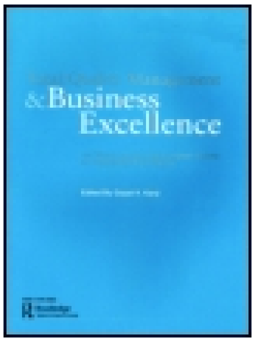

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Interpretive framework by analysing the enablers for implementation of Industry 4.0: an ISM approach

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Today, industries are compelled to manufacture the products of excellent quality to meet the ever-increasing consumer demands competitively. Hence, implementing Industry 4.0 is becoming essentially the new age solution for industrial operations. This study attempts to categorise the important technological enablers for the Indian manufacturing industry in implementing Industry 4.0. In this context, 14 selected and identified enablers, namely Visual Computing, Big Data, Product Life Cycle Management, Supply Chain, Top Level Management, Collaborative Productivity, Internet of Things, Horizontal and Vertical Integration, Mass Customisation, Cyber-Physical System, Additive Manufacturing, Professional Training and Development, Networked Manufacturing Systems and Operational Efficiency, are identified through the review of literature and expert's opinion for implementing Industry 4.0. Interpretive structural modelling (ISM) methodology is employed to appreciate the mutual relationships among the identified enablers. Furthermore, contextual interactions among the enablers are established by brainstorming with experts. The identified 14 technological enablers are further classified as dependent and driving factors. Later, the validation of the factors is done by MICMAC analysis. The interactions amongst these enablers will help the manufacturing organisations to prioritise and administer these factors efficiently and effectively to reap benefits during the implementation of Industry 4.0. Therefore, this study analyses the enablers to implement Industry 4.0 in the manufacturing industries. Also, it develops an interpretive framework that will help understand the interdependence of the enablers.

Keywords: Industry 4.0; ISM approach; MICMAC analysis; manufacturing industry; enablers

1. Introduction

Industry 4.0 is Germany's industrial reforms of manufacturing industries with high cutting edge and competitive manufacturing practice (Kagermann, Helbig, Hellinger, & Wahlster, 2013). Industry 4.0 optimises the use of computers and robotics connected remotely to minimising the human effort (Singh, 2017). Industrial production is driven by global competition poised to confront ever-changing market place. Therefore, the need of the present context is industry 4.0 which is a promising approach based on the integration of manufacturing and business process for increasing the value chain of the company (Rojko, 2017). Due to the importance of transition towards achieving a challenging position of a country in the global market, some governments lead such initiatives to support the transition all over the world (Rojko, 2017). Similarly few countries like North America practise concept like Industrial Internet in late 2012 and benefited by 49.6% of the global economy. China drew inspiration from Industry 4.0 concept which actually originated from German industry and

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started adopting it to fulfil the needs through 'Made in China 2025' in order to upgrade the Chinese industries in 2015 (Liao, Deschamps, Loures, & Ramos, 2017). This would undoubtedly initiate the manufacturing industries of various countries and would be more of interconnected, real time-oriented, smart and integrated processing which would result in the generation of huge volume of information (Bauernhansl, Hompel, & Vogel-Heuser, 2014). Since, the smart management technique of Industry 4.0 will provide quality information of the product processing (Constantinescu, Francalanza, Matarazzo, & Balkan, 2014) and quality management information data to help the management taking better decision (Shin, Dahlgaard, Dahlgaard-Park, & Kim, 2018).

The concept of Industry 4.0 has resulted in a paradigm shift in the business model and in the business operation of the organisation. The concept of Industry 4.0 such as smart factory, Cyber-Physical Systems (CPS), Internet of Things (IOT) and Internet of Services (IOS) will enable faster, more flexible and more efficient process to produce high-quality product at lower cost and ultimately changing and improving the competitiveness of company (Hartmann (2015); Lasi, Fettke, Kemper, Feld, and Hoffmann (2014); Shin et al. (2018); Constantinescu et al. (2014)).

Various concepts in Industry 4.0, namely Internet of Things (IOT), Big Data (BD), Vertical Integration, Horizontal Integration, Visual Computing (VC), Product Lifecycle Management (PLM), Network Manufacturing System (NM) and Additive Manufacturing (AM), were studied and discussed by a number of authors, namely Witkowski (2017); Yan, Meng, Lu, and Li (2017); Kang et al. (2016); Posada et al. (2015); Brettel, Friederichsen, Keller, and Rosenberg (2014); Paranitharan, Babu, Pandi, and Jeyathilagar (2017) and Holmström, Partanen, Tuomi, and Walter (2010) and identified them as enablers of integrated environment in Industry 4.0. But these driving enablers are limited in the Indian context. Hence this study tries to explore the influencing (or) motivating factor of Industry 4.0 concept in the Indian context. This study also acts as a pioneering approach that may analyse the driver enablers in manufacturing industries. With these above considerations, this study attempts to analyse enablers of Industry 4.0 with the aid of proposed framework, namely Interpretive Structural Modelling (ISM) to analyse the problem within Indian context with the help of expert opinion and with support of literature.

The main objectives of this paper are

- To identify the enablers that drive the implementation of Industry 4.0 in the Indian context.
- To propose a framework to analyse Industry 4.0 with the aid of ISM.
- To validate our ISM result with the support of expert opinion and literature.

The remaining sections of this paper are organised as follows. Section 2 explores the concept of Industry 4.0 with the existing literature review. The problem description and methodology of the study are detailed in section 3. The discussion and conclusion of the study are provided in section 4. The unique contribution to theory and practice are discussed in section 5, followed by the limitation with future scope of research in section 6.

2. Literature review

This study aims at implementing Industry 4.0 in the manufacturing industry in India where it seems Indian manufacturers are yet to adopt Industry 4.0 in full scale. To make this study more contentious a rigorous literature review was conducted by using an online computerised database like Taylor and Francis, Science direct, Google scholar, Springer, world scientific and inderscience to understand and identify the enablers of Industry 4.0 and to adopt those in the Indian context by Interpretative structural modelling methodology.

2.1. *Review of Industry 4.0*

The implementation of Industry 4.0 includes various processes. Among which the Internet of Things (IOT) and services is one which actually transforms manufacturing process to a smart environment (Kagermann et al., 2013). IOT is considered as one among the four key elements that contribute to Industry 4.0 (Hermann, Pentek, & Otto, 2016). Advanced technologies (e.g. embedded systems) of Industry 4.0 integrate operators, physical objects, manufacturing lines, machines and processes to form a new kind of value chain (Schuh, Potente, Varandani, & Schmitz, 2014). Out of which IOT and Big data help in predictive maintenance by improving the reliability of the system (Yan et al., 2017) which is considered to be the backbone of Industry 4.0 (Witkowski, 2017). This needs creation of an integrated environment in order to represent a transparent product process to manage the data more efficiently (Kang et al., 2016). Zezulka, Marcon, Vesely, and Sajdl (2016) opined that the most promising technology of Industry 4.0 will be the Internet of Services (IOS), IOT and Internet of People (IOP). Internet protocol (IPv6) is also used along with IOT and IOS which uniquely identifies the network resources, information, objects and people within the organisation or within the network (Kagermann et al., 2013). Furthermore, Cyber-Physical System (CPS) is considered to be another enabler which helps in cross-linking the manufacturing system by operating both self-organised and decentralised manner in decision-making (Stock and Seliger (2016) and Strandhagen, Alfnes, Strandhagen, and Vallandingham (2017)). Industry 4.0 requires both physical and digital domain and this technique can be implemented with the help of the CPS (Kagermann et al. 2013; Eleftheriadis and Myklebust 2017; Stock and Seliger, (2016)). In this regard, it could be noted that a complete digital model of the product, intelligent factory and CPS are the important features contributing towards the success of the 'Fourth Revolution' (Witkowski, 2017). Industry 4.0 requires both physical and digital domain and this technique can be implemented with the help of the CPS (Kagermann et al., 2013). IOT and the CPS help communicates with employees to form a network in the real-time environment of Industry 4.0. another enabler value chain via IoS helps the workers connected by both internal and cross-organisational services (Strandhagen et al., 2017), through which both physical and digital world is merged in one platform called the next-generation industrialisation (Lasi et al., 2014). Industrialisation paved the way for Smart machines. Smart machines help in autonomously triggering actions for the exchange of information and controlling (Kagermann et al. (2013); Závadská and Závadský (2018)). Furthermore, Industry 4.0 helps in collaborating productivity across different departments and also helps produce products at a lower price. In addition, Cyber-Physical System (CPS) and IOT help collect and exchange information autonomously from the industrial resources like machines, materials, products (Qin, Liu, & Grosvenor, 2016). The visual computing is also considered to be an important part for industry 4.0 which helps acquire, analyse and synthesise the visual data which provide tools and give valuable support for the efficient operations of industry (Posada et al., 2015). In addition, Singh (2017) has discussed about the product to make closer to the customer, based on market requirement by a process called product lifecycle management through different process such as production, IT, systems engineering and business system to a new level through PLM in order to improve business.

Brettel et al. (2014) and Holmström et al. (2010) have discussed more about additive manufacturing and its various benefits over conventional manufacturing methods which help in formulating customisation process, improve supply chain, spare parts production and after-sales service in Industry 4.0. The Networked manufacturing is also an enabler which helps to interact within the organisation (Khajavi, Partanen, & Holmström, 2014), and gives a complete overview of the inventory and the efficiency of the process flow of the product (Hermann et al., 2016), and helps in effectively transporting the finished goods (Atzori, Iera, & Morabito, 2010). Holmström et al. (2010) have studied the three fundamental dimensions of Industry 4.0, namely vertical integration, horizontal integration and manufacturing systems connected by a network, wherein vertical and horizontal integration helps the industry digitalisation across the entire value chain (Schumacher, Erol, & Sihn, 2016). The vertical integration will be a major concern for the Human resource department since it can affect the existing hierarchical level (Kagermann et al., 2013). Wang, Wan, Li, and Zhang (2016) have also studied about the vertically integrating levels of integration of automation using ERP and Manufacturing execution system which will result in reconfigurable manufacturing system (Brettel et al., 2014) and used as tools for planning and manufacturing in order to be competitive (Manufuture, 2004). Horizontal integration helps the flow of material and creates value for the company (Wang et al., 2016) to achieve an upper hand on every manufacturer with the network (Lin, Nagalingam, Kuik, & Murata, 2012). Customisation of products can be achieved using back-to-back engineering solutions (Wang et al., 2016) which helps the customer understand the product features and receive advice about the utilisation of the product (Qin et al., 2016).

At the helm of affairs, the role of top-level management could not be taken afar due to their importance having the sole responsibility in planning, strategising and implementing Industry 4.0. Their participation increasingly parts with in improving the way in which their information systems are being managed effectively. The management concepts are being advocated to include viewing information systems as a business within a business, managing the information resource by a committee, developing strategic plans for the information systems and understanding the contingency approach to management. Top-level management has a great influence on determining the success factor of Industry 4.0. They also hold the responsibility by providing general guidance for the information systems activity. Top-level management can empower each employee and take critical decisions based on the available information for the betterment of the organisation. Thus the role of management in Industry 4.0 is indeed a very important issue which many researchers have not explored fully (Piccarozzi, Aquilani, and Gatti (2018); Shamim, Cang, Yu, and Li (2016)). The top-level management is a complex one because it varies according to geographical variations, relative people culture and attitude.

2.2. *Interpretive structural modelling*

Interpretative structural modelling (ISM) is a learning process and it is being used for the past 25 years to understand the complex situation of the client. And it provides solutions to complex problems (Mohammed, Shankar, & Banwet, 2008). ISM is a computer-assisted process that enables individuals or group to develop a complex relationship between the elements in the complex situation (Warfield, 1974). This ISM method is a group judgemental decision whether and how items are related to finding solutions for a complex situation. The hierarchical structures are portrayed in a digraph model (Sage, 1977). In this study, enablers are considered to be the structure of the comprehensive model for Industry 4.0 implementation.

Sharma, and Gupta, (1995) used ISM methodology in the Indian context to develop a hierarchy of action in waste management project. Ravi and Shankar (2005) used ISM for examining the barriers of reverse logistics. Singh, Garg, Deshmukh, and Kumar (2007) modelled the critical success factors of advanced manufacturing technology implementation using ISM. Soti, Shankar, and Kaushal (2010) and Dubey, Gunasekaran, Childe, Fosso Wamba, and Papadopoulos (2016) used ISM to analyse the enablers of six sigma implementation. Digalwar, Jindal, and Sangwan (2015) measures the level of world-class performance of manufacturing practice in the Indian context and furthermore, Paranitharan and Babu (2019) studied the performance of integrated practice critical success factor using the ISM methodology. With a complete understanding of ISM application, this study tries to evaluate the Industry 4.0 enablers by adopting the ISM approach.

From the literature review discussed above, it is clear that most of the literature mainly focused on enablers derived from two or few processes. However, these literature resources provide basic idea about the industry 4.0 implementation through the enablers which have been derived from the process described in the above review especially in the Indian context. Hence this study provides a significant approach to the problem of implementing Industry 4.0 in Indian industry.

3. Problem description and methodology

Industry 4.0, being an advanced process integrating the latest development in information technology, got started in the manufacturing sectors in developed countries. The developing country like India is yet to follow the suit and has a compulsion to adopt Industry 4.0 in order to face the severity of challenges from international markets. The nascent stage in implementing the Industry 4.0 process in India needs careful planning and rigorous implementation. In order to plan and decide a suitable strategy for implementation in Indian industry, we need the exploration of the influencing drivers that are enablers of Industry 4.0 in the Indian context. The identified enablers, which are purported to be implemented in the Indian manufacturing industry, have been explained in Table 1.

3.1. *Questionnaire development*

The questionnaire-based survey is used to evaluate the identified enabler's relationship for constructing the ISM-based model. One-hundred and fifty different manufacturing industries that manufacture pumps, home appliances, auto components, computer and electronic products were approached over phone, direct visits and mails for explaining the objectives and concept of this research. The respondents were requested to rate their opinions based on the importance of 14 enablers with five-points Likert scale for the successful implementation of Industry 4.0. The Likert scale '1' indicates strongly disagree and very low in support for the implementation of Industry 4.0 and '5' indicates strongly agree and very high in support for the implementation of industry 4.0 concept in the Indian manufacturing industry. A total of 150 industries were targeted for the study. Out of 150 industries, duly and corrected 118 (78.66%) responses were received. Among 78.66% of respondents, 36.45% of respondents are general managers, 27% are operational managers and the remaining 36% of responses were from assistant managers and senior engineers. According to Malhotra and Grover (1998) 20% of positive response rate is considered as enough for a survey-based study. Therefore, the responses of 118 respondents from various industries (78.34%) are considered for ranking the enablers based on the mean score values using the weighted average method. The responses were subjected to Principal Component Analysis (PCA) to evaluate the construct validity and the result has been depicted in Table 2. The reliability and internal consistency of collected data of the enablers were

Table 1. Description of Industry 4.0 enablers.

Enabler. No	Enablers	Description	Literature Support
1	Big Data (BD)	The huge amount of data available provides new solutions for predictive maintenance.	Witkowski (2017); Yan et al. (2017); Kang et al. (2016)
2	Visual Computing (VC)	Visual computing is a technique used to collect data and then analyse the available data using various computing tools. Visual computing technologies are an asset.	Posada et al. (2015)
3	Product Life cycle Management (PLM)	Cross-linked product life cycle is a major element for the value creation networks in Industry 4.0.	Stock et al. (2016); Singh (2017)
4	Additive Manufacturing (AM)	Additive manufacturing has benefits over conventional manufacturing methods and helps in design customisation for Industry 4.0	Brettel et al. (2014); Holmström et al. (2010); Khajavi et al. (2014)
5	Networked Manufacturing (NM)	The network gives a complete overview of the stock in the inventory and the product flow process efficiency which helps in better management and planning on safety stock	Hermann et al. (2016); Khajavi et al. (2014); Atzori et al. (2010)
6	Horizontal and Vertical Integration (HVI)	Vertical integration will be a major concern for the IT department since this can affect the existing hierarchical level within the factory. Horizontal integration using network ensures the smooth flow of materials among various departments.	Kagermann et al. (2013); Brettel et al. (2014); Wang et al., (2016)
7	Internet of Things (IOT)	Internet of Things (IOT) and services is a collaboration of various products and services through the industrial level, connected using the internet and can be termed as Industrial Internet.	Kagermann et al. (2013); Shrouf, Ordieres, and Miragliotta (2014); Qin et al. (2016); Gilchrist (2016)
8	Cyber-Physical System (CPS)	The intelligent cross-linking in a manufacturing system is realised by the application of CPS. Here CPS can be operational in two ways, that	Stock et al. (2016); Kagermann et al.,(2013); Lee, Bagheri, and Kao (2015).

(*Continued*)

Table 1. Continued.

Enabler. No	Enablers	Description	Literature Support
		is self-organised and decentralised.	
9	Collaborative Productivity (CP)	Networking helps teams work together more efficiently.	Schuh et al. (2014)
10	Top-Level Management (TM)	Involvement of top-level management is an important factor in calculating the success of the industry 4.0. They are responsible for providing general guidance for the information systems activity.	Piccarozzi et al. (2018); Shamim et al. (2016)
11	Mass Customisation (MC)	Customisation not only enables the customer to get the production information of the product, but also helps the customer to gain knowledge about the optimum utilisation.	Qin et al. (2016)
12	Supply Chain (SC)	A company, in order to have a strategic superiority, should give importance to values. It should readily respond to the opportunities available in the market, with the help of their existing internal resources.	Laursen and Svejvig (2016)
13	Professional Training and Development (PTD)	Employees are most affected by changes in technology in an organisation. Readiness in this dimension can be determined by analysing employee's current skills and the ability to acquire new skills. This requires employees to get well equipped with the digital workplace	Singh (2017)
14	Operational Efficiency (OE)	Industry 4.0 offers new approaches for dealing with complexity and improving operational efficiency.	Tortorella, Miorando, Caiado, Nascimento, and Portioli (2018); Küpper, Heidemann, Ströhle, Spindelndreier, and Knizek (2017); Gilchrist (2016); Lee, Kao, and Yang (2014).

tested by calculating Cronbach Alpha using statistical package for social science. The Cronbach alpha of all enablers was around 0.80. It indicates that there is a good internal consistency with the enablers. The value of Cronbach Alpha was within the limit recommended by Nunnally (1978). The overall mean score of enablers was '3.837' for our case which was '> 3.0' which are used for validation of factors (Paranitharan and Babu (2019); Mahajan, Agrawal, Sharma, and Nangia (2014)). Based on this all the enablers used for further

Table 2. Rank, loadings, mean score, validity and reliability.

Enablers	Expert loadings				Mean Score	Standard Deviation	Rank	Cronbach Alpha
Enabler1- BD	**0.882**	0.140	0.100	0.135	4.120	0.483	4	0.809
Enabler 2-VC	**0.869**	0.148	0.040	0.113	3.856	0.420	8	
Enabler 3- PLM	**0.857**	0.129	0.002	0.143	3.860	0.385	7	
Enabler 4-AM	**0.846**	0.228	0.113	0.160	2.86	0.420	14	
Enabler 5-NM	0.136	**0.861**	0.107	0.078	4.516	0.412	2	0.847
Enabler 6-HVI	0.084	**0.849**	−0.006	0.097	4.102	0.285	5	
Enabler 7-IOT	0.279	**0.740**	0.080	0.185	4.325	0.605	3	
Enabler 8-CPS	0.145	**0.738**	0.046	0.202	3.986	0.421	6	
Enabler 9-CP	0.099	−0.022	**0.901**	0.034	3.845	0.325	9	0.852
Enabler 10-TM	0.005	0.075	**0.892**	−0.007	4.527	0.246	1	
Enabler 11-MC	0.088	0.122	**0.828**	0.055	2.986	0.426	13	
Enabler 12-SC	0.090	0.168	0.029	**0.875**	3.542	0.385	12	0.843
Enabler 13-PTD	0.233	0.071	0.079	**0.836**	3.684	0.186	10	
Enabler 14-OE	0.152	0.262	−0.023	**0.810**	3.584	0.483	11	
		Overall mean score			3.837	0.462		

Extraction Method: Principal Component Analysis. ***Rotation Method:*** Varimax with Kaiser Normalisation.

analysis in the ISM. Fifteen experts from the above industries with practical knowledge and experience who are holding the positions of general managers, operational managers, assistant managers and engineers from senior to junior levels belonging to manufacturing, new product development, design and quality departments were identified, selected and used in this study as experts in order to be used in the ISM approach.

3.2. *Interpretative structural modelling*

Interpretive structural modelling (ISM) is a methodology used to find the relationship between the variables or enablers for a specific problem or issue. The primary theory of the ISM is to use the knowledge and practical experience of experts to split a multifaceted system into several sub-elements (systems) and create a systematic framework with various levels to emphasise the dominance factors in implementing a particular system, as shown in Figure 1. The developed framework will depict the arrangement of a complex problem or issue in a carefully planned model (Raj, Shankar, & Suhaib, 2008). Characteristics of the ISM methodology include (1) incorporating the knowledge base and the judgements of experts systematically, (2) giving an abundant opportunity for amendment of judgements, and (3) less computational efforts for criteria ranging from 10 to 25 numbers (4) used as a practical tool for various applications. Because of these characteristics, this method is more suitable for the current analysis with 14 factors compared with all other methodologies. The methodology has been depicted in the figure below:

Some of the important characteristics of the ISM technique (Vinodh, Ramesh, & Arun, 2016) include:

(1) This method is interpretative as it helps to make a decision on how different enablers are related.
(2) It is a modelling procedure as relationships among the enablers are represented in the digraph model.

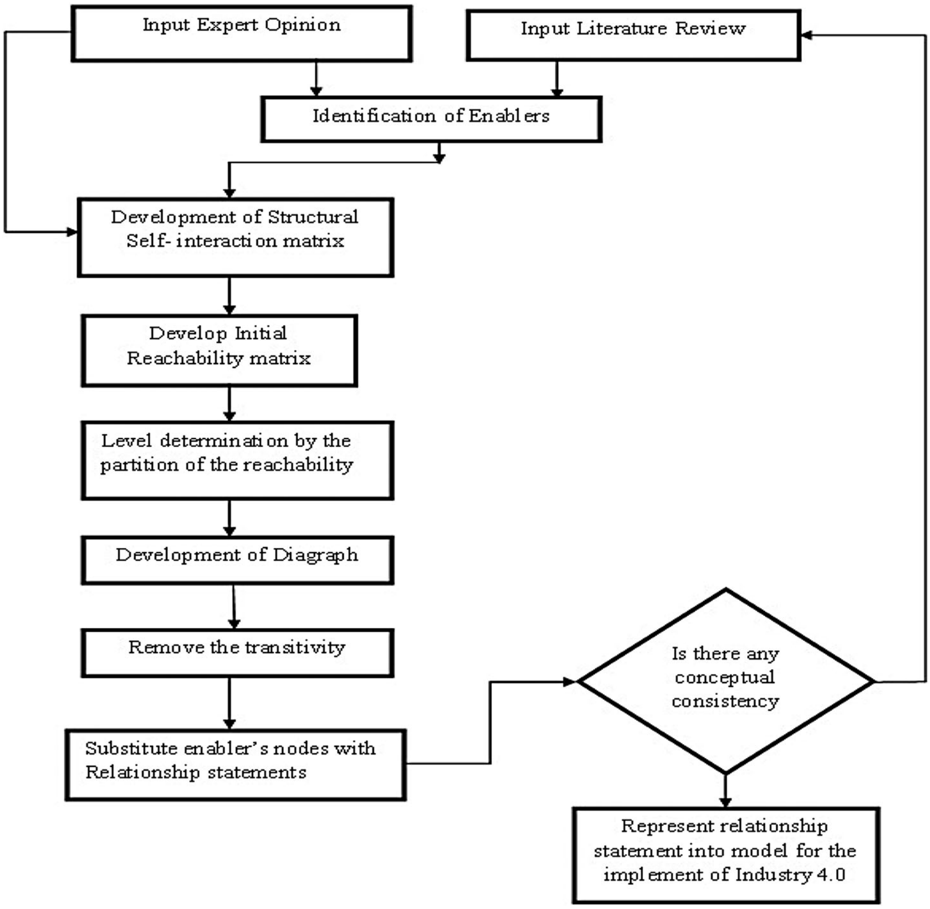

Figure 1. Methodology of the ISM approach.

(3) It is also a systematic framework as the structure is developed from multifaceted sets.
(4) It facilitates individual and group learning process.
(5) It creates direction and order on the correlation among a variety of system elements.

Enablers that are identified can be related to each other, irrespective of the complexity of problems. The direct and indirect relationships between the factors are helpful in understanding the accurate situation, rather than considering the individual factor alone. Using this process, we can form a structure of elements into a comprehensive systematic model by analysing the enablers in the form of the set both directly and indirectly (Lasi et al., 2014; Hartmann, 2015). The model thus obtained is carefully shifted to design a pattern of graphics and words (Kagermann et al. (2013); Bauernhansl et al. (2014); Valdez, Brauner, Schaar, Holzinger, and Zieflea (2015); Constantinescu et al. (2014)). In a complex situation, ISM helps in analysing how each factor contributes to the situation over the other (Qureshi, Kumar, and Kumar (2007); Shin et al. (2018)). This section deals with the discussion of the ISM methodology. Steps involved in the ISM methodology are as follows.

Step 1: The variables that influence the system are identified and listed. In our research work, the variables are the enablers to implement Industry 4.0 in the Indian manufacturing industry.

Step 2: The enablers identified in the previous step are used to find out the relative relationship among them with respect to the context.

Step 3: A Structural Self-Interaction Matrix (SSIM) is built to show the pairwise relationship among enablers of the system.

Step 4: From the SSIM, a reachability matrix is developed and the obtained matrix is checked for transitivity, which is an assumption made in ISM. For example, if enabler B is related to enabler C, and enabler C is related to enabler D, then enabler B is essentially related to enabler D.

Step 5: The reachability matrix thus obtained from step 4 is partitioned on different levels.

Step 6: A directed graph is drawn, based on the relationship in the reachability matrix, followed by the removal of transitivity links.

Step 7: The digraph created in step 6 is converted into an ISM framework by replacing the nodes with the enabler statements.

3.3. *Structural self-Interaction matrix (SSIM) and reachability matrix*

The relevant enablers for Industry 4.0 are identified and the significant enablers are selected from the group by brainstorming sessions with experts. The next step in the methodology is to analyse and find out the contextual relationship among the enablers. The relationship, thus identified among enablers, is based on the pair of variables that are examined. Thus a matrix is developed based on the expert opinion and dependencies. Based on the contextual relationship, SSIM has been developed.

The direction of the relationship between the enablers (i and j) is denoted using four symbols:

V: If enabler i leads to enabler j but if both the enablers are not interdependent;
A: If enabler j leads to enabler i but if both the enablers are not interdependent;
X: If both the enablers are interdependent;
O: Both the variables are unrelated;

For example, variable V is mentioned in the cell (1, 14) because variable 1 leads to variable 14. In the same way, variable A is mentioned in the cell (1, 12) because variable 1 is driven by variable 12. A similar method is adopted for filling the SSIM, as shown in Table 3, with appropriate variables.

After forming SSIM with the help of the above variables, the SSIM table is converted into a binary matrix called an initial reachability matrix, as shown in Table 4, where the variables V, A, X, and O in the matrix are substituted with numbers 1 and 0 based on the following rules in the initial reachability matrix:

- If the entry is V in the cell (i, j), that cell will be substituted by number 1, whereas the number for cell (j, i) will be 0; for example '1' has been given to cell (1, 14) and '0' to cell (14, 1).
- If the entry is A in the cell (i, j), that cell will be substituted by number 0, whereas the number for cell (j, i) will be 1; for example '0' has been given to cell (1, 12) and '1' to cell (12,1).

Table 3. Structural self-interaction matrix.

Enablers	14	13	12	11	10	9	8	7	6	5	4	3	2
1	V	V	A	V	A	V	V	X	A	V	V	V	X
2	V	V	A	V	A	V	V	X	A	V	V	V	–
3	V	A	A	V	A	X	A	A	A	A	A	–	–
4	V	X	A	V	A	V	A	A	A	X	–	–	–
5	V	X	A	V	A	V	A	A	A	–	–	–	–
6	V	V	X	V	A	V	V	V	–	–	–	–	–
7	V	V	A	V	A	V	V	–	–	–	–	–	–
8	V	V	A	V	A	V	–	–	–	–	–	–	–
9	V	A	A	V	A	–	–	–	–	–	–	–	–
10	V	V	V	V	–	–	–	–	–	–	–	–	–
11	V	A	A	–	–	–	–	–	–	–	–	–	–
12	V	V	–	–	–	–	–	–	–	–	–	–	–
13	V	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 4. Initial reachability matrix.

Enablers	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1	1	1	1	1	0	1	1	1	0	1	0	1	1
2	1	1	1	1	1	0	1	1	1	0	1	0	1	1
3	0	0	1	0	0	0	0	0	1	0	1	0	0	1
4	0	0	1	1	1	0	0	0	1	0	1	0	1	1
5	0	0	1	1	1	0	0	0	1	0	1	0	1	1
6	1	1	1	1	1	1	1	1	1	0	1	1	1	1
7	1	1	1	1	1	0	1	1	1	0	1	0	1	1
8	0	0	1	1	1	0	0	1	1	0	1	0	1	1
9	0	0	1	0	0	0	0	0	1	0	1	0	0	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	0	0	0	0	0	0	0	0	0	0	1	0	0	1
12	1	1	1	1	1	1	1	1	1	0	1	1	1	1
13	0	0	1	1	1	0	0	0	1	0	1	0	1	1
14	0	0	0	0	0	0	0	0	0	0	0	0	0	1

- If the entry is X in the cell (i, j), that cell will be substituted by number 1, whereas the number for cell (j, i) will also be 1; for example '1' has been given to cell (1, 2) and also to cell (2,1).
- If the entry is O in the cell (i, j), that cell will be substituted by number 0, whereas the number for cell (j, i) will also be 0.

The final reachability matrix is then obtained, as shown in Table 5, by incorporating the transitivity as discussed in the ISM methodology.

3.4. *Level partitions*

From the final reachability matrix, the reachability set and the antecedence set can be obtained for each variable. Subsequently, the intersection set of these sets have also been derived. The variables are given different levels in the ISM hierarchy based on their similarity between reachability set and the intersection set. From Table 5, it is seen that the

Table 5. Final reachability matrix.

Enablers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Driver Power
1	1	1	1	1	1	0	1	1	1	0	1	0	1	1	11
2	1	1	1	1	1	0	1	1	1	0	1	0	1	1	11
3	0	0	1	0	0	0	0	0	1	0	1	0	0	1	4
4	0	0	1	1	1	0	0	0	1	0	1	0	1	1	7
5	0	0	1	1	1	0	0	0	1	0	1	0	1	1	7
6	1	1	1	1	1	1	1	1	1	0	1	1	1	1	13
7	1	1	1	1	1	0	1	1	1	0	1	0	1	1	11
8	0	0	1	1	1	0	0	1	1	0	1	0	1	1	8
9	0	0	1	0	0	0	0	0	1	0	1	0	0	1	4
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
11	0	0	0	0	0	0	0	0	0	0	1	0	0	1	2
12	1	1	1	1	1	1	1	1	1	0	1	1	1	1	13
13	0	0	1	1	1	0	0	0	1	0	1	0	1	1	7
14	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Dependence	6	6	12	10	10	3	6	7	12	1	13	3	10	14	

operational efficiency has been found in Level 1. The iteration has been continued till the level of each variable has been identified, as in Table 6.

3.5. *Formation of ISM-based model*

A structural model named digraph is developed based on the final reachability matrix. The removal of the transitivity links and replacement of the node numbers in the enablers of the ISM model, as shown in Figure 2, was achieved. 'Top Management Commitment' has a very high significance in the implementation of Industry 4.0 by the Indian automobile industry based on the ISM hierarchy.

3.6. *MICMAC analysis*

Multiplication properties of matrices are the main principle behind the MICMAC analysis (Diabat & Govindan, 2011; Kannan, Pokharel, & Kumar, 2009). The goal of the MICMAC

Table 6. Partitioning of variables.

Enablers	Reachability set	Antecedent set	Intersection set	Iteration level
1	1,2,3,4,5,7,8,9,11,13,14	12,10,6,2,1,7	1,2,7	VI
2	1,2,3,4,5,7,8,9,11,13,14	1,2,6,7,10,12	1,2,7	VI
3	3,9,11,14	1,2,3,4,5,6,7,8,9,10,12,13	9,3	III
4	3,4,5,9,11,13,14	1,2,1,4,5,6,7,8,10,13,12	4,5,13	IV
5	3,4,5,9,11,13,14	1,2,1,4,5,6,7,8,10,12,13	4,5,13	IV
6	1,2,3,4,5,6,7,8,9,11,12,13,14	6,10,12	6,12	VII
7	1,2,3,4,5,7,8,9,11,13,14	1,2,6,7,10,12	1,2,7	VI
8	3,4,5,8,9,11,13,14	1,2,1,6,7,8,10,12	8	V
9	3,9,11,14	1,2,3,4,5,6,7,8,9,10,12,13	3,9	III
10	1,2,3,4,5,6,7,8,9,10,11,12,13,14	10	10	VIII
11	1,11,14	1,2,3,4,5,6,7,8,9,10,11,12,13	11	II
12	1,2,3,4,5,6,7,8,9,11,12,13,14	6,10,12	6,12	VII
13	3,4,5,9,11,13,14	1,2,4,5,6,7,8,10,12,13	4,5,13	IV
14	14	1,2,3,4,5,6,7,8,9,10,11,12,13,14	14	I

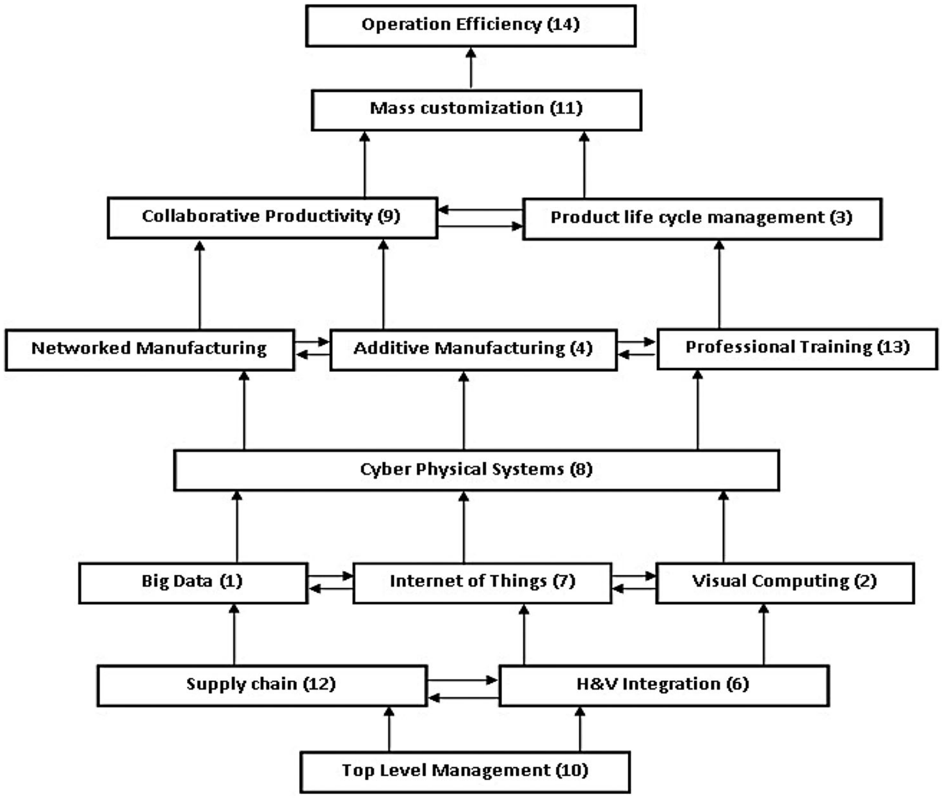

Figure 2. ISM framework (Diagraph).

is to group the factors after analysing, based on its dependence and driving powers. A graph is plotted with dependence power along the X-axis and driving power along the Y-axis.

The driving power and the dependence of the enablers are displayed in Table 5 in the final reachability. These driving power and dependence values have been used in the MICMAC analysis to classify the enablers into autonomous, dependent, linkage, and independent (driver) variables, as shown in Figure 3.

- Enablers that have weak driving power and weak dependence are indicated in the first quadrant that consists of the autonomous variables/enablers.
- Enablers that have weak driving power but strong dependence are indicated in the second quadrant that is identified as dependant variables.
- Enablers that have strong driving power and strong dependence are indicated in the third quadrant identified as linkage variables.
- Enablers having strong driving power but weak dependence are in the fourth quadrant as independent variables.

Adoption of ‘Industry 4.0’ in the traditional manufacturing system is not an easy task. Without analysing the enabler industries will not know where to initiate the implementation of ‘Industry 4.0’. This study will help the management in identifying the significant enablers for Industry 4.0. The driver and dependence power diagram obtained from the

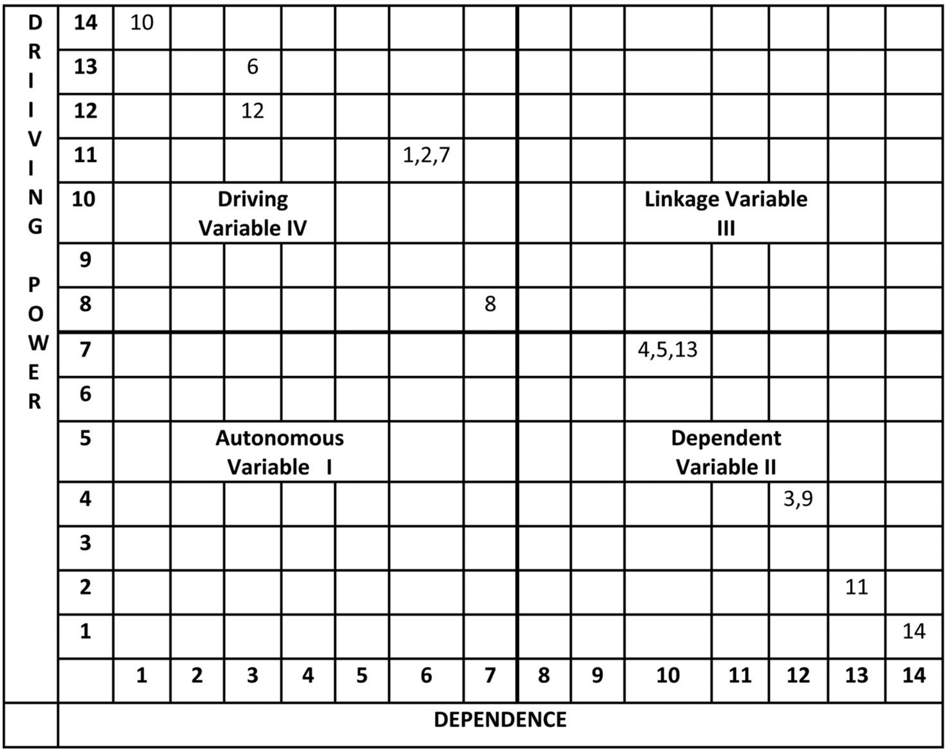

Figure 3. MICMAC graph.

MICMAC analysis gives an insight into the relative importance and interdependencies between the enablers.

Enablers are classified as follows after the MICMAC analysis:

- *Autonomous variables in quadrant 1:* The autonomous enablers have weak powers in both driving and dependence of cluster. In the present study, there are no autonomous drivers. This is confirmed that the identified enablers of Industry 4.0 have no weak enablers towards implementation.
- *Dependent variables in quadrant 2:* There are seven enablers in this quadrant, namely Additive manufacturing (AM)-(4), Collaborative Productivity (CP)-(9), Product Life Cycle Management (PLM)-(3), Mass Customisation (MC)-(11), Networked Manufacturing (NM)-(5), Operational Efficiency (OC)-(14) and Professional Training and Development (PTD)-(13) that are weak drivers but strongly dependent on one another. So they are positioned in the top of ISM hierarchy model.
- *Linkage variables in Quadrant 3:* In this cluster, enablers have strong driving power and dependence power and they consists of 'linkage factors'. The significance of this third quadrant is any change accruing in the enablers will affect other enablers. Due to this circumstance, these enablers are unstable. There are no enablers falling under linkage enabler in implementing 4.0.
- *Driving variables in Quadrant 4:* It has strong driving power and dependence power and there are seven enablers falling under driving enablers. They are classified into three categories, namely management, technology and manufacturing support

system. In the management category, there are two enablers, namely Top-Level Management (TM)-(10), Horizontal and Vertical Integration (HVI)-(6). Top-level Management involvement has the highest driving power but low dependence power. And in the technology category, the enablers, namely Big Data (BD)-(1), Visual Computing (VC)-(2) and Internet Of Things (IOT)-(7) which help to reduce inventory and also improve process efficiency. The final category is the management support system and the enabler is Supply Chain (SC)-(12) which get support by implementing management category enablers for improving procurement, logistics and warehouse improvement. They are present in the bottom of the ISM hierarchy model. Thus the enablers act as the foundation of Industry 4.0 implementation in the manufacturing industry. Thus for effective performance in the Indian context, these are important drivers/enablers.

4. Discussion and conclusion

Manufacturing companies have to increase their productivity and efficiency of their manufacturing system in order to remain competitive. In industry 4.0, digitalisation forces the organisation to enhance the present manufacturing system of Industry 4.0 (Lugert, Völker, & Winkler, 2018). In order to implement Industry 4.0 and maintain competitiveness, the enablers may be suitable and serve the purpose. This article examines the enablers of Industry 4.0 through the ISM approach. The importance of various components and concept of Industry 4.0 has been studied by various authors. Rajput and Singh (2019) have discussed the integrated approach of PCA- ISM- DEMATEL will influence the most powerful IOT enablers with the ecosystem and big data and implementing these in Industry 4.0. Zezulka et al. (2016) are also supporting this point that IoT, Visual computing and CPS are the most capable technology of Industry 4.0. Eleftheriadis and Myklebust (2017) have discussed the cross-linking of manufacturing system which is realised through the application of CPS. Furthermore, Rymaszewska, Helo, and Gunasekaran (2017); Miorandi, Sicari, Pellegrini, and Chlamtac (2012) and Gupta (2015) have insisted that the product–service system, increased proportionate network and other potential innovative components of Industry 4.0 are leveraged through IOT.

This study evidences the contextual relationship among the 14 enablers of Industry 4.0 by the evaluation using the ISM approach. In order to identify the enablers using multilevel hierarchy, the driving and dependence power under four cluster are used to understand their interrelationship of each enabler to strategic decision for implementation. The important finding of this study has been presented below:

(1) The ISM cluster matrix is shown in Figure 3, wherein there are no autonomous enablers. They have weak power in the cluster and has no power of influence on the systems. Therefore, the management gives the least important to the cluster and hence it becomes void. Hence they can give attention to the other three clusters of ISM digraph.
(2) There are no enablers which are under linkage cluster, due to its absence the strong driving power and strong dependence power will not have a relationship with the other enablers of Industry 4.0 implementation.
(3) The enablers, namely additive manufacturing, operational efficiency, networked manufacturing, professional training and development, collaborative productivity, product life cycle management and mass customisation, have strong dependence

power and weak driving power and hence they depend on the other enablers. Product life cycle management brings the improved business level (Singh, 2017) and supports the value creation network in Industry 4.0 (Nyffenegger, Hänggi, & Reisch, 2018). Additive Manufacturing plays an important role in designing the product based on customisation (Amiron, Latib, & Subari, 2019) and also improves the supply chain and after-sale service (Khajavi et al., 2014). Networked Manufacturing and Collaborative Productivity helps the team more effectively in productivity (Madakam, Ramaswamy, & Tripathi, 2015) and transporting the finished goods (Shin et al., 2018). Lasi et al. (2014) and Valdez et al. (2015) support the findings that enable mass customisation by the communication of every entities in the value stream of Industry 4.0. This study also gives importance to the enablers, namely professional training and development and operational efficiency. It is a primary tool to equip the employees with digital workplace (Flores, Maklin, Golob, Al-Ashaab, and Tucci (2018); Amiron et al., 2019) and the new wave of digitalisation in business automation improves the operational efficiency.

(4) The enablers big data, visual computing, horizontal and vertical integration, cyber-physical system, supply chain and top-level management were identified as independent enablers having driving power. These seven enablers are interrelated with each other in implementing industry 4.0 (Mohelska and Sokolova (2018); Tu (2018); Ngai, Moon, Riggins, and Yi (2008)). However, they are different from concept and different during implementation. The collaboration of various enablers in industrial levels is connected with the internet and automation which will increase productivity at a faster rate with the involvement of top-level management.

To conclude, the seven driver enablers, namely driving enablers, namely big data, visual computing, horizontal and vertical integration, cyber-physical system, supply chain and top-level management, undisputedly play an important role in implementing industry 4.0. The remaining seven dependent enablers, namely additive manufacturing, operational efficiency, networked manufacturing, professional training and development, collaborative productivity, product life cycle management and mass customisation draw the power from the driving enablers for the successful implementation of Industry 4.0. In this paper, the contextual relationship of 14 enablers was studied and the ISM model was structured. This study also supports the reliability and validity of Industry 4.0 enablers' prevailing implementation in the Indian manufacturing industry. Therefore, the author suggests that the 14 enablers of Industry 4.0 must be implemented in the Indian industry. Since the strategical implementation of industry 4.0 is successfully not only in Indian industry and also globally.

5. Unique contributions

The contribution of the Industry 4.0 enablers through the ISM approach in manufacturing industries has been presented in the following two aspects, namely contribution to theory and contribution to practice.

- **Unique Contribution to Theory**

The ISM model of Industry 4.0 was constructed using enablers in the present study. This study offers two major contributions to the literature on enablers of Industry 4.0. The present ISM model of Industry 4.0 is the novel contribution and is a first attempt to develop a conceptual relationship among the enablers of Industry 4.0 in the Indian context. The prevailing literature of industry 4.0 has focused on a few enablers. However, more enablers are identified for the successful implementation of industry 4.0 in the manufacturing Industry. The present work is an attempt to contribute to the literature in the academic arena. Second, the present study adopts the qualitative methodology to develop the theoretical framework of Industry 4.0. However, the literature on the industry is still in the nascent stage. In this present work the ISM is used to develop the theoretical framework. The qualitative research methodology in theory building findings supports the work of (Barratt, Choi, & Li, 2011; Rajput and Singh 2019; Xu, Xu, and Li 2018; Singh and El-Kassar 2019).

- **Unique Contribution to Practice and implications**

By analysing the dominant enablers for adoption of Industry 4.0, the apprehension of implementing Industry 4.0 in manufacturing industries will be eliminated. This can lead to mass customisation, and the industries improved their ability to sustain in the global market. During the implementation of Industry 4.0, enablers at the foundation level are to be implemented initially as other enablers are driven by them. From the result, it is evident that industries must have the support of top management to undergo any cultural change. For any change to happen in the industry, both employees and top management must develop awareness and adequate knowledge about the importance of implementing the system. Based on the financial status and nature of working, organisations need to implement enablers such as big data, visual computing, product life cycle management, additive manufacturing, and networked manufacturing systems for achieving the operational efficiency. This study may help the managers for wants and needs of the organisation for prioritising and allocating of resources in an effective and efficient way to implement Industry 4.0. In addition, the result of ISM analysis may prompt the managers to successfully implement Industry 4.0.

6. Limitations and future scope of work

In this study, only 14 enablers were developed under Industry 4.0 using the ISM methodology in an Indian manufacturing context. This study is restricted to only 14 enablers. The analysis based on expert opinion cannot be avoided. However, the robustness of this study may vary, by increased numbers of expert and/or the inclusion of experts from various industrial sectors. This study deals with Industry 4.0 in manufacturing sectors through the ISM approach, there is a scope in extending validation of framework through structural equation modelling (SEM) and use of mixed approach like DEMATEL, Analytical Network Process (ANP), Total Interpretive Structural Modelling (TISM) and SEM. The result of the mixed approach may reveal that the causal relationship between the enablers with the hierarchical structure, relative factor and ISM network of Industry 4.0.

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