International Journal of Global Business and Competitiveness (2021) 16:1–14
https://doi.org/10.1007/s42943-020-00018-0

ORIGINAL RESEARCH

Hierarchy of Critical Success Factors (CSF) for Lean Six Sigma (LSS) in Quality 4.0

Neeraj Yadav[1] · **Ravi Shankar**[1] · **Surya Prakash Singh**[1]

Received: 30 September 2020 / Accepted: 14 December 2020 / Published online: 29 January 2021

Abstract
The fourth industrial revolution, often termed as Industry 4.0 or Smart Manufacturing, is influencing all aspects of business management. Application of Industry 4.0 for quality management purpose is termed Quality 4.0. Lean Six Sigma (LSS) implementation process is also getting influenced by Quality 4.0. Use of Lean Six Sigma in Industry 4.0/Quality 4.0 can create differentiation in performance, and will improve competitiveness of organizations, besides making them future ready. Critical Success Factors (CSF) for Lean Six Sigma in Quality 4.0 set-up are recently established. However, the hierarchy of Critical Success Factors (CSF) for Lean Six Sigma under Quality 4.0 framework is not yet available. This paper establishes the hierarchy using multiple methodologies including ISM (Interpretive Structural Modelling) and TISM (Total Interpretive Structural Modelling), MICMAC (cross-impact matrix multiplication applied to classification), and Hierarchical Clustering. Managerial and theoretical implications of this study are presented from both Lean Six Sigma, and Information Technology perspectives.

Keywords Lean Six Sigma · Quality 4.0 · Industry 4.0 · Critical success factors · Hierarchical relationship · Interpretive structural modelling · TISM · MICMAC · Smart manufacturing

Introduction

Information technologies of fourth industrial revolution, i.e. Industry 4.0, are influencing all aspects of business management. Application of Industry 4.0 technologies for quality management is termed Quality 4.0 (Jacob 2017; Juran 2019). Lean Six Sigma (LSS) is also significantly affected by Industry 4.0 (Onur and Omer 2018; Park et al. 2020). Critical success factors for Lean Six Sigma under Quality 4.0 are identified by Yadav et al. (2021). However, hierarchy of these factors is not established.

Hierarchy of CSF for LSS without Quality 4.0 is attempted by multiple researchers using different methodologies. Belhadi et al. (2019) established hierarchy using AHP (analytical hierarchy process). Laosirihongthong et al. (2006) also adopted AHP approach. Zandhessami and Rahgozar (2018) used Dematel (Decision Making Trial and Evaluation Laboratory) approach for this purpose. Sreedharan et al. (2018) used TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution) methodology to establish hierarchy of critical failure (not success) factors for LSS.

Jha et al. (2019) established hierarchy of CSF for LSS using ISM (interpretive structural modelling) methodology. Sindhwani et al. (2019) followed ISM approach to establish CSF for LSS, Agile, and Green Manufacturing system. Soti et al. (2010) also used ISM techniques to explore hierarchy of LSS enablers. In ISM-based studies, MICMAC (cross impact matrix multiplication applied to classification) method was also used to classify factors in different categories. Hierarchical clustering approach is also followed by

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s42943-020-00018-0.

Neeraj Yadav
ny.iitd@gmail.com

Ravi Shankar
r.s.research@gmail.com

Surya Prakash Singh
surya.singh@gmail.com

[1] Department of Management Studies, Indian Institute of Technology (IIT) Delhi, Vishwakarma Bhawan, 4th Floor, Shaheed Jeet Singh Marg, Hauz Khas, New Delhi 110016, India

many researchers to establish hierarchy in LSS (Duarte et al. 2012; Ray et al. 2013; Sordan et al. 2020).

This paper aims to establish hierarchy of Critical Success Factors (CSF) for Lean Six Sigma (LSS) in Quality 4.0 set-up using three methodologies, i.e., ISM (Interpretive Structural Modeling) and TISM (Total Interpretive Structural Modeling), MICMAC (cross-impact matrix multiplication applied to classification), and Hierarchical Clustering.

The study is compiled in six different sections. Literature review is carried out in "Literature Review" section. It covers elementary concepts including Lean Six Sigma, Industry 4.0, Quality 4.0, and their importance for business enterprises and competitiveness. Critical Success Factors (CSF) for Lean Six Sigma (LSS) previously available are also reviewed in this section. Explanation of methodologies is provided in "Methodologies Used" section. Model building is done in "Model Building and Result" section. Discussion and conclusions form "Discussion and Conclusion" section of the study. Research implications, limitations, and directions for future research are furnished in "Implications, Limitations, and Direction for Future Research" section.

Literature Review

The literature review is performed to explore details about Lean Six Sigma, Industry 4.0, and Quality 4.0. It also explores Critical Success Factors (CSF) for Lean Six Sigma (LSS) using Quality 4.0, and the hierarchy of CSF for LSS.

Lean Six Sigma

Lean Six Sigma (LSS) is an umbrella term used to describe set of tools and methods that cut-down process waste and unwanted variation. It makes processes robust, reliable, consistent, and efficient. The focus areas of LSS are presented in Fig. 1. On eliminating all wastes, the system is considered to be Lean (Dahlgaard and Dahlgaard-Park 2006; Hicks 2007). Similarly, when variation is reduced to an extent that its standard deviation is six times lesser than permissible variation on each side of target value, it is considered to have attained Six Sigma performance level (Soti et al. 2010). The concept of LSS is universal and applies to all business processes and all types of businesses (Bento and Tontini 2019; Gelmez et al. 2020).

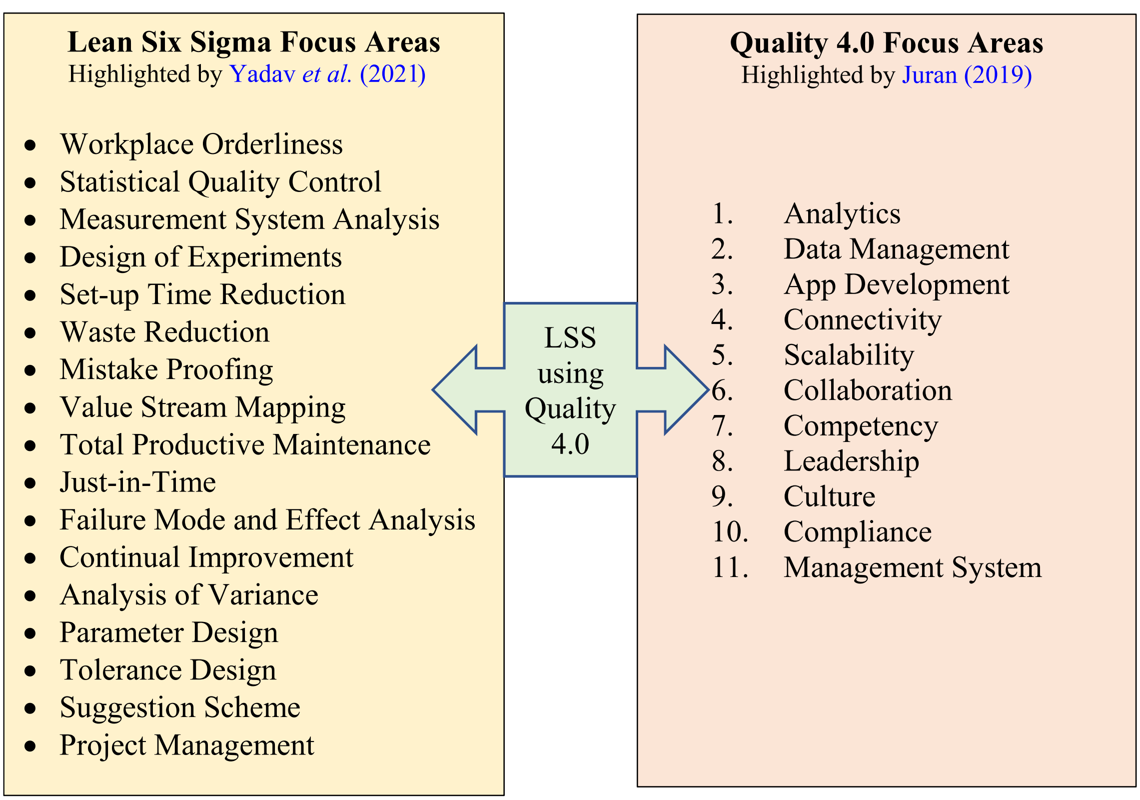

Fig. 1 Lean Six Sigma and Quality 4.0 Interface

Industry 4.0

This is another name of fourth industrial revolution or smart manufacturing. It refers to use of Information and Communication Technologies (ICT) for connecting machines, process, and people for real-time information and related analytics with minimum human involvement (Roche 2019). The Industry 4.0 framework can be applied to any business through its nine pillars which include IOT (internet of things), Big-Data, Cloud Computing, Advanced Simulation, Autonomous Systems, Universal Integration, AR (Augmented Reality), Additive Manufacturing, and Cyber Security (Burrell 2019). When used in a business they accomplish goals of automation, efficiency, and performance improvement.

Quality 4.0

Using pillars of Industry 4.0 to achieve the goal of quality improvement is prime domain of Quality 4.0 (Jacob 2017). Eleven dimensions of possible integration of quality management and information technologies of Industry 4.0 are prescribed by Juran (2019) as shown in Fig. 1. When specifically used for Lean Six Sigma, these information technologies of Industry 4.0 make the entire implementation process Simple, Speedy, and Smart (Park et al. 2020). Many barriers for Lean Six Sigma implementation, e.g., improper communication, inadequate data collection; highlighted by Sindhwani et al. (2019) can be overcome using Quality 4.0 framework. However, it requires meticulous planning and painstaking execution. Factors that play pivotal role in this process, are identified by Yadav et al. (2021) as Critical Success Factors (CSF) for LSS using Quality 4.0 framework. Their hierarchy howbeit, is yet to be explored and is attempted in this study.

Lean Six Sigma, Quality 4.0, and Competitive Advantages

It is being argued that countries are no longer facing competition from each other's labor rates, trade policies, or manpower availability. The real competition is in adopting latest technologies. In future, the export potential of a country, and competitiveness of its industries will be largely dependent on the extent to which they have implemented Industry 4.0/Quality 4.0. Referring to the competition between two fastest growing economies of the world, India and China, Joshi et al. (2020) argued that their future competition is not with each other but with Industry 4.0. According to them, the Adidas factory in US is planning to minimize outsourcing by adopting Industry 4.0 to bring down their cost of production several times. By automating extremely labor-oriented industry—Garments and Textiles, with Sewbots (robots designed for sewing operations), Adidas is aiming at per t-shirt manufacturing cost of just 33 cents. No country can beat this cost using manual labor. Other industries in developed countries are also using similar approach. Industry 4.0 will propel productivity, and Quality 4.0 will ensure the output is meeting customer requirements. While technologies of Industry 4.0 and Quality 4.0 are available to all countries and all industries, the real differentiation in performance and competitiveness will come from how well they are implemented. Adoption of practices like Lean Six Sigma in Industry 4.0/Quality 4.0 will create differentiation in performance, and will be a key factor for improving competitiveness and export orientation of a company, or even a country.

Another facet of Quality 4.0 is that the cost of technology reduces with time; whereas, the cost of manual labor increases with time. Therefore, to remain competitive and in business, embracing Quality 4.0 is becoming inevitable. This paradigm shift is not just affecting manufacturing organizations, IT (information technology) and service firms are also facing the heat of Quality 4.0. Manual jobs, e.g., customer support, decision-making, training, etc., are getting automated and driven by applications, software, neural networks, AI (artificial intelligence), etc. Lee et al. (2019) demonstrated application of Quality 4.0 in improving competitiveness not only in manufacturing firms, but also in the service firms such as Clova of South Korea. Erboz (2020) established linkage between Industry 4.0 and R&D (Research and Development) process of a firm, and showed how it can improve competitiveness of firms in Turkey.

Yadav et al. (2020) established that ICT (information and communication technologies) of Industry 4.0/Quality 4.0 and Lean Six Sigma not just influence quality related aspects of an organization but significantly influence performance of other functions also, e.g., purchase, production, supply chain, human-resources, sales, etc. Business process improvement is linked with firm level competitiveness, which further drives national level competitiveness (Ambastha and Momaya 2004). Therefore, it is vital for organizations to apply Lean Six Sigma in Quality 4.0 environment and to understand its Critical Success Factors (CSF) so that they can achieve improvement across all functions, and remain competitive.

Critical Success Factors (CSF) for Lean Six Sigma (LSS) Using Quality 4.0

CSF when LSS is implemented without Quality 4.0 are identified in different studies. Belhadi et al. (2019) identified them for small and medium enterprises (SME). Sreedharan et al. (2018) established them for manufacturing and service enterprises. Jha et al. (2019) established CSF for LSS in Indian manufacturing companies. Sindhwani et al. (2019) reported CSF when LSS is implemented with other strategies, e.g., Agile and Green. CSF for LSS use in a non-specific business unit are also available (Laosirihongthong et al. 2006; Sreedharan et al. 2018).

Yadav et al. (2021) established 18 critical success factors for Lean Six Sigma under Quality 4.0 framework. Out of these 7 factors were exclusively applicable for Quality 4.0 framework, and 11 factors were applicable without Quality 4.0, e.g., top management commitment, LSS training, etc. Table 1 specifies these factors and their classification. Relevance of these factors for LSS in Quality 4.0 environment is provided in Annexure (Table A-1).

Research Gap and Value Addition

While hierarchy of CSF for LSS in different contexts is available, it is not established for Quality 4.0 environment. This study bridges the gap. ISM methodology is used for this purpose and is supported with MICMAC analysis and hierarchical clustering. Rationale and details of these methodologies are provided in next section. Apart from bridging the research gap, the study will also help organizations in achieving business excellence in future. Quality 4.0 makes organizations future ready, applying Lean Six Sigma in Quality 4.0 makes them competitive, and applying it in a methodical way with proper understanding of CSF and their hierarchy will help them achieve business excellence.

Methodologies Used

In introduction section research works using ISM, AHP, MICMAC, TOPSIS, and hierarchical clustering methodologies were highlighted. AHP and TOPSIS methods are particularly useful when different factors have unequal weightages. In this study, all critical factors are being considered without any relative weightage. The aim is to identify their hierarchy and how they are related with each other. Therefore, ISM, MICMAC, and Hierarchical clustering methods are used in this study. TISM techniques are applied on ISM model to bring clarity.

Interpretive Structure Modeling (ISM)

The ISM is an interactive and iterative process. It is considered interactive in the sense that opinion of experts is used for relationship identification among pairs of factors. It is iterative in the manner that the model is built in step-by-step manner and level-portioning is done in multiple iterations.

Steps involved in ISM are well documented (Dwivedi et al. 2017; Sushil 2017, 2018). These steps are described in detail in Annexure (Table A-2).

Total Interpretive Structural Modeling (TISM)

The cognitive aspects of any topic include 5 W and 1H (who, why, when, what, where, and how) question. ISM covers the 'what' and 'how' aspects of a topic but in TISM 'why' aspect gets added (Sushil 2017). While making hierarchical model using ISM, transitive links are dropped. However, in TISM specific transitive links that are helpful in explaining relationship between factors are retained (Sushil 2017). TISM improves ISM by offering explanation of both nodes and links. (Jena et al. 2017; Sushil 2018). Therefore, in TISM for every significant transitive link, an explanatory or interpretation statement is supplemented (Senthil and Vinodh 2020).

TISM has been used in prior research to enhance ISM models (Dubey et al. 2015; Jena et al. 2017; Manjunatheshwara and Vinodh 2018; Sandbhor and Botre 2014).

MICMAC (Cross Impact Matrix Multiplication Applied to Classification)

MICMAC is a matrix-based factor classification method. Using MICMAC analysis, factors considered in ISM model can be placed in different quadrants according to the combination of their driving power and dependence. Factors belonging to low dependence and low driving power are termed 'autonomous'. Factors having high dependence but low driving power are called 'dependent'. Factors with low dependence but high driving power are termed 'drivers'. The last category pertains to high dependence and high driving power. These are termed 'linkage' factors (Chowdhury et al. 2020; Senthil and Vinodh 2020).

To prepare MICMAC graph, horizontal and vertical lines are drawn at the middle value of number of factors. Interaction of these two lines create four quadrants which are used to place autonomous, dependent, drivers, and linkage factors in their respective quadrants. Autonomous factors are unlinked or less linked with other factors and changes in these factors do not influence other parts of the system. Drivers and linkage factors have high driving power and changes in them alters entire system dynamics. Therefore, they demand utmost attention and careful analysis (Sandbhor and Botre 2014; Sushil 2018).

Hierarchical Clustering

It is a method of grouping factors together or forming clusters based on similarity of factors. The method is widely used in data mining and statistical analysis (Ferreira and Hitchcock 2009).

Normally two types of clustering are common, Agglomerative and Divisive. Agglomerative clustering is a bottom-up approach whereas, Divisive clustering is a top-down

Table 1 Critical success factors (CSF) for Lean Six Sigma (LSS)

S. No.	CSF of LSS	CSF type (generic/ quality 4.0)	Literature ref. codes#							
			A	B	C	D	E	F	G	H
1	"Top-Management-Commitment"	Generic	Y	Y	Y	Y	Y	Y	Y	Y
2	"Funds/Resource Availability"	Generic	Y	Y		Y	Y	Y	Y	Y
3	"Training-on-Lean-Six-Sigma"	Generic	Y	Y	Y	Y	Y	Y	Y	Y
4	"Employee-Involvement"	Generic		Y			Y	Y	Y	Y
5	"High-Volume and Low-Variety Set-up"	Generic				Y	Y			Y
6	"Project Management Skills"	Generic								
7	"Use of ERP System"	Quality 4.0		Y	Y					Y
8	"Bar-Coded and/or RFID-Enabled Inventory Management"	Quality 4.0								Y
9	"Mechanism of Feedback-to-Processes, and Corrective-Action from Data-Analysis"	Generic								Y
10	"Skilled-Employees"	Generic					Y	Y		Y
11	"Automation"	Quality 4.0								Y
12	"Use of Data-Analysis and Prediction System"	Quality 4.0								Y
13	"Prior Quality-Management-System Use e.g. ISO 9001/IATF 16,949"	Generic					Y		Y	Y
14	"Use of Line-Balancing and Production-Levelling Practices"	Generic								Y
15	"Use of Software/Application with Capability to Auto-Adjust Processes based on Process-Data"	Quality 4.0								Y
16	"Change Management Culture"	Generic	Y			Y	Y	Y		Y
17	"Timely and Accurate Data Availability"	Quality 4.0								Y
18	"Use of Data Processing Software or Application"	Quality 4.0								Y

#Literature Reference Codes: A: Belhadi et al. (2019); B: Jha et al. (2019); C: Laosirihongthong et al. (2006); D: Sindhwani et al. (2019); E: Soti et al. (2010); F: Sreedharan et al. (2018); G: Zandhessami and Rahgozar (2018); H: Yadav et al. (2021). Letter Y in a column indicates presence of CSF in that literature. Literature reference codes A, B, and D were researched for manufacturing firms, whereas C, E, F, G, H were researched for generic environment covering both manufacturing and service enterprises approach. When the cluster formation begins with one factor and other factors are added to it to move up, it is referred as Agglomerative or bottom-up approach. On the other hand, when all factors form one cluster and splitting is done as one moves down in hierarchy, it is termed Divisive or top-down approach (Uluskan 2019).

The arrangement of clusters is shown by a tree diagram called Dendrogram. Proximity matrix provides measure of closeness of each factor-pair in a cluster.

Model Building and Result

For identifying hierarchical relationships among the 18 CSF given in Table 1, steps described in Annexure (Table A-2) are used to build ISM model. A team of seven members helped in identifying relationship decisions among these 18 CSF. Details of team members are presented in Table 2. The pair-wise relationship among these 18 factors is shown in Table 3 (Initial Reachability Matrix). This initial reachability matrix is checked for transitivity, and all transitive relations are converted from 0 to 1 in Table 4 (Final reachability matrix). The shaded cells of Table 4, except diagonal cells, represent transitive relationships.

Level Partitioning

The final reachability matrix is used to identify reachability-set (the set of factors which a factor drives) and antecedent-set (the set of factors by which a factor is driven) of each factor. Subsequently, their intersection-set is identified. Those factors for which intersection-set and reachability-set are identical, are partitioned. This implies that factors partitioned at Level-1 are removed from the table for further

Table 2 Details of experts consulted to arrive at relationship decisions among 18 CSF for LSS in Quality 4.0

Experience (years)	Qualifications	Current role	Type of organization
23	MBA, Six Sigma Master Black Belt	Principal Consultant	Consultancy
30	Ph.D	Professor	Educational
20	Ph.D	Professor	Educational
21	MBA	Owner, LSS Enterprise using Quality 4.0	Manufacturing Industry
25	Graduate	Owner, LSS Enterprise without Quality 4.0	Manufacturing and After-Sales Service
40	Graduate, LSS Green Belt	Manager, LSS Enterprise not using Quality 4.0	Manufacturing Industry
22	Graduate	Manager, IT Company	IT (Information Technology) Firm

Table 3 Initial reachability matrix

CSF	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
2	0	1	1	0	0	1	1	1	0	1	1	1	1	0	1	0	1	1
3	1	0	1	1	0	1	0	0	1	1	0	1	0	1	0	1	0	0
4	0	0	0	1	0	0	0	0	1	0	0	1	0	1	0	1	1	0
5	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
6	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
7	0	0	0	1	0	0	1	1	1	0	0	1	0	0	0	1	1	1
8	0	0	0	0	0	0	0	1	1	0	1	1	0	0	1	0	1	0
9	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	1	1	0	1	0	1	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0
13	0	0	0	1	0	0	0	0	1	1	0	0	1	0	0	1	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
15	0	0	0	0	0	0	0	0	1	0	1	1	0	0	1	0	1	1
16	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	1	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
18	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1

iterations. The process is repeated in iterative manner until all factors are partitioned. This process is shown in Annexure (Table A-3 to Table A-9) in seven successive iterations.

Hierarchical Clustering

The hierarchical clustering of all 18 factors using agglomerative clustering, i.e., bottom-up approach, as described in "Methodologies Used" section, is performed using SPSS software. To measure proximity between factor pairs, squared Euclidean distance is used in this software. The average linking between groups or clusters is presented in Annexure (Table A-10). Proximity Matrix of Factor Pairs is presented in Annexure (Table A-11). Proximity matrix provides measure of distance between pairing elements. The lowest value pair is first merged in clustering because they are most homogeneous. According to Pandove et al. (2019), in agglomerative clustering the coefficients are calculated by dividing the heterogeneity of a variable in a cluster it first joins, by dividing it with heterogeneity of the final joining of a cluster, averaged over all samples. Smaller values of coefficients represent higher homogeneity of cluster elements. Yim and Ramdeen (2015) clarified that increase in values of coefficient suggests increase in heterogeneity of clusters being clubbed.

Hierarchical Relationship Models

The ISM/TISM model formed using factor partitioning is shown in Fig. 2. Links among factors at successive levels are shown with solid lines whereas, the links among different levels, and transitive links are shown with dotted lines as per guidelines of TISM described in "Methodologies Used" section. The MICMAC analysis, classifying these factors in different quadrants according to the combination of their driving power and dependence, is shown in Fig. 3. Dendrogram produced by Hierarchical Clustering is presented in Fig. 4. Critical Success Factors (CSF) from 1 to 18 are visible as VAR0001 to VAR0018, respectively, in the dendrogram.

Discussion and Conclusion

The ISM model presented in Fig. 2 established hierarchy of Critical Success Factors (CSF) for Lean Six Sigma (LSS) implementation using technologies of Quality 4.0. The model shows direct links among factors between successive levels with firm lines and transitive links with dotted lines.

Three factors namely Top management commitment (factor-1), Funds/Resource availability (factor-2), and Training on LSS (factor-3); drive ERP use (factor-7) in the organization as shown in Fig. 2. ERP use helps in connecting all functions of the organization, and ensures process monitoring and goal setting. ERP however, can function effectively only when all inventory items are bar-coded or made RFID enabled (factor-8) for proper accounting and recording all input–output material transactions. Without bar-coding or RFID tagging, these tasks become mammoth activities. Therefore, ERP use lead to Bar Coding/RFID enabled inventory system. Although ERP use, and Bar Coding/

Table 4 Final reachability matrix

CSF	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Drv.
1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	**17**
2	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	**17**
3	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	**17**
4	0	0	0	1	0	0	0	0	1	0	0	1	0	1	0	1	1	0	**6**
5	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	**2**
6	0	0	0	1	0	1	0	0	1	1	0	1	0	1	0	0	0	0	**6**
7	0	0	0	1	0	0	1	1	1	1	1	1	0	1	1	1	1	1	**12**
8	0	0	0	1	0	0	0	1	1	1	1	1	0	0	1	1	1	1	**10**
9	0	0	0	0	0	0	0	0	1	1	0	1	0	1	0	0	1	0	**5**
10	0	0	0	0	0	0	0	0	1	1	0	1	0	1	0	0	0	0	**4**
11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	**1**
12	0	0	0	0	0	0	0	0	1	1	0	1	0	1	0	0	1	0	**5**
13	0	0	0	1	0	0	0	0	1	1	0	1	1	1	0	1	1	1	**9**
14	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	**1**
15	0	0	0	1	0	0	0	0	1	1	1	1	0	1	1	1	1	1	**10**
16	0	0	0	1	0	0	0	0	1	1	0	1	0	1	0	1	1	0	**7**
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	**1**
18	0	0	0	0	0	0	0	0	1	1	0	1	0	1	0	0	1	1	**6**
Dep.	**3**	**3**	**3**	**10**	**1**	**4**	**4**	**5**	**14**	**13**	**8**	**14**	**4**	**14**	**6**	**9**	**13**	**8**	

Drv driving power, *Dep* dependence

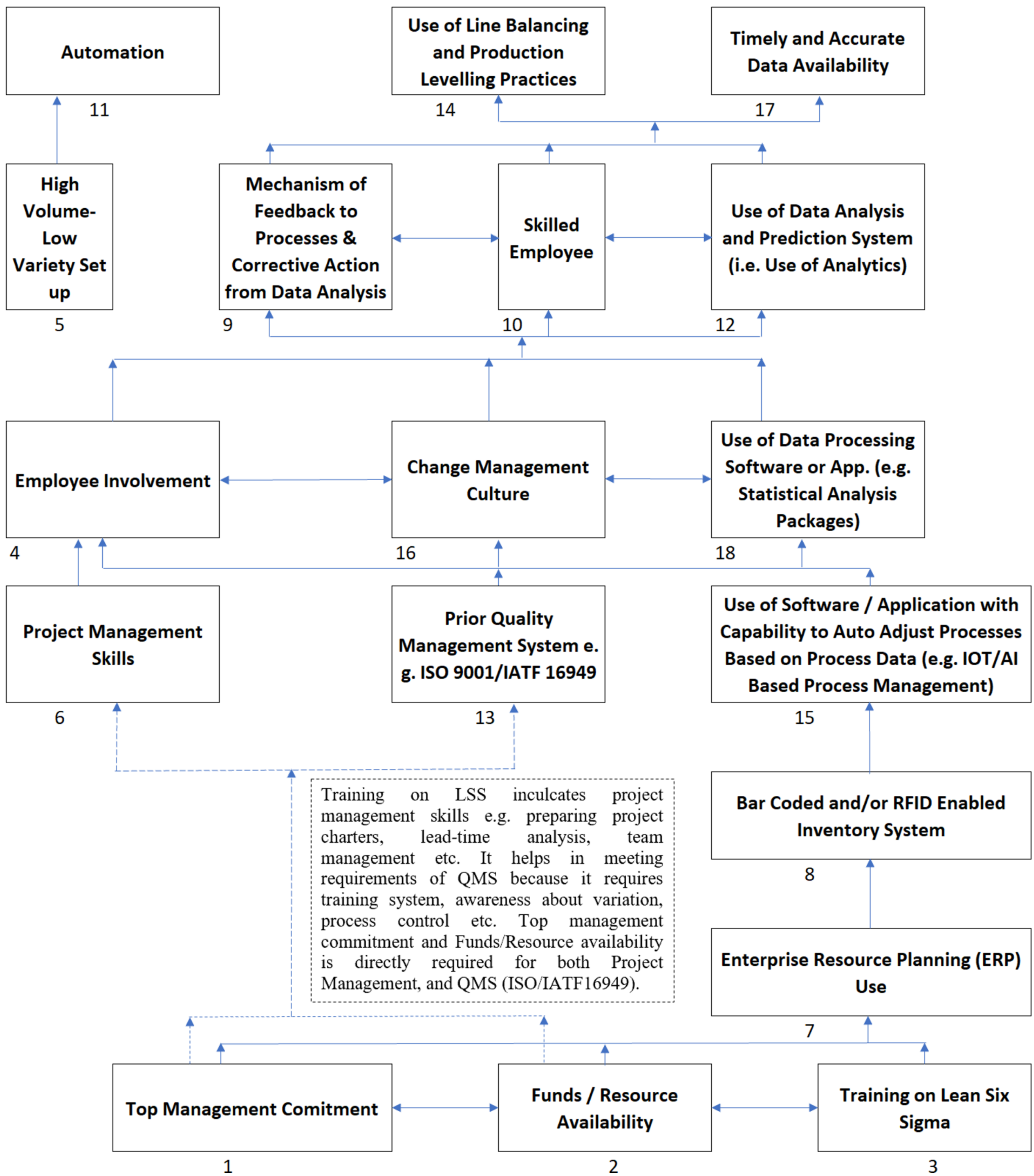

Fig. 2 ISM (Interpretive Structural Modelling)/TISM (Total ISM) hierarchical model of CSF for LSS using Quality 4.0

RFID-tagging can provide information on product/process/system status, they cannot alter processes or systems. Quality 4.0 framework uses IOT (internet of things) and AI (artificial intelligence) powered devices and algorithms which can predict process performance to automatically trigger adjustments in processes. Therefore, ERP and Bar-coded/RFID enabled system espouses use of software/applications that leverage power of IOT/AI (factor-15) as depicted in ISM model.

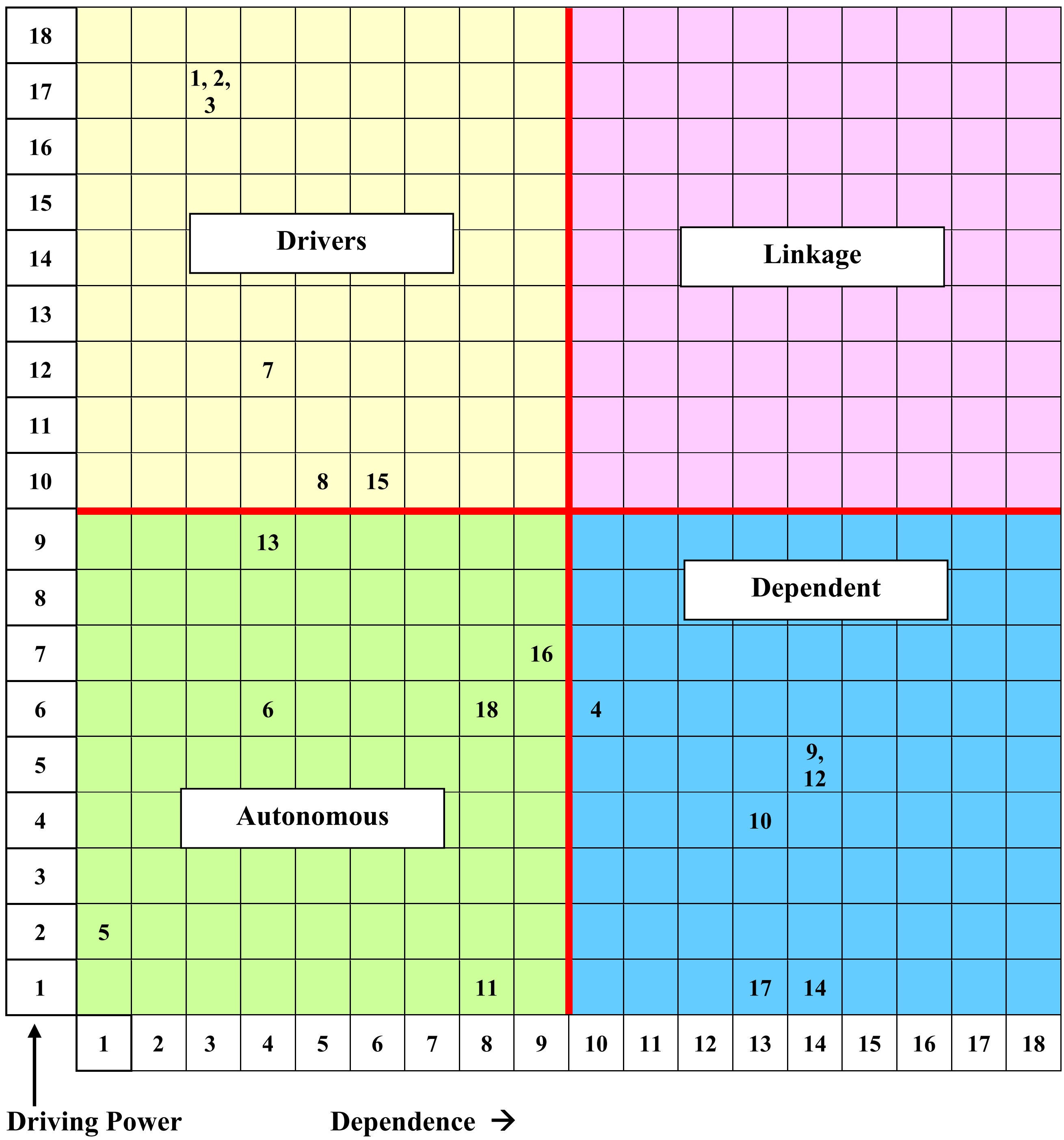

Fig. 3 MICMAC (cross-impact matrix multiplication applied to classification) Analysis. 18 Critical Success Factors (CSF) for Lean Six Sigma (LSS) in Quality 4.0 are shown in different quadrants of MICMAC according to the combination of their driving power and dependence value

Top management commitment (factor-1), Funds/Resource availability (factor-2), and Training on LSS (factor-3) also helps in inculcating Project management skills (factor-6) in the organization, and use of Quality Management Systems (QMS), e.g., ISO 9001/IATF 16949 etc., in the organization (factor-13). These links are shown with dotted lines in ISM/TISM model.

Quality management systems (factor-13) and project management skills (factor-6) ensure that processes are documented and standardized; roles and responsibilities are clearly defined; and configuration management practices,

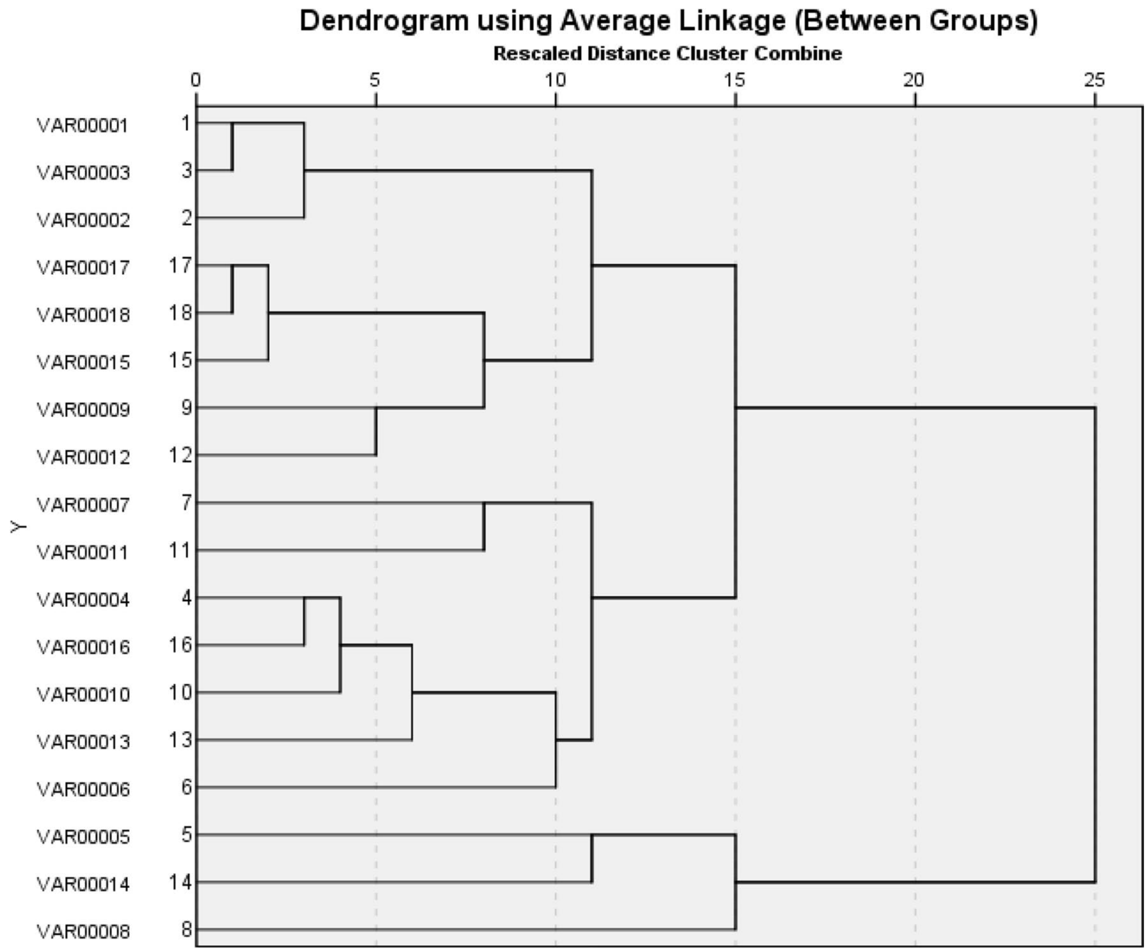

Fig. 4 Dendrogram of Critical Success Factors for Lean Six Sigma implementation using Quality 4.0

i.e., methods to maintain system integrity during changes, are used. This brings Change management Culture (factor-16) in the organization and improves Employee Involvement (factor-4). Additionally, to fully utilize capabilities of IOT- and AI-enabled generic packages (factor-15), support of specialized statistical packages/data processing software (factor-18) is needed for LSS implementation. Therefore, factor 6, 13, and 15 lead to factor-4, factor-16, and factor-18 as logically shown in ISM model.

Factor 4, 16, and 18 then drive three other factors. These are factor-9 (Mechanism of feedback to processes and corrective actions), factor-10 (skilled employees), and factor-12 (use of data analysis and prediction systems, i.e., predictive and prescriptive analytics).

These three factors (9, 10, and 12) lead to two other quintessential factors for success of any LSS drive. These are Timely and accurate data availability (factor-17), and Use of line balancing and production levelling practices (factor-14). These two factors bring organizations in Lean state, i.e., single piece flow, synchronous layout, and data-driven decisions.

Another very important factor for LSS success in Quality 4.0 is Automation (factor-11). It is classified as an autonomous factor in MICMAC analysis, i.e., it is neither driven by many factors nor it drives many factors. However, it directly helps in making LSS initiative successful under Quality 4.0 framework. In Fig. 2 it is shown at zenith of the ISM model and is driven by another autonomous factor, factor-5 (High volume-low variety setup). Typically, high volume-low variety setups are used in either mass-scale production or process industries, because they do not undergo frequent changes. Automating such systems is therefore both easy and logical. However, having this type of set-up is often not in the control of management. It is rather a peculiar trait of business. Therefore, this factor is neither driven by other factors nor it drives many. The ISM model expresses this logic in a lucid manner.

MICMAC analysis presented in Fig. 3 supports these conclusions. Four quadrants of MICMAC have different factors assigned to them according to their unique characteristics. The bottom left quadrant of this figure represents autonomous variables which are factor-5, 6, 11, 13, 16 and 18. Six factors are in top left quadrant representing 'drivers' of the system. These factors have high driving power and therefore, they affect other factors remarkably. Any changes in these factors can potentially influence entire system. These factors include factor number 1, 2, 3, 7, 8, and 15.

The top-right quadrant is linkage-factor quadrant but is empty as no factor belongs to this category. Factors in this quadrant although have high driving power, they also have high dependence. Therefore, they are usually unstable. The fact that no CSF in this study falls in this quadrant shows robustness of the model because any alterations in any factor will not bring instability to the model.

The bottom-right quadrant also has six factors and they represent 'dependent' factors. These factors receive power or thrust from 'driving' factors to contribute in the system.

Both MICMAC and ISM model thus explain the CSF hierarchy with similar logic.

The dendrogram in Fig. 4 shows hierarchical association of different factors. Factor 1 to 18 are shown as VAR0001 to VAR0018, respectively, in the dendrogram. Factor 1, 2 ,3 which form base of ISM model are grouped together in dendrogram also. The proximity matrix in Annexure (Table A-11) also reveals low values, i.e., closeness among these factors. Factor 4 and 16 are also placed close to each other in both ISM model, and dendrogram. Same observation applies to factor 6 and 13, 5 and 14, 9 and 12 also.

One contrasting but logical revelation between ISM and clustering model is grouping of factors 7, 11, 15, 17, and 18. These six CSF belong to Quality 4.0 category of LSS in Table 1. In the ISM model, these are placed at different levels but in dendrogram they appear together. This is primarily due to the requirement of similar inputs and efforts (information-technology oriented thinking and packages). Their presence in ISM model at different levels shows need of effort required to align these with LSS theme. For instance, factor 15 and 17 (both Quality 4.0 linked CSF for LSS) are two levels apart in ISM model. If LSS implementation is not the aim, it is very easy to ensure timely and accurate data availability (factor-15) using IOT devices and AI powered software (factor-17). However, when LSS is attempted, just availability of these two factors in the system is not sufficient, they have to be linked with other LSS success factors, e.g., skilled employees, employee involvement, change management culture, etc.

The same rationale applies to other factors which are at different levels in ISM but are placed closely in clustering. Thus, these two models complement each other in explaining hierarchy of CSF for LSS using Quality 4.0 technologies.

Comparison of Hierarchical Models with Prior Studies

This study provides hierarchy of 18 Critical Success Factors (CSF) for Lean Six Sigma success using Quality 4.0 framework. Seven factors are related exclusively with information technologies of Quality 4.0 whereas, eleven factors are not exclusive for Quality 4.0 framework. Prior studies had not considered Quality 4.0-related factors. Therefore, comparison with earlier research works is focused on those eleven factors which are applicable for LSS success without Quality 4.0.

Belhadi et al. (2019) provided ranking of ten different CSF using AHP. Top management commitment was highest rated factor; followed by requirement of funds, culture and employee competence, performance measurement, LSS learning, project management aspects, and employee involvement. In this study also top management commitment, and Lean Six Sigma training are two most influential drivers at level-1 in ISM model. These factors lead to project management skills, which in turn leads to employee involvement.

Laosirihongthong et al. (2006) also used AHP methodology for model building and expressed following factors as most prominent drivers: top management leadership, training and understanding of LSS, project management skills, customer orientation.

Sreedharan et al. (2018) used TOPSIS approach to describe Critical Failure Factors (opposite of success factors) and therefore their top contributors for failure of LSS were lack of Leadership, Lack of IT (information technology) support, lack of problem-solving culture, lack of focus on human factors. These factors are in line with main drivers of LSS identified in this study. Also, the lack of information technology (IT) failure factor is addressed in this study under Quality 4.0 framework. Zandhessami and Rahgozar (2018) used Dematel method for identifying hierarchy of critical factors. They also found top leadership, and committed workforce as main drivers of LSS.

In all these studies, although different techniques of hierarchy classification were used; main drivers for LSS were found similar to this study, i.e., top management commitment, availability of funds, training on LSS, and project management skills.

In ISM methodology-based research, Jha et al. (2019) provided hierarchy of 11 CSF using 6 levels. They too found top management involvement, and organizational infrastructure as main drivers; whereas project management, education and training, process management, and human resource management were other factors at higher levels.

Sindhwani et al. (2019) used both ISM and MICMAC analysis from LSS barriers perspective. In their study also no linkage factors were found in MICMAC. Three factors were in autonomous quadrant including Lack of training on LSS, Volatile demand, and Market competition. 'Lack-of-training-on-LSS' barrier is exactly opposite of the success factor—'Training on LSS' used in this study. 'Volatile-demand' barrier corresponds to 'high volume-low variety' success factor of this study. In both cases, these factors were in autonomous quadrant of MICMAC.

Soti et al. (2010) also used both ISM and MICMAC analysis to classify 11 factors in 7 levels of hierarchy. Similar to this study, they too found top management commitment, funds requirements, and LSS training as main drivers. However, in their study, no autonomous factors were reported and five factors were found in Linkage-factor quadrant. In this study, Linkage factor quadrant has no factor but five autonomous factors are revealed. However, the dependent factor quadrant resembles in both studies and includes factors such as timely and accurate data, and skilled man-power.

Apart from these similarities and contrasts, the inclusion of Quality 4.0-related factors and their hierarchy establishment remains novel feature of this study.

Implications, Limitations, and Direction for Future Research

The research has multiple implications in both theory and practice, as highlighted in following sections.

Implications for Theory of Lean Six Sigma

Through this research, the theory of Lean Six Sigma has added a new dimension. How different success factors for LSS in Quality 4.0 framework are connected with each other was unknown earlier or had no conclusive evidences about their linkages. The study has filled that void.

Implications for Practice of Lean Six Sigma

Organizations and LSS experts have just started dwelling into Quality 4.0 framework. Clarity is still needed on how to integrate important factors of both LSS and Quality 4.0. The linkages revealed in this research among different CSF will ensure that pitfalls of LSS implementation are avoided. LSS activities can be prioritized according to the hierarchical model. Factors which are grouped together in dendrogram (Fig. 4) can be planned and used together with similar strategies and resources to save time, energy, and cost.

Implications for Information-Technology (I.T.) Fraternity

IT (information technology) community can benefit from this study in multiple ways. It can use Lean Six Sigma as a new business domain. LSS is an already known and established practice in business world. Its challenges are also widely known. This study has established linkages between LSS success and various IT products and solutions, e.g., ERP system (factor-7), bar-coding and RFID systems (factor-8), predictive and prescriptive analytics software (factor-12), IOT and AI-based solutions (factor-15), devices for data capturing, transmission, and storage (factor-17), statistical analysis software (factor-18).

Various IT-enabled or IT-linked services, e.g., Cloud Services, Networking Services, and related hardware (e.g., servers, routers, sensors), etc., can be propositioned for LSS solutions. IT professionals can also venture into LSS consultancy with this information.

Limitations and Directions for Future Research

Quality 4.0 concept is in a nascent stage of development. A study by Yadav et al. (2021) is available on CSF for LSS using Quality 4.0 framework. The CSF identified in this study were based on responses from diversified industries. When LSS is used in a specific business, CSF may be little different. Similar studies can be attempted for such specific business categories. As the Quality 4.0 concept evolves, more factors may get revealed and can be used for further modelling. When the Quality 4.0 technologies will mature, relative importance of various CSF will also become available, which can be used for TOPSIS and AHP analysis as discussed in "Methodologies Used" section. Findings of AHP and TOPSIS methods can then be compared with ISM/TISM model presented in this research. This study used agglomerative clustering technique for establishing hierarchy of CSF for LSS, however other techniques can also be explored, e.g., data of LSS organizations that successfully implemented LSS using Quality 4.0 framework. Their success parameters can be drilled down to different success factors using divisive clustering. Hierarchy of CSF for LSS in Quality 4.0 can also be explored when LSS is implemented in an integrated manner with other improvement methodologies, e.g., TRIZ, Agile, Green Manufacturing, ISO standards, etc.

Key Questions Reflecting Applicability in Real Life

Quality 4.0 and Industry 4.0, both are gaining traction in business world. However, there are more questions than answers around these topics. This research relates with some key questions enumerated below:

1. How Industry 4.0, Quality 4.0, and Lean Six Sigma influence one another?
2. What are the critical success factors for making Lean Six Sigma deployment successful in Quality 4.0 environment? Are these factors different from non-Quality 4.0 environment?
3. What is the hierarchy of critical success factors when Lean Six Sigma is implemented under Quality 4.0?
4. In which order, information technology aspects and Lean Six Sigma aspects shall be grouped to facilitate simultaneous implementation of Lean Six Sigma, and Quality 4.0?
5. How Industry 4.0/Quality 4.0 will influence competitiveness of developing countries or economies such as India, China, and other BRICS nations? What role Lean Six Sigma can play in improving competitiveness and its components such as efficiency, cost reduction, process improvement, etc.?

Acknowledgements Authors express their gratitude towards the anonymous reviewers of the article and editorial team members of the journal, especially the Editor-in-chief, for their constructive comments and value-adding suggestions which significantly helped in improving the manuscript.

Funding This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

Ambastha, A., & Momaya, K. (2004). Competitiveness of firms: review of theory, frameworks and models. *Singapore Management Review, 26*(1), 45–61.

Belhadi, A., Touriki, F., & Elfezazi, S. (2019). Evaluation of critical success factors (CSFs) to lean implementation in SMEs using AHP: a case study. *International Journal of Lean Six Sigma, 10*(3), 803–829.

Bento, G. D. S., & Tontini, G. (2019). Maturity of lean practices in Brazilian manufacturing companies. *Total Quality Management and Business Excellence*. https://doi.org/10.1080/14783363.2019.1665827.

Burrell, D. (2019). Principles of Industry4.0 and the 9 Pillars. https://www.plextek.com/insights/insights-insights/industry-4-0-and-the-9-pillars/. Accessed 27 Sept 2020.

Chowdhury, N. A., Ali, S. M., Paul, S. K., Mahtab, Z., & Kabir, G. (2020). A hierarchical model for critical success factors in apparel supply chain. *Business Process Management Journal*. https://doi.org/10.1108/BPMJ-08-2019-0323.

Dahlgaard, J. J., & Dahlgaard-Park, S. M. (2006). Lean production, six sigma quality, TQM and company culture. *The TQM Magazine, 18*(3), 263–281.

Duarte, B., Montgomery, D., Fowler, J., & Konopka, J. (2012). Deploying LSS in a global enterprise—project identification. *International Journal of Lean Six Sigma, 3*(3), 187–205.

Dubey, R., Gunasekaran, A., Sushil, & Singh, T. (2015). Building theory of sustainable manufacturing using total interpretive structural modelling. *International Journal of Systems Science: Operations and Logistics, 2*(4), 231–247. https://doi.org/10.1080/23302674.2015.1025890.

Dwivedi, Y. K., Janssen, M., Slade, E. L., Rana, N. P., Weerakkody, V., Millard, J., et al. (2017). Driving innovation through big open linked data (BOLD): exploring antecedents using interpretive structural modelling. *Information Systems Frontiers, 19,* 197–212.

Erboz, G. (2020). A qualitative study on industry 4.0 competitiveness in Turkey using porter diamond model. *Journal of Industrial Engineering and Management, 13*(2), 266–282. https://doi.org/10.3926/jiem.2915.

Ferreira, L., & Hitchcock, D. B. (2009). A comparison of hierarchical methods for clustering functional data. *Communications in Statistics-Simulation and Computation, 38,* 1925–1949.

Gelmez, E., Özceylan, E., Mete, S., & Durmuşoğlu, A. (2020). An empirical research on lean production awareness: the sample of gaziantep. *International Journal of Global Business and Competitiveness, 15*(1), 10–22.

Hicks, B. J. (2007). Lean information management: understanding and eliminating waste. *International Journal of Information Management, 27*(4), 233–249.

Jacob, D. (2017). What is Quality4.0. https://blog.lnsresearch.com/quality40. Accessed 27 Sept 2020.

Jena, J., Sidharth, S., Thakur, L. S., Pathak, D. K., & Pandey, V. C. (2017). Total interpretive structural modeling (TISM): approach and application. *Journal of Advances in Management Research, 14*(2), 162–181.

Jha, P. C., Aggarwal, R., & Aggarwal, B. (2019). Studying the interrelationships amongst various success factors for implementing Six Sigma in Indian manufacturing SMEs. *International Journal of Computer Applications, 178*(23), 38–44. https://doi.org/10.5120/ijca2019919072.

Joshi, M., Abidi, S., Kumar, A. (2020). India's Competitor In Exports Is Not China But Industry 4.0. http://www.businessworld.in/article/India-s-Competitor-In-Exports-Is-Not-China-But-Industry-4-0/16-07-2020-298241/ Accessed 21 Nov 2020.

Juran (2019). Quality4.0: The Future of Quality. https://www.juran.com/blog/quality-4-0-the-future-of-quality. Accessed 27 Sept 2020.

Laosirihongthong, T., Rahman, S., & Saykhun, K. (2006). Critical success factors of six-sigma implementation: an analytic hierarchy process based study. *International Journal of Innovation and Technology Management, 3*(3), 303–319.

Lee, S. M., Lee, D., & Kim, Y. S. (2019). The quality management ecosystem for predictive maintenance in the Industry 4.0 era. *International Journal of Quality Innovation, 5*(4), 1–11.

Manjunatheshwara, K. J., & Vinodh, S. (2018). Application of TISM and MICMAC for analysis of influential factors of sustainable development of tablet devices: a case study. *International Journal of Sustainable Engineering, 11*(5), 353–364. https://doi.org/10.1080/19397038.2017.1387186.

Onur, D., Omer, F.G. (2018). Data Perspective of Lean Six Sigma in Industry4.0 Era: A Guide to Improve Quality. http://www.ieomsociety.org/paris2018/papers/170.pdf. Accessed 27 Sept 2020.

Pandove, D., Goel, S., & Rani, R. (2019). General correlation coefficient based agglomerative clustering. *Cluster Computing, 22,* 553–583. https://doi.org/10.1007/s10586-018-2863-y.

Park, S. H., Dahlgaard-Park, S. M., & Kim, D. C. (2020). New paradigm of lean six sigma in the 4th industrial revolution era. *Quality Innovation Prosperity, 24*(1), 1–16.

Ray, S., Das, P., & Bhattacharyay, B. K. (2013). Success factors characterisation towards Six Sigma implementation in Indian industries. *International Journal of Six Sigma and Competitive Advantage*. https://doi.org/10.1504/IJSSCA.2012.053457.

Roche, R. (2019). The Nine Pillars of Industry4.0 - Transforming Industrial Production. https://circuitdigest.com/article/what-is-industry-4-and-its-nine-technology-pillars. Accessed 27 Sept 2020

Sandbhor, S., & Botre, R. (2014). Applying total interpretive structural modeling to study factors affecting construction labour productivity. *Australasian Journal of Construction Economics and Building, 14*(1), 20–31. https://doi.org/10.5130/AJCEB.v14i1.3753.

Senthil, K. D., & Vinodh, S. (2020). TISM for analysis of barriers affecting the adoption of lean concepts to electronics component manufacture. *International Journal of Lean Six Sigma*. https://doi.org/10.1108/IJLSS-09-2018-0100.

Sindhwani, R., Mittal, V., Singh, P., Aggarwal, A., & Gautam, N. (2019). Modelling and analysis of barriers affecting the implementation of lean green agile manufacturing system (LGAMS). *Benchmarking: An International Journal, 26*(2), 498–529.

Sordan, J. E., Oprime, P. C., Pimenta, M. L., Chiabert, P., & Lombardi, F. (2020). Lean Six Sigma in manufacturing process: a bibliometric study and research agenda. *The TQM Journal, 32*(3), 381–399.

Soti, A., Shankar, R., & Kaushal, O. P. (2010). Modelling the enablers of six sigma using interpreting structural modelling. *Journal of Modelling in Management, 5*(2), 124–141.

Sreedharan, R. V., Gopikumar, V., Nair, S., Chakraborty, A., & Antony, J. (2018). Assessment of critical failure factors (CFFs) of Lean Six Sigma in real life scenario: evidence from manufacturing and service industries. *Benchmarking: An International Journal, 25*(8), 3320–3336.

Sushil. (2017). Modified ISM/TISM process with simultaneous transitivity checks for reducing direct pair comparisons. *Global Journal of Flexible Systems Management, 18,* 331–351. https://doi.org/10.1007/s40171-017-0167-3.

Sushil. (2018). Incorporating polarity of relationships in ISM and TISM for theory building in information and organization management. *International Journal of Information Management, 43,* 38–51. https://doi.org/10.1016/j.ijinfomgt.2018.06.003.

Uluskan, M. (2019). Analysis of Lean Six Sigma tools from a multidimensional perspective. *Total Quality Management and Business Excellence, 30*(9–10), 1167–1188. https://doi.org/10.1080/14783363.2017.1360134.

Yadav, N., Shankar, R., & Singh, S. P. (2020). Impact of Industry4.0/ICTs, Lean Six Sigma and quality management systems on organisational performance. *The TQM Journal, 32*(4), 815–835. https://doi.org/10.1108/TQM-10-2019-0251.

Yadav, N., Shankar, R., & Singh, S. P. (2021). Critical success factors for lean six sigma in quality 4.0. *International Journal of Quality and Service Sciences*. https://doi.org/10.1108/IJQSS-06-2020-0099.

Yim, O., Ramdeen, K. T. (2015). Hierarchical cluster analysis: comparison of three linkage measures and application to psychological data. *The Quantitative Methods for Psychology*, *11*(1), 8–21. http://www.tqmp.org/RegularArticles/vol11-1/p008/p008.pdf.

Zandhessami, H., & Rahgozar, A. (2018). Six sigma project critical success factor prioritization using MADM technique. *International Journal of Applied Research in Management and Economics, 1*(1), 1–11.

Neeraj Yadav is a Certified Six Sigma Master Black Belt, Certified Lean Management Professional, and Certified Lead Auditor for ISO 9001, ISO 14001, ISO 45001 management systems. He is a researcher at Indian Institute of Technology (IIT) Delhi and has around 25 years of professional experience.

Ravi Shankar from Indian Institute of Technology (IIT) Delhi, India has published over 400 papers with citations exceeding 23,000 as on July 2019 and an H-index of 63. He also taught at Asian Institute of Technology Thailand, French-Vietnamese Center for Management Education, Vietnam, and has research association with Aston Business School Birmingham UK, School of Business and Economics Loughborough University UK, Business School Sheffield University UK, Newcastle University UK, University of Connecticut USA, Rutgers Business School USA, Fox Business School Philadelphia USA, South East European Research Centre Greece, University of Padua Italy, Aalborg University Denmark, etc.

Surya Prakash Singh is the Professor of Operations Management at Indian Institute of Technology (IIT) Delhi, India. He has over 150 publications with more than 25,000 readings and over 2000 citations and an H-index of 22. He has also worked as Research Fellow at National University of Singapore-Massachusetts Institute of Technology (NUS-MIT).