

Lean Six Sigma implementation: modelling the interaction among the enablers

Shruti J. Raval, Ravi Kant & Ravi Shankar

To cite this article: Shruti J. Raval, Ravi Kant & Ravi Shankar (2018): Lean Six Sigma implementation: modelling the interaction among the enablers, Production Planning & Control, DOI: [10.1080/09537287.2018.1495773](https://doi.org/10.1080/09537287.2018.1495773)

To link to this article: <https://doi.org/10.1080/09537287.2018.1495773>



Published online: 12 Sep 2018.



Submit your article to this journal [↗](#)



View Crossmark data [↗](#)



Lean Six Sigma implementation: modelling the interaction among the enablers

Shruti J. Raval^a, Ravi Kant^a and Ravi Shankar^b

^aDepartment of Mechanical Engineering, S. V. National Institute of Technology, Surat, India; ^bDepartment of Management Studies, Indian Institute of Technology Delhi, New Delhi, India

ABSTRACT

Lean Six Sigma (LSS) methodology has been acquiring a prominent position in organisations. The aim of this study is to demonstrate an approach to LSS implementation in organisations using the development of a hypothetical model based on interpretive structural modelling (ISM) and fuzzy Matriced Impacts Croisés Multiplication Appliquée à un Classement (fuzzy MICMAC) analysis phenomenon. Seventy Lean Six Sigma enablers (LSSEs) have been identified through extensive literature review and out of which 40 most important LSSEs were finalised through opinions of experts both from industry and academia. Furthermore, the valuable expert opinions have been applied to determine contextual relationships between these significant LSSEs and a hierarchical model has been created based on an ISM. The fuzzy MICMAC analysis has also been utilised to classify the enablers based on the dependence and driving power, and validate the created ISM-based model. The developed hierarchical model will assist to understand interrelationships and interdependencies among the identified LSSEs. Having high driving and low dependence power, the LSSEs have strategic significance because of their driving character. On the other hand, having high dependence and low driving power, LSSEs are more performance orientated. The mutual influence, driving and dependence power of LSSEs render valuable information to top management to distinguish between independent and dependent LSSEs. An organisation desiring of adopting LSS may get benefited by the understanding of LSSEs and their interactions.

ARTICLE HISTORY

Received 1 November 2017
Accepted 10 June 2018

KEYWORDS

Lean Six Sigma; interpretive structural modelling; fuzzy MICMAC; Lean Six Sigma enablers

1. Introduction

In today's competitive business environment, many organisations are under pressure to satisfy the customers and improve bottom line results due to the declining revenues and erosion of operating margins. Customer satisfaction has become the top priority for any organisation. To survive in this competitive environment, an organisation has to supply goods and best quality of the services with the minimum cost (Majstorovic et al. 2016; Näslund 2008). Lean thinking and Six Sigma methodology are well-demonstrated and influential processes for the attending this goal. Lean stresses on pace, the flow of the process and waste (Muda), whereas Six Sigma is about defects, statistical quality control and variation (Mi Dahlggaard-Park et al. 2006). Though these methods are not mutually exclusive, the flow is negatively affected by defects and variation, where the quality is negatively affected by unnecessary wastes. The merger of Lean and Six Sigma is known as Lean Six Sigma (LSS) or Lean Sigma which can reap the benefits of both individual practices and can also assist in overcoming the limitations of stand-alone methodology (Clegg, Pepper, and Spedding 2010). The concept of combining Lean Manufacturing and Six Sigma principles began in the late 1990s (Snee 2010; Michael, Rowlands, and Kastle 2004). When Lean and Six Sigma were used together, by elimination of waste, the rate of responding to the needs of the customer increased and by variation elimination, the

value and quality of the products and service were also created. Therefore, the merger of Lean and Six Sigma known as LSS is regarded as a new evolution of management tool to improve bottom line results (Snee 2010), to maximise shareholder value (Tsironis, Psychogios, and Al-Mashari 2016), to fasten the rate of high quality production (Mi Dahlggaard-Park and Bendell 2006; Vinodh, Kumar, and Vimal 2014), to face competitive market situations such as quality and cost and speed by the process of operational excellence (Abu Bakar, Subari, and Mohd Daril 2015; Gnanaraj et al. 2012). Salah, Rahim, and Carretero (2010) concluded that the LSS merger is possible and beneficial to achieve overall customer satisfaction.

Many researchers demonstrated the successful implementation of LSS (Agarwal et al. 2016; Akbulut-Bailey, Motwani, and Smedley 2012; Anderson and Kovach 2014; Psychogios, Atanasovski, and Tsironis 2012; Sunder 2016). Nevertheless, many organisations did not get benefit from the LSS as its execution methodology was not shown effectively (Kumar et al. 2008; Albliwi et al. 2014; Ali, Choong, and Jayaraman 2016). Although LSS renders many benefits, planning and managing the same are very difficult tasks. The LSS implementation demands time to realise its full impact. Difficulty faced by the manufacturing organisations, particularly these are situated in developing countries like India, is to transform the traditional manufacturing system to LSS system. There is confusion in the minds of managers about ways of tackling

this transition process. Several difficulties/barriers are encountered during this transition process. These roadblocks which make this transition a difficult task include lack of funds, lack of resources, lack of visionary leadership, etc. hinders which hinder this transition procedure, certain enablers trigger the LSS implementation (Ali, Choong, and Jayaraman 2016; Antony et al. 2012; Assarlind, Gremyr, and Bäckman 2013; Fadly Habidin and Mohd Yusof 2013).

Any quality improvement the success initiative depends upon the technical and system oriented factors such as working culture, organisation policies, working climate, job procedures and company's environment (Abu Bakar, Subari, and Mohd Daril 2015; Furterer and Elshennawy 2005; Manville et al. 2012). The success and failure of LSS initiative related to those factors can be regarded as enablers of LSS implementation. Albliwi et al. (2014) stated that many organisations failed to adopt LSS because the organisations failed to focus on enablers during implementation. Snee (2010) stated that success and failure possibility of LSS implementation depend on where and how it is exercised. These enablers assist the managers to implement LSS in their organisations. To accomplish the transition process without many hurdles, it is needed to analyse these enablers and understand its effectiveness. There are several studies that explore the LSSEs. But mere LSSEs identification is not enough. These enablers not only affect the LSS implementation process, but also influence one another. Therefore, it is essential to recognise the nature of these enablers and their mutual relationship so that the driving enablers (which support other enablers) and dependent enablers (which are influenced by other enablers) are identified. An attempt has been made in this study to analyse these enablers using an interpretive structural modelling (ISM) and fuzzy Matriced Impacts Croisés Multiplication Appliquée à un Classement (fuzzy MICMAC) approach to achieve the above-mentioned objective. ISM is an advanced planning methodology for recognising and summarising the relationships among specific items which define a problem or an issue (Sage 1977; Watson 1978; Warfield 1974; Kumar et al. 2016; Agi and Nishant 2017). The ISM method provides a means by which researchers can impose an order, build relationships between and create models around the elements of a system (Farris and Sage 1975). Fuzzy MICMAC analysis assists in examining and clustering the factors of interest in accordance with driving and dependence power (Kant and Singh 2009). The ISM and fuzzy MICMAC analyses and models help decision-makers to visualise the issues through a systems approach and then recognise elements that have a high level of influence and hence require high prioritisation and substantial effort to resolve (Bhosale and Kant 2016; Panahifar, Byrne, and Heavey 2014). Hence, in this article, LSSEs have been studied using the ISM and fuzzy MICMAC approach which renders the LSSEs interrelationships and their driving and dependence power. Initially, 70 LSSEs were identified through extensive literature review and out of which 40 most important LSSEs were finalised through opinions of experts both from industry and academia.

The detailed methodology regarding finalising these LSSEs is presented in Section 2.1. The opinions from the expert's committee were used to prepare relationship matrix which was later used to create the ISM model. While creating theoretical foundations for LSS implementation, vital three questions were posed. What are LSSEs? How are they interconnected? And what kind of dependencies lies among them? This study has three main objectives. I. To identify the LSSEs through the literature review and expert opinion. II. To recognise the interrelationships between the LSSEs. III. To characterise the enablers on the premise of their driving force and dependence power, and to find the most affecting enabler.

This article is structured as follows: in Section 2, the literature concerning LSS enablers and finalisation of enablers are presented. The problem description and methodology part are explained in Section 3. The application of integrated ISM and fuzzy MICMAC methodology in case organisation is explained in Section 4. In Section 5, the key findings from the ISM and fuzzy MICMAC method and analysis are discussed. Finally, the concluding remarks and managerial implication were presented in Section 6. Section 7 includes the limitations and future research scope.

2. Literature review and finalisation of enablers

According to Laureani and Antony (2018), the identification and focus on enablers of LSS are essential for the guaranteed success of LSS initiatives. The enablers are not key objectives but are the activities and practices (Saraph, Benson, and Schroeder 1989) that can be adjusted for implementation by the top management to accomplish the organisation's goals (Antony 2014; Jeyaraman and Kee Teo 2010; Manville et al. 2012). The enablers are concerned to an organisation's current situation and future success (Setijono, Laureani, and Antony 2012). Psychogios, Atanasovski, and Tsironis (2012) classified LSS critical success factors (CSFs)/enablers into two categories, namely the facilitators and the inhibitors. The factors that improve the implementation procedure and have positive impact are considered as the facilitators, whilst the implementation barriers considered as inhibitors. It can also be classified as institutional or contextual factors, namely the elements focused on organisational characteristics viewed as institutional factors, while the organisational structure factors are considered as the contextual elements.

Jeyaraman and Kee Teo (2010) presented a conceptual framework for adopting LSS in electronic manufacturing service industry in Malaysia. Their study presented a structure based on enablers obtained from previous studies. Setijono, Laureani, and Antony (2012) surveyed the manufacturing and service industries to identify the key enablers for successful LSS implementation. They found that management commitment, cultural change, linking LSS to business strategy and leadership styles were identified as the most important enablers in these industries. Antony et al. (2012) applied and analysed the LSS in higher education institutions. They presented various challenges and barriers to be encountered during the introduction of LSS in the higher education sector.

Table 1. Information of experts' details.

Experts	Academia/industry/consultant	Current position	Numbers of years of experiences
EX1	Industry	President	32 years
EX2	Industry	Senior director of system	19 years
EX3	Industry	LSS projects leader	12 years
EX4	Industry	Operations engineer	09 years
EX5	Industry	Manufacturing manager	16 years
EX6	Consultant	Consultant	25 years
EX7	Academia	Professor and researcher	21 years
EX8	Academia	Associate professor and researcher (Six sigma black belt)	14 years
EX9	Academia	Assistant Professor and LSS researcher	10 years

Wang and Chen (2012) found: management commitment, employees training and availability of resources as the most critical enablers in a panel equipment manufacturing industry. Also, many authors documented various benefits of LSS implementation (Leseure et al. 2010; Eriksson and Eriksson 2017; Shokri, Waring, and Nabhani 2016; Chen and Lyu 2009; Garza-Reyes et al. 2016). But, still in the developing country like India the rate of LSS implementation has been much slower than expected (Gupta, Acharya, and Patwardhan 2012). One of the primary causes for this is the lack of comprehensive and thorough guidelines. In addition, one of the main challenges is lack of understanding of enablers and barriers of LSS implementation. Many studies have focused on identification of various enablers of LSS implementation in the field; however, studies to fully understand its main enablers are still in their infancy. In the context of these observations on intensive literature review was conducted using the SCOPUS database, which facilitate to identify 70 LSSEs.

2.1. Finalisation of enablers

The fundamental cornerstone to ISM and fuzzy MICMAC is the opinion of experts regarding the system. Warfield (1974) suggest that ISM model development necessitates the participation of up to eight experts. In this study, the inputs from an expert committee consisting of five industrial, one consultant and three academic experts were utilised. Table 1 shows the details of the experts. All the industry experts are from the case organisation A, wishes to implement LSS. Each expert had more than 10 years of experience in the area of Lean and Six Sigma.

Initially, the intensive literature review was conducted, which was then followed by gather of opinion by experts. A total of 70 LSSEs was identified. Brainstorming and nominal group techniques are used to identify LSSEs and demonstrate mutual relationship. In the first session, the research agenda and its significance were discussed. During the second session, all the LSSEs were discussed and were segregated into groups with similar traits and assign them into groups: enablers based on management and leadership, training, culture, performance, resources, strategy and project, supplier and customer relationship, networking and communication, knowledge management, human resource (HR), financial and tools and techniques. Later, within an environment of mutual respect, six major clusters of LSSEs have been developed: strategic, an organisation, cultural, financial, customer and based on supplier. During the third

session, the expert panel decides which enablers are best to pursue, the same meaning enablers are discarded and appropriate enablers are to be merged. Forty LSSEs were finalised and each of these LSSEs was accommodated under one of six developed clusters (refer Table 2). After finalising the most pressing enablers for the LSS implementation, the next session was organised to establish the relationship among these LSSEs. The experts were asked about the mutual relationship between LSSEs. To carry out any further modification, the final list of LSSEs and the contextual relationship was circulated among the experts. Furthermore, last phase was added to the traditional ISM process. In this phase, the framework determinations were presented to the experts for the model and results validation and for identification of implications for practice.

3. Problem description and methodology

3.1. Problem description

A case company A wishes to implement LSS for removal of non-value added activities and improve the quality in order to survive in competitive business environment. The company A is a medium-size manufacturing organisation located in Gujarat state of India. This company was established in the year 1983. 800 employees are working in this company. The turnover of this company is more than US\$600 million. The company involves in manufacturing the conventional green sand and producing centrifugal casting products. The mission of this company is to provide world-class technology to suit specific Indian economic and production needs and to consistently develop new technologies for meeting the emerging needs of the foundry industry. At present, the company A is the single source of supply for the products such as green sand process and chemically bonded sand machines, sand preparation and re-conditioning equipment, moulding and pouring plants and centrifugal casting machines. This has been made possible by imposing a stringent quality improvement and quality control system throughout the company. The company A is equipped with modern machines and latest technology, well-established infrastructure, trained workforce, competent research and development and system team for the continuous product improvement and new machine development.

The company A wishes to implement LSS for (i) introducing LSS tools in the new development for better utilisation of all resources and saving the bottom line; (ii) replacing the existing facility, with the existing facility, the case company is

Table 2. LSSEs and literature support.

Main criteria	LSSEs code	Sub criteria	Effect of LSSEs	Literature support
Strategic based LSSEs	LSSE01	Top-management commitment, involvement and support	Top management involvement ensures the human resource support, financial support, availability of funds, assistance in removing obstacles, regular reviewing LSS project progress, and assured recognition and rewards for participants.	Albliwi et al. 2014; Ali, Choong, and Jayaraman 2016; Antony 2014; Antony et al. 2012; Antony, Setijono, and Dahlgaard 2016; Bhat and Jnanesh 2014; Clegg, Pepper, and Spedding 2010; Fadly Habidin and Mohd Yusof 2013; Hilton and Sohal 2012; J. Thomas et al. 2014; Jayaraman, Leam Kee, and Lin Soh 2012; Jeyaraman and Kee Teo 2010; Lertwattanapongchai and William Swierczek 2014; Leseure et al. 2010; Manville et al. 2012; Näslund 2008; Psychogios, Atanasovski, and Tsironis 2012; Psychogios and Tsironis 2012; Setijono, Laureani, and Antony 2012; Wang and Chen 2012
	LSSE02	Strategic planning and direction	An effective strategic planning helps to determine overall strategic directions that could orient the LSS implementation plan.	Antony et al. 2012; Albliwi et al. 2014; Bhat and Jnanesh 2014; Lertwattanapongchai and William Swierczek 2014; Antony, Setijono, and Dahlgaard 2016; Franchetti and Barnala 2013; Abu Bakar, Subari, and Mohd Daril 2015
	LSSE03	Linking LSS to business/organisation strategy	It helps to integrate the continuous enhancement into organisation strategy and link the success of the overall company and initiative together.	Abu Bakar, Subari, and Mohd Daril 2015; Albliwi et al. 2014; Antony 2014; Jeyaraman and Kee Teo 2010; Lertwattanapongchai and William Swierczek 2014; Manville et al. 2012; Psychogios and Tsironis 2012
	LSSE04	Project management	The project selection, prioritisation, tracking and review of the project are most critical for the implementation of LSS.	Abu Bakar, Subari, and Mohd Daril 2015; Albliwi et al. 2014; Antony et al. 2012; Antony, Setijono, and Dahlgaard 2016; Clegg, Pepper, and Spedding 2010; Fadly Habidin and Mohd Yusof 2013; Hilton and Sohal 2012; Jayaraman, Leam Kee, and Lin Soh 2012; Jeyaraman and Kee Teo 2010; Lertwattanapongchai and William Swierczek 2014; Leseure et al. 2010; Manville et al. 2012; Näslund 2008; Psychogios, Atanasovski, and Tsironis 2012; Setijono, Laureani, and Antony 2012
	LSSE05	Performance measurement and benchmarking practices	The performance measurement's quantitative indicators help in tracking the LSS progress against organisational strategy.	Abu Bakar, Subari, and Mohd Daril 2015; Albliwi et al. 2014; Ali, Choong, and Jayaraman 2016; Antony, Setijono, and Dahlgaard 2016; Hilton and Sohal 2012; Jeyaraman and Kee Teo 2010; Lertwattanapongchai and William Swierczek 2014; Leseure et al. 2010; Näslund 2008
	LSSE06	Change management	The change management helps to proceed an organisation from current condition to the required future state. Change management may be carried out using tools and techniques that can transform people.	Antony 2014; Hilton and Sohal 2012; Lertwattanapongchai and William Swierczek 2014
	LSSE07	Linking LSS to core business processes	Linking LSS to core business process helps in empowering organisation with continuous business process improvements and reduces process-related costs.	Jeyaraman and Kee Teo 2010; Ali, Choong, and Jayaraman 2016; Abu Bakar, Subari, and Mohd Daril 2015; Kumar, Kumar, and Haleem 2015
	LSSE08	Developing organisational readiness for LSS	It assists to seeing the organisational preparedness for LSS implementation activities.	Abu Bakar, Subari, and Mohd Daril 2015; Ali, Choong, and Jayaraman 2016; Antony et al. 2012; Manville et al. 2012; Psychogios, Atanasovski, and Tsironis 2012
Organisational based LSSEs	LSSE09	LSS supportive organisational structure	The LSS organisation structure defines the roles and responsibility, and the flow of information among the different levels of management.	Albliwi et al. 2014; Hilton and Sohal 2012; Jeyaraman and Kee Teo 2010; Kumar, Kumar, and Haleem 2015; Leseure et al. 2010; Näslund 2008; Setijono, Laureani, and Antony 2012
	LSSE10	LSS supportive organisational infrastructure and resources	By formulating LSS infrastructure, managers realize the LSS initiatives' importance and involve the employees in the implementation process.	Abu Bakar, Subari, and Mohd Daril 2015; Albliwi et al. 2014; Ali, Choong, and Jayaraman 2016; Antony 2014; Antony et al. 2012; Assarlind, Gremyr, and Bäckman 2013; Jeyaraman and Kee Teo 2010; Kumar, Kumar, and Haleem 2015; Lertwattanapongchai and William Swierczek 2014; Manville et al. 2012; Setijono, Laureani, and Antony 2012; Snee 2010
	LSSE11	Consistent and accurate data collection	Consistent and accurate data ultimately provides better organisational success as the decisions are made by referring fact data instead of practice and human intuition-oriented data.	Albliwi et al. 2014; Ali, Choong, and Jayaraman 2016; Franchetti and Barnala 2013; Abu Bakar, Subari, and Mohd Daril 2015; Kumar, Kumar, and Haleem 2015

(continued)

Table 2. Continued.

Main criteria	LSSEs code	Sub criteria	Effect of LSSEs	Literature support
	LSSE12	Standard operating procedures	Each entity needs to be documented and every process needs to be mapped. In addition, manual, standards, functions, tools, calibrations and a well written operating procedure are required as, in absence of anyone, the next can operate functions without any major difficulties.	Albliwi et al. 2014; Franchetti and Barnala 2013; Abu Bakar, Subari, and Mohd Daril 2015; Kumar, Kumar, and Haleem 2015
	LSSE13	Awareness programme for LSS	It provides information about how the new methodology can apply to their organisation and the gains achieved by the implementation and how this implementation can help organisations to meet today's business challenges.	Setijono, Laureani, and Antony 2012; Albliwi et al. 2014; Antony, Setijono, and Dahlgaard 2016; Abu Bakar, Subari, and Mohd Daril 2015; Kumar, Kumar, and Haleem 2015
	LSSE14	Effective scheduling of LSS activities	Effective scheduling of activities assists in meeting LSS implementation roadmap.	Ali, Choong, and Jayaraman 2016; Kumar, Kumar, and Haleem 2015
	LSSE15	LSS supportive knowledge management	It helps to understand the system.	Hilton and Sohal 2012; Näslund 2008
	LSSE16	Frequent communication and assessment on LSS result	The effective communication will help to build the team, guide people through LSS journey and institute a common language for continuous improvement. The periodic reviews will guarantee that the programme remains on track.	Abu Bakar, Subari, and Mohd Daril 2015; Albliwi et al. 2014; Antony et al. 2012; Antony, Setijono, and Dahlgaard 2016; Fadly Habidin and Mohd Yusof 2013; Hilton and Sohal 2012; Jayaraman, Leam Kee, and Lin Soh 2012; Jayaraman and Kee Teo 2010; Laureani, Brady, and Antony 2013; Lertwattanapongchai and William Swierczek 2014; Manville et al. 2012; Näslund 2008; Setijono, Laureani, and Antony 2012
Culture based LSSEs	LSSE17	Linking LSS to reward and recognition system	Liking LSS to reward and recognition helps to create more interest in the workforce to involve in the kaizen activity and continuous improvement projects.	Abu Bakar, Subari, and Mohd Daril 2015; Fadly Habidin and Mohd Yusof 2013; Jayaraman, Leam Kee, and Lin Soh 2012; Jayaraman and Kee Teo 2010; Lertwattanapongchai and William Swierczek 2014; Manville et al. 2012
	LSSE18	Quality-driven company/organisational culture and ethics	Overall employee's, involvement and continuous improvements enforce change in organisational culture and ultimately help to satisfy the customer demands.	Abu Bakar, Subari, and Mohd Daril 2015; Antony et al. 2012; Bhat, Gijo, and Jnanesh 2014; Fadly Habidin and Mohd Yusof 2013; Franchetti and Barnala 2013; Hilton and Sohal 2012; Jayaraman, Leam Kee, and Lin Soh 2012; Jourabchi et al. 2014; Lertwattanapongchai and William Swierczek 2014; Leseure et al. 2010; Näslund 2008; Psychogios, Atanasovski, and Tsironis 2012; Psychogios and Tsironis 2012; Wang and Chen 2012
	LSSE19	Selection and retention of staff	The organisation workforce is one of the most significant assets. Organisation staff is an investment, that will if efficiently managed and trained render long-term benefits to the company in the form of productivity.	Antony, Setijono, and Dahlgaard 2016; Setijono, Laureani, and Antony 2012
	LSSE20	Employee involvement and commitment	Overall involvement of employees in LSS activities helps to establish better work culture, increased job satisfaction of employees and enhanced of organisational commitment.	Antony 2014; Albliwi et al. 2014; Bhat and Jnanesh 2014; Antony, Setijono, and Dahlgaard 2016; Kumar, Kumar, and Haleem 2015
	LSSE21	Teamwork	The team members should be elected based on analytical, statistical and technical skill, the ability of knowledge transference and interrelationship. This helps to facilitate the LSS practice.	Leseure et al. 2010; Psychogios and Tsironis 2012; Lertwattanapongchai and William Swierczek 2014; Abu Bakar, Subari, and Mohd Daril 2015; Antony, Setijono, and Dahlgaard 2016; Franchetti and Barnala 2013; Kumar, Kumar, and Haleem 2015

(continued)

Table 2. Continued.

Main criteria	LSSEs code	Sub criteria	Effect of LSSEs	Literature support
Financial based LSSEs	LSSE22	Employee empowerment	For effective LSS implementation, the roles and responsibility should be defined. And the targets should link to annual performance appraisal.	Lertwattanapongchai and William Swierczek 2014; Antony, Setijono, and Dahlgaard 2016; Kumar, Kumar, and Haleem 2015
	LSSE23	Education and training (Understanding the tools and techniques)	The sound education and appropriate training provide the vital knowledge such as LSS tools, benefits of the LSS implementation, what modification of the system is required, platform to educate future leaders and various ways to adopt the required modification.	Albliwi et al. 2014; Ali, Choong, and Jayaraman 2016; Antony 2014; Antony et al. 2012; Antony, Setijono, and Dahlgaard 2016; Bhat and Jnanesh 2014; Clegg, Pepper, and Spedding 2010; Fadly Habidin and Mohd Yusof 2013; Hilton and Sohal 2012; J. Thomas et al. 2014; Jayaraman, Leam Kee, and Lin Soh 2012; Jayaraman and Kee Teo 2010; Lertwattanapongchai and William Swierczek 2014; Manville et al. 2012; Näslund 2008; Psychogios, Atanasovski, and Tsironis 2012; Psychogios and Tsironis 2012; Setijono, Laureani, and Antony 2012; Wang and Chen 2012
	LSSE24	Sufficient time to solve problems	If any rush to solve the problem without taking sufficient time to understand the problem, often the solution is missing the mark and ultimately ends in loss to the company.	Jeyaraman and Kee Teo 2010; Albliwi et al. 2014
	LSSE25	Sharing of project success stories and best practices	The LSS project success story motivates other employees of the organisation to engage in LSS projects.	Abu Bakar, Subari, and Mohd Daril 2015; Fadly Habidin and Mohd Yusof 2013; Jayaraman, Leam Kee, and Lin Soh 2012; Jayaraman and Kee Teo 2010
	LSSE26	Funds for specialized manpower training	LSS should be considered as project-based methodology. The involvement of Master Black Belt (MBB), Black Belt (BB) and Green Belt (GB) is very essential for LSS implementation. There is a requirement of funds for specialized training like MBB, BB, and GB.	Albliwi et al. 2014; Ali, Choong, and Jayaraman 2016; Abu Bakar, Subari, and Mohd Daril 2015; Kumar, Kumar, and Haleem 2015; Jayaraman, Leam Kee, and Lin Soh 2012; Fadly Habidin and Mohd Yusof 2013
	LSSE27	Funds for financial incentives	It is one of the best practices to motivate employees for successfully implementing LSS initiatives.	Jeyaraman and Kee Teo 2010; Ali, Choong, and Jayaraman 2016; Abu Bakar, Subari, and Mohd Daril 2015; Kumar, Kumar, and Haleem 2015
	LSSE28	Funds for operational expenditure	The LSS demands substantial investment for creating various assets, generating resources, hardware and software purchase, preparation materials, consultation service, organisation rewards and reorganisation system, MBB, BB and GB training and others to build up and sustain the culture.	Albliwi et al. 2014; Ali, Choong, and Jayaraman 2016; Abu Bakar, Subari, and Mohd Daril 2015; Kumar, Kumar, and Haleem 2015; Fadly Habidin and Mohd Yusof 2013
	LSSE29	Financial benefits sharing among employees due to LSS	Top management motivates the LSS implementation through financial rewards in the form of money or expensive goods and services or through investments in the forms like cantina, wardrobes, salaries increment or yearly bonuses.	Albliwi et al. 2014; Ali, Choong, and Jayaraman 2016; Abu Bakar, Subari, and Mohd Daril 2015; Kumar, Kumar, and Haleem 2015
	LSSE30	Funds for LSS supportive hardware and software	LSS software and hardware purchasing is an investment in originating resources which helps in successful LSS implementation.	Setijono, Laureani, and Antony 2012; Fadly Habidin and Mohd Yusof 2013; Albliwi et al. 2014; Lertwattanapongchai and William Swierczek 2014; Ali, Choong, and Jayaraman 2016; Abu Bakar, Subari, and Mohd Daril 2015; Kumar, Kumar, and Haleem 2015; Assarlind, Gremyr, and Bäckman 2013
	Customer based LSSEs	LSSE31	Linking LSS with customer preferences	It helps to fulfil the needs of the customers.

(continued)

Table 2. Continued.

Main criteria	LSSEs code	Sub criteria	Effect of LSSEs	Literature support
Supplier based LSSEs	LSSE32	Customer satisfaction and delight	Customer satisfaction and delight will change the way of organisational thinking and more attention can be paid to any customer-related issues.	Abu Bakar, Subari, and Mohd Daril 2015; Antony, Setijono, and Dahlgaard 2016; Lertwattanapongchai and William Swierczek 2014; Manville et al. 2012; Psychogios and Tsironis 2012
	LSSE33	Customer relationship management	The customer relationship management improves the experience of the customers and adds long-term customer value by removing the waste.	Setijono, Laureani, and Antony 2012; Psychogios and Tsironis 2012; Ali, Choong, and Jayaraman 2016
	LSSE34	Customer focused information and analysis	The customer-centric information and analysis utilise the customer information tactically and help in overcoming customer dissatisfaction and deliver customer demands sensibly.	Antony 2014; Antony, Setijono, and Dahlgaard 2016; Abu Bakar, Subari, and Mohd Daril 2015
	LSSE35	Understanding the customer demand	The organisation must be accountable and aware about hearing the customer's voice, satisfy the needs and expectations of the customers and forecast the customer demand.	Albliwi et al. 2014; Franchetti and Barnala 2013; Antony, Setijono, and Dahlgaard 2016
	LSSE36	Linking LSS to buyer-suppliers	Customer-supplier relation serves a better flow of information. Knowledge management helps to achieve successful LSS implementation.	Jeyaraman and Kee Teo 2010; Abu Bakar, Subari, and Mohd Daril 2015; Kumar, Kumar, and Haleem 2015
	LSSE37	Supplier relationship management	The effective supplier relationship management helps in developing a better quality design product. It meliorates strategic partnership and long-term relationship and improves the performance of purchase management and the job ordering system.	Psychogios and Tsironis 2012; Albliwi et al. 2014; Abu Bakar, Subari, and Mohd Daril 2015; Kumar, Kumar, and Haleem 2015
	LSSE38	Extending LSS to supply chain	Extending LSS to supply chain accomplishes the customer satisfaction related delivery, quality, and cost.	Setijono, Laureani, and Antony 2012; Ali, Choong, and Jayaraman 2016; Abu Bakar, Subari, and Mohd Daril 2015
	LSSE39	Effective feedback and communication system	Feedback and continuous communication have strong links to the satisfaction of employees and enhancement of productivity.	Abu Bakar, Subari, and Mohd Daril 2015; Albliwi et al. 2014; Antony et al. 2012; Antony, Setijono, and Dahlgaard 2016; Fadly Habidin and Mohd Yusof 2013; Hilton and Sohal 2012; Jayaraman, Leam Kee, and Lin Soh 2012; Jeyaraman and Kee Teo 2010; Laureani, Brady, and Antony 2013; Lertwattanapongchai and William Swierczek 2014; Manville et al. 2012; Näslund 2008; Setijono, Laureani, and Antony 2012
	LSSE40	Joint problem solving approach	Any organisation can effectively solve novel and complex works by employing the organisational joint problem-solving approach.	Jeyaraman and Kee Teo 2010; Setijono, Laureani, and Antony 2012; Psychogios and Tsironis 2012; Albliwi et al. 2014; Antony, Setijono, and Dahlgaard 2016; Abu Bakar, Subari, and Mohd Daril 2015; Kumar, Kumar, and Haleem 2015

facing a few wastes such as the high cost of rework, high motions of workers, large amount of defects, over-processing and various non-value added activities; also, the company A receives a major complaint from customers related to maintenance activities; (iii) controlling the quality for the survival in today's competitive business environment. The case company A confronts a number of problems when doing LSS initiatives because any quality initiative requires taking into considering of various complex elements systematically, such as the aim, organisation's culture, resource conditions,

training requirements and even the organisation preference. This case company A is interested to recognise the most significant LSSEs and to examine the interaction and interdependencies among these LSSEs.

3.2. Methodology

The main aim of LSS is to target every type of opportunity for improvement within the organisation. Many researchers demonstrated the successful implementation of LSS. Nevertheless,

Table 3. ISM and MICMAC/fuzzy MICMAC as reported in literature.

Field	Details	Literature support
Green supply chain management	To analyse the influential factors on implementing green supply chain management practices.	Agi and Nishant 2017
Supply chain	To analyse the sustainable supply chain management enablers.	Dubey et al. 2017
Supply chain	To develop relationship between supply chain knowledge flow enablers (SCKFEs).	Bhosale and Kant 2016
Green Lean Six Sigma	To analyse the barriers in Green Lean Six Sigma product development.	Kumar et al. 2016
Information systems	To formalise the relationships between the selected failure factors of information systems project failure.	Hughes et al. 2016
Mass customisation	To examine the enablers of mass customisation of Indian manufacturing industries (particularly footwear industries).	Purohit et al. 2016
Risk management	To analyse the supply chain risks in Indian apparel retail chains.	Venkatesh, Rathi, and Patwa 2015
Collaborative planning, forecasting and replenishment (CPFR)	To analyse the interactions among CPFR barriers.	Panahifar, Byrne, and Heavey 2014
Medical tourism	To analyse the interactions among key medical tourism enablers (MTEs) and to study the direct and indirect effects of each enabler on the growth of medical tourism in India.	Ranjan Debata et al. 2013
TQM	To analyse the interactions among TQM enablers.	Singh and Sushil 2013

many organisations did not get benefit from the LSS as its execution methodology was not shown effectively (Albliwi et al. 2014). There are several studies focuses on identification of key factors for successful implementation of LSS. But mere success factor identification is not enough. To address this gap, the key enablers for successful LSS implementation have been identified and introduced in this study. It is apparent that no single LSSE would lead to achieving LSS implementation; hence, it becomes more important to recognise the relationship of LSSEs with each other. ISM methodology has been widely utilised for analysing and examining the association among different factors. The ISM method provides a means by which researchers can impose an order, build relationships between and create models around the elements of a system (Farris and Sage 1975). The goal of MICMAC analysis is to analyse the components based on their driving and dependency power and clustering them into four categories: autonomous, dependent, linkage and independent (Duperrin and Godet 1973). The results of this analysis can help to make the strategic and tactical decisions in organisations to move from a traditional manufacturing system to LSS system. The integrated ISM and fuzzy MICMAC methods have been applied in several fields are presented in Table 3.

Both the ISM and fuzzy MICMAC are the powerful tools to develop a relational structural model and classify LSSEs according to their power, hence, the hybrid ISM and fuzzy MICMAC approach have been utilised in this study.

3.2.1. Interpretive structural modelling (ISM) and relationship model development

ISM is an interactive technique in which dissimilar and directly related factors or components of the case company are ordered into a systematic hierarchical model recognised as a structural model (Warfield 1974). ISM technique can be referred as a graph theory application in which hypothetical, conceptual and computational leverage are utilised to develop a digraph (directed graph) or network for depicting the contextual relationship pattern of a set of variables (Watson 1978). Usually, the mental model is vague when

many factors are involved and it turns out to be complicated to understand the direct and indirect relationship between the variables. ISM provides a clear understanding of all the factors and their association with other factors (Farris and Sage 1975). The most favourable benefit of ISM technique is that it changes unclear and inadequately enunciated models of systems into visible and clear models. However, this methodology is not free from disadvantages. The primary negative mark of this methodology is that of the inclination of the individual who is judging the factors. The relation among the factors dependably relies upon that of the individual's information and familiarity with the firm, its operations and its industry. This bias can influence the finally developed model and ISM does not give any weights related to the factors (Bhosale and Kant 2016).

The following five steps were followed in this research to develop ISM (Farris and Sage 1975; Janes 1988).

Step 1: Identify the LSSEs: Recognise the important LSSEs with the help of literature review, expert opinions and brain-storming.

Step 2: Define the contextual relationship: From the factors identified in the first step, establish a contextual relationship among LSSEs and set up an auxiliary self-interaction network (SSIM) in view of pair-wise examination of components of the framework under consideration. The contextual relationship is depending on the structure type such as priority, intend and mathematical dependence process, and this provides the relationship nature amongst the variables (Singh and Sushil 2013).

Step 3: Develop a reachability matrix: Building up a reachability network from the SSIM by changing over the data in every cell of the network from step 2 into binary digits (0 and 1) and check transitivity (that is if factor A is related to factor B and factor B is related to factor C, then factor A is necessarily related to factor C).

Step 4: From step 3, obtain the final reachability matrix and then part it into different levels based on reachability and antecedents sets for every variable through a progression of cycles known as the level partitioning.

Step 5: After drawing a directed graph or diagraph, remove the transitive links from diagraph based on the relationships given in the reachability matrix. Afterwards, replace the resultant directed graph using an ISM model by substituting the variables nodes with statements.

3.2.2. Fuzzy MICMAC

MICMAC, an approach that enables a systematic analysis of complex issues, was developed by Duperrin and Godet (1973). MICMAC is an indirect classification method which critically analyses the scope of each component of the ISM framework (Singh et al. 2003; Kant and Singh 2009). The goal of MICMAC analysis is to analyse the components based on their driving and dependency power and clustering them into four categories: autonomous, dependent, linkage and independent. Many researchers have utilised MICMAC analysis in a several of fields, including knowledge management, total quality management and supply chain management (Singh and Sushil 2013; Singh et al. 2003; Raut, Narkhede, and Gardas 2017). The traditional MICMAC investigation considers just 0,1 binary type of relationships. To enhance the sensitivity of MICMAC analysis, this study utilises fuzzy set theory (FST).

Chang and Wang (2009) and Dubois and Prade (1978) noted that fuzzy numbers are a fuzzy subset of real numbers, presenting the expansion of the idea of the confidence interval. The membership function of the fuzzy set specifies the degree to which an input belongs to a set, the output of a membership function is always limited between 0 and 1, is known as a value of grade of membership. This membership function is used in the fuzzification and defuzzification, to map the non-fuzzy input values to fuzzy linguistic terms and vice versa.

The given fuzzy number \tilde{A} is a fuzzy set, with membership function $\mu_{\tilde{A}}(X)$ comprises the following features:

Definition 1: $\mu_{\tilde{A}}(X)$ is a continuous mapping from R to the interval of $[0, 1]$.

Definition 2: $\mu_{\tilde{A}}(X)$ is a convex fuzzy subset and $\mu_{\tilde{A}}(X)$ is the normalisation of a fuzzy subset which means that there exists a number X_0 that makes $\mu_{\tilde{A}}(X) = 1$.

The triangular fuzzy numbers (TFNs) are defined as a fuzzy number represented by three points as TFNs $\mu_{\tilde{A}}(X) = A = (\tilde{l}, \tilde{m}, \tilde{r})$. The characteristics and membership function of the TFNs are shown in Equation (1) and Figure 1.

$$\mu_{\tilde{A}}(X) = \begin{cases} 0, & x \leq l, \\ \frac{x-l}{m-l}, & l \leq x \leq m \\ \frac{r-x}{r-m}, & m \leq x \leq r \\ 0, & x \geq r \end{cases} \quad (1)$$

'A' denotes fuzzy set, 'x' is a member or element of a set A, while l, m, r are the real numbers. According to the extension principles and characteristics proposed by Zadeh (1965), the TFNs are noted as $A = (\tilde{l}, \tilde{m}, \tilde{r})$. The linguistic scale used for the rating of alternatives is presented in Table 4.

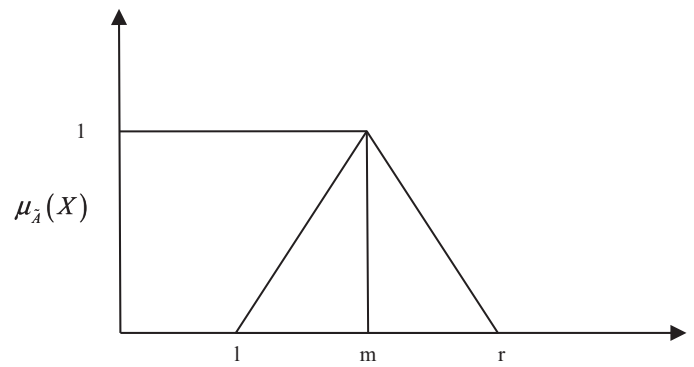


Figure 1. Triangular fuzzy number.

Table 4. The fuzzy linguistic scale.

Linguistic terms	Linguistic values
No Influence (No)	(0,0,0)
Very Low Influence (VL)	(0,0,1,0.3)
Low Influence (L)	(0,1,0.3,0.5)
Medium Influence (M)	(0.3,0.5,0.7)
High Influence (H)	(0.5,0.7,0.9)
Very High Influence (VH)	(0.7,0.9,1)
Complete influence (C)	(1,1,1)

The fuzzy values are not suitable for matrix operations; hence, defuzzication is required for further aggregation to replace the fuzzy numbers to the crisp value, this defuzzication is carried out using the best non-fuzzy performance (BNP) value. To defuzzify the TFNs into best non-fuzzy performance (BNP) values, the following equation is used:

$$BNP_{ij} = \frac{[(r-l) + (m-l)]}{3} + l. \quad (2)$$

4. Application of ISM and fuzzy MICMAC in case company

The ISM method was used to examine and study the interactions between the LSSEs. The clustering of LSSEs based on driving and dependence power has been accomplished using fuzzy MICMAC. Figure 2 depicts the flowchart of applied method.

4.1. Interpretive structural modelling and relationship model development

ISM is often used to provide the fundamental understanding of complex situations, as it assists to decompose a complicated system into several sub-systems (elements) and construct a multilevel structural model using practical experience of experts and their knowledge.

4.1.1. Structural self-interaction matrix (SSIM)

From the rigorous literature reviews, initially, total 70 numbers of LSSEs had been identified. The 40 most influential enablers were obtained using examination and consultations with the expert team of nine members. For investigating LSSEs in creating SSIM, the contextual relationship between

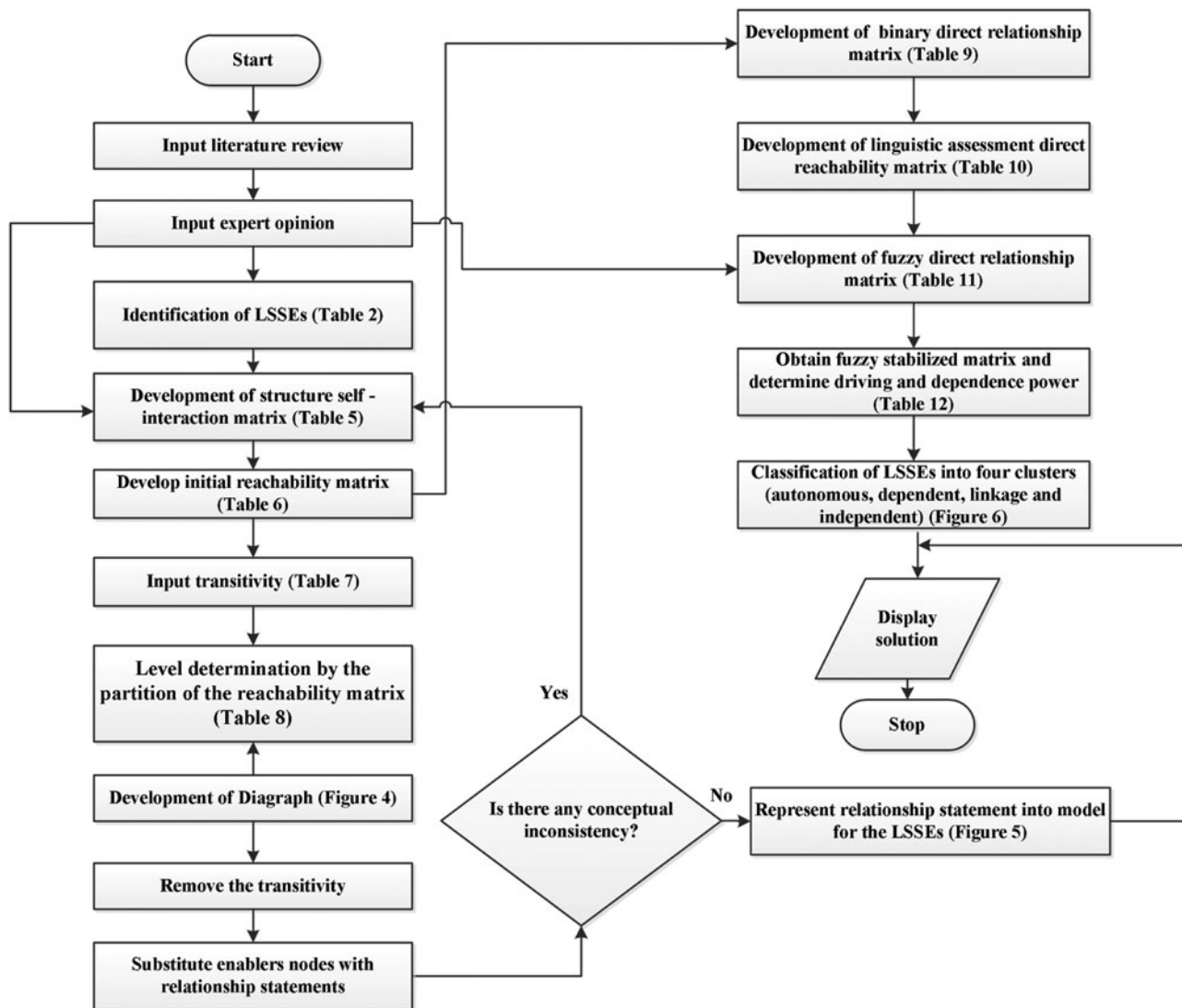


Figure 2. Integrated ISM and FMICMAC methodology flow chart.

a pair of enablers, and the association among two enablers i and j were established, and the associated direction of this relation was discussed. Following four symbols have been used to demonstrate the direction of relationship among enablers (i and j).

1. V: enabler i will help in achieving enabler j .
2. A: enabler j will help in achieving enabler i .
3. X: enabler i and enabler j will improve each other.
4. O: enabler i and enabler j are not related.

Where index i is for enablers in row and j is for enablers in column. Table 5 shows the SSIM matrix of 40 LSSEs, developed as per contextual relationship among the factors and from the expert suggestions. The following will describe the exercise the V, A, X and O in SSIM:

- Enabler LSSE1 helps to achieve enabler LSSE40. This means that enabler, namely 'Top-management commitment, involvement and support' will help to achieve enabler 'Joint problem solving approach'. Therefore, the

relationship between LSSE1 and LSSE40 is denoted by 'V' and allotted to (1,40) in the SSIM matrix.

- Enabler LSS39 can be achieved by LSS40. LSS40, namely 'Joint problem solving approach' would help to achieve LSS39, namely 'Effective feedback and communication system'. Hence, the relationship among these LSSEs is denoted by 'A' in the SSIM matrix.
- LSS38 and LSS 40 help to achieve each other. LSS38, namely 'Extending LSS to supply chain' and LSS40, namely 'Joint problem solving approach', help to achieve each other. Thus, symbol X is allotted to (38,40) cell in the SSIM matrix.
- No relationship exists among change management (LSS6) and extending LSS to supply chain (LSS38), and thus symbol O is allotted to (6,38) cell in the SSIM matrix.

4.1.2. Initial reachability matrix (IRM)

The binary matrix presents the existence of relationship among LSSEs. The SSIM matrix is transformed into binary matrix called the initial reachability matrix. The SSIM was transformed into initial reachability matrix, which is shown in

Table 5. Structural self-interaction matrix.

Sr. no.	LSSE code	40	39	38	...	14	...	4	3	2
1	LSSE1	V	V	V	...	V	...	V	V	V
2	LSSE2	V	V	V	...	V	...	V	V	
3	LSSE3	V	V	O	...	O	...	V		
...			
6	LSSE6	V	V	O			
...			
38	LSSE38	X	V							
39	LSSE39	A								
40	LSSE40									

Table 6. Initial reachability matrix.

Sr. no.	LSSE code	1	2	3	...	14	...	38	39	40
1	LSSE1	1	1	1	...	1	...	1	1	1
2	LSSE2	0	1	1	...	1	...	1	1	1
3	LSSE3	0	0	1	...	0	...	0	1	1
...
6	LSSE6	0	0	0	...	0	...	0	1	1
...
38	LSSE38	0	0	0	...	0	...	1	1	1
39	LSSE39	0	0	0	...	0	...	0	1	0
40	LSSE40	0	0	0	...	0	...	1	1	1

Table 6, by altering every V, A, X and O by binary digits 0 and 1 as per given case. The rules of substitution are as follows (Malone 1975; Farris and Sage 1975):

- if the (i, j) entry in the SSIM is V, then the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry becomes 0;
- if the (i, j) entry in the SSIM is A, then the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry becomes 1;
- if the (i, j) entry in the SSIM is X, then the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry also becomes 1; and
- if the (i, j) entry in the SSIM is O, then the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry also becomes 0.

4.1.3. Final reachability matrix (FRM)

The final reachability is acquired from the initial reachability matrix after compressing the transitivity. The transitivity of the relationships is a fundamental supposition made in the ISM methodology. The transitivity property assists to remove the gaps between the criteria if any. The transitivity is described here by presenting Figure 3; according in the case being regarded here if LSSE A is associated to LSSE B (i.e. AaB), LSSE B is associated to LSSE C (i.e. BaC), so LSSE A is necessarily associated to LSSE C. e.g. LSSE3, 'Linking LSS to business/organisation strategy' is associated to LSSE36, namely 'Linking LSS to buyer-suppliers'. LSS36, 'Linking LSS to buyer-suppliers' is associated to LSS38, 'Extending LSS to supply chain', thus LSS3 is necessarily associated to LSS36. The final reachability matrix is generated after incorporating the transitivity relationships denoted by 1*. The final reachability matrix is presented in Table 7.

4.1.4. Level partitions

Level partitions are made to define the hierarchy of the variables. The reachability and antecedent set for each LSSEs are

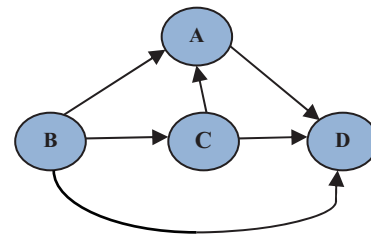


Figure 3. Transitivity diagram.

Table 7. Final reachability matrix.

Sr. no.	LSSE Code	1	2	3	...	14	...	38	39	40
1	LSSE1	1	1	1	...	1	...	1	1	1
2	LSSE2	0	1	1	...	1	...	1	1	1
3	LSSE3	0	0	1	...	1*	...	1*	1	1
...
6	LSSE6	0	0	0	...	1*	...	1*	1	1
...
38	LSSE38	0	0	0	...	0	...	1	1	1
39	LSSE39	0	0	0	...	0	...	0	1	0
40	LSSE40	0	0	0	...	0	...	1	1	1

determined from the final reachability matrix. The reachability set for an enabler comprises the enabler itself and the other enablers on whom it may help to impact. The antecedent set comprises the enabler itself and the other enablers, which may help in assisting the enabler itself. After determining reachability set and antecedent set, intersections between these sets are obtained against the enablers. In the event that it happens that the reachability set and the intersection set are the same for any enabler, then that enabler is given to the top-level in the ISM hierarchy (Kant and Singh 2009; Sage 1977) which would not help mitigate some other enablers over their own particular level. This indicates the completion of iteration 1. Table 8 shows that during the first iteration of reachability matrix, the performance measurement and benchmarking practice and customer satisfaction and delight are at Level I. In this way, it would be situated at the top of the ISM framework. After the identification of the top-level component, it is disposed of from the other remaining factors, and cycle 2 is completed by following the same strategy. This cycle of iteration proceeds until the levels of every enabler is discovered. In the second iteration, understanding the customer demand, linking LSS with customer preferences and customer-focused information and analysis are presented. The rest interaction is presented in Table 8. These levels help in constructing the directed graph and the final ISM framework.

4.1.5. Developing the ISM model

The structural model is created in perspective of the level segments of the components and the final reachability matrix. In the event that there is a relationship between the LSSEs i and j , this is shown by an arrow, points from i to j . Figure 4 portrays this network, which is called a directed graph or digraph. By removing the transitivities among the LSSEs, the directed graph is finally changed into the ISM-based model as indicated in Figure 5.

Table 8. Level of LSSEs.

LSSE code	Reachability set	Antecedent set	Intersection set	Level
LSSE1	1	1	1	XIII
LSSE2	2,7,26,27,28,30	1,2,7,26,27,28,30	2,7,26,27,28,30	XII
LSSE3	3,9	1,2,3,7,9,26,27,28,30	3,9	XI
LSSE4	4,6	1,2,3,4,6,7,9,10,11,12,13,15,16,17,18,19,20,21,22,23,24,25,26,27,28,30	4,6	VI
LSSE5	5,32	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40	5,32	I
LSSE6	4,6	1,2,3,4,6,7,9,10,11,12,13,15,16,17,18,19,20,21,22,23,24,25,26,27,28,30	4,6	VI
LSSE7	2,7,26,27,28,30	1,2,7,26,27,28,30	2,7,26,27,28,30	XII
LSSE8	8	1,2,3,4,6,7,8,9,10,11,12,13,15,16,17,18,19,20,21,22,23,24,25,26,27,28,30	8	V
LSSE9	3,9	1,2,3,7,9,26,27,28,30	3,9	XI
LSSE10	10,17,22,23	1,2,3,7,9,10,17,22,23,26,27,28,30	10,17,22,23	X
LSSE11	11,12,20,21	1,2,3,7,9,10,11,12,17,20,21,22,23,26,27,28,30	11,12,20,21	IX
LSSE12	11,12,20,21	1,2,3,7,9,10,11,12,17,20,21,22,23,26,27,28,30	11,12,20,21	IX
LSSE13	13,18	1,2,3,7,9,10,11,12,13,15,16,17,18,19,20,21,22,23,24,25,26,27,28,30	13,18	VII
LSSE14	14	1,2,3,4,6,7,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,30	14	V
LSSE15	15,16,19,24,25	1,2,3,7,9,10,11,12,15,16,17,19,20,21,22,23,24,25,26,27,28,30	15,16,19,24,25	VIII
LSSE16	15,16,19,24,25	1,2,3,7,9,10,11,12,15,16,17,19,20,21,22,23,24,25,26,27,28,30	15,16,19,24,25	VIII
LSSE17	10,17,22,23	1,2,3,7,9,10,17,22,23,26,27,28,30	10,17,22,23	X
LSSE18	13,18	1,2,3,7,9,10,11,12,13,15,16,17,18,19,20,21,22,23,24,25,26,27,28,30	13,18	VII
LSSE19	15,16,19,24,25	1,2,3,7,9,10,11,12,15,16,17,19,20,21,22,23,24,25,26,27,28,30	15,16,19,24,25	VIII
LSSE20	11,12,20,21	1,2,3,7,9,10,11,12,17,20,21,22,23,26,27,28,30	11,12,20,21	IX
LSSE21	11,12,20,21	1,2,3,7,9,10,11,12,17,20,21,22,23,26,27,28,30	11,12,20,21	IX
LSSE22	10,17,22,23	1,2,3,7,9,10,17,22,23,26,27,28,30	10,17,22,23	X
LSSE23	10,17,22,23	1,2,3,7,9,10,17,22,23,26,27,28,30	10,17,22,23	X
LSSE24	15,16,19,24,25	1,2,3,7,9,10,11,12,15,16,17,19,20,21,22,23,24,25,26,27,28,30	15,16,19,24,25	VIII
LSSE25	15,16,19,24,26	1,2,3,7,9,10,11,12,15,16,17,19,20,21,22,23,24,25,26,27,28,31	15,16,19,24,26	VIII
LSSE26	2,7,26,27,28,30	1,2,7,26,27,28,30	2,7,26,27,28,30	XII
LSSE27	2,7,26,27,28,30	1,2,7,26,27,28,30	2,7,26,27,28,30	XII
LSSE28	2,7,26,27,28,30	1,2,7,26,27,28,30	2,7,26,27,28,30	XII
LSSE29	29,36,37,38,40	1,2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,36,37,38,40	29,36,37,38,40	IV
LSSE30	2,7,26,27,28,30	1,2,7,26,27,28,30	2,7,26,27,28,30	XII
LSSE31	31	1,2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,33,36,37,38,39,40	31	II
LSSE32	5,32	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40	5,32	I
LSSE33	33,39	1,2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,33,36,37,38,39,40	33,39	III
LSSE34	34	1,2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,33,34,36,37,38,39,40	34	II
LSSE35	35	1,2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,33,35,36,37,38,39,40	35	II
LSSE36	29,36,37,38,40	1,2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,36,37,38,40	29,36,37,38,40	IV
LSSE37	29,36,37,38,40	1,2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,36,37,38,40	29,36,37,38,40	IV
LSSE38	29,36,37,38,40	1,2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,36,37,38,40	29,36,37,38,40	IV
LSSE39	33,39	1,2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,33,36,37,38,39,40	33,39	III
LSSE40	29,36,37,38,40	1,2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,36,37,38,40	29,36,37,38,40	IV

4.2. Fuzzy MICMAC analysis

On comparing the hierarchy of components of the ISM framework, in the different classifications, it brings about a rich source of information. Fuzzy MICMAC analysis is conducted to obtain new insights into the dependencies existing among the LSSEs identified by the ISM technique. This study utilises FST to enhance the sensitivity of MICMAC analysis. In fuzzy MICMAC, an additional probability of association among the components is presented. From Table 6, we can state that the relationship between LSSE3 and LSSE38 and LSSE3 and LSSE40 have equal significance and indicated by 1. But actually, the relationship among these LSSEs cannot generally be equivalent. A few relations might be strong, some might be very strong and a few relations might be weak.

4.2.1. Binary direct relationship matrix (BDRM)

A binary direct reachability matrix (BDRM) is developed by analyzing the immediate relationship among the LSSEs in the ISM as appeared in Table 7. Table 9 demonstrates the BDRM by changing the diagonal entries to zero of the value of Table.

4.2.2. Development of linguistic assessment direct reachability matrix (LADRM)

The opinion from the same expert committee was drawn to rate the relationship between two LSSEs. The qualities for the relationship among two LSSEs were then set on the BDRM to get a linguistic assessment direct relationship matrix (LADRM). Table 10 demonstrates the LADRM matrix of LSSEs. The fuzzy direct reachability matrix (FDRM) is displayed in Table 11.

4.2.3. Fuzzy MICMAC-stabilised matrix

The FDRM is taken as the base to begin the procedure. The matrix is multiplied repeatedly up to a power until the hierarchies of the driver power and dependence are stabilised. The multiplication process follows the principle of fuzzy matrix multiplication (Kandasamy, Smarandache, and Ilanthenral 2007) rather than Boolean multiplication of matrices. According to FST, when two fuzzy matrices are multiplied, the product matrix also becomes a fuzzy matrix. The multiplication rule is as follows:

$$\text{Fuzzy multiplication } C = (A * B) = \max K[\min(a_{ik}, b_{kj})],$$

where, $A = [a_{ik}]$ and $B = [b_{kj}]$.

The driving power of the LSSE in fuzzy MICMAC is obtained by adding the entries of possibilities of interactions

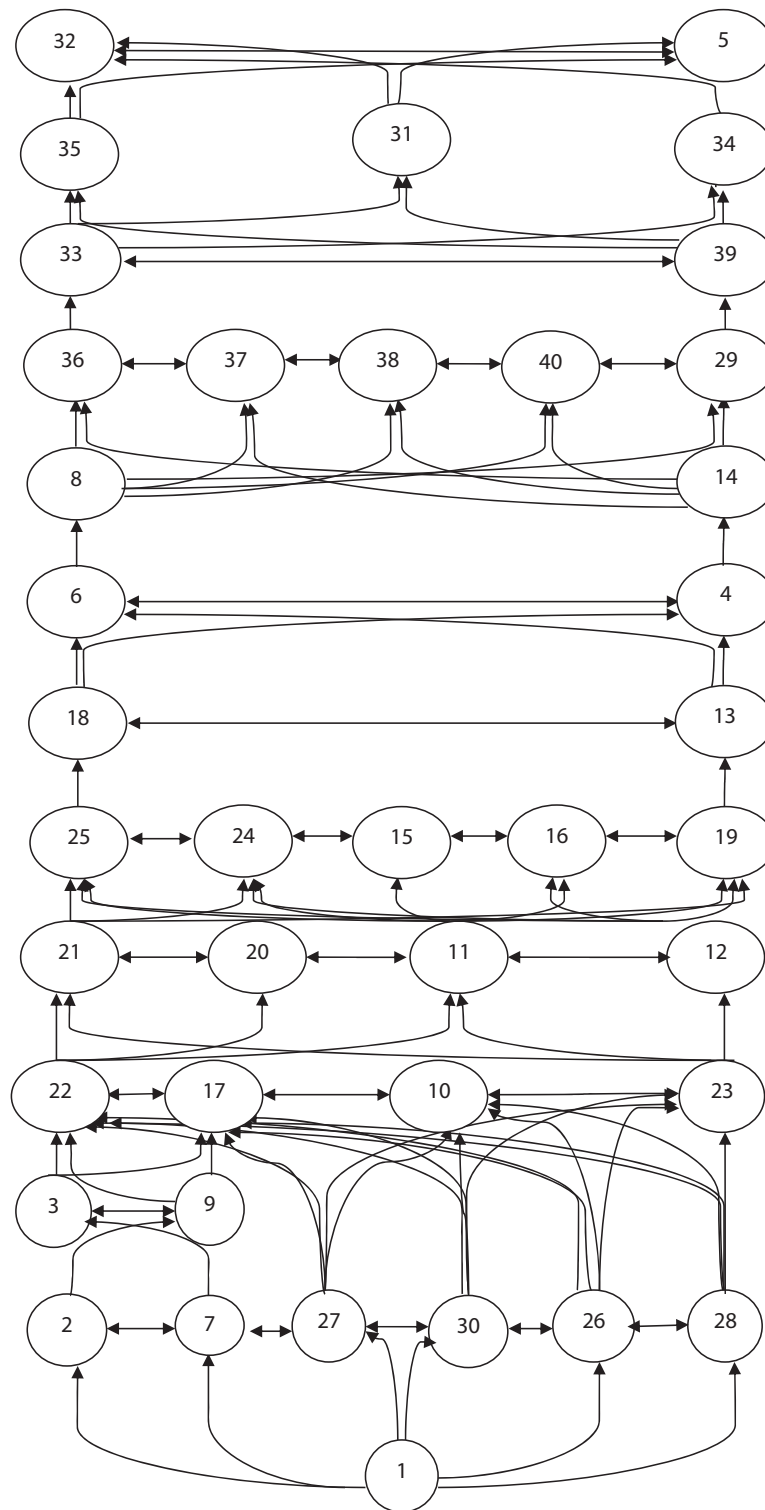


Figure 4. Digraph shows the relationship among the LSSEs.

in the rows, and the dependence of the LSSE is determined by summing the entries of possibilities of interactions in the columns. A stabilised matrix is presented in Table 12.

5. Discussions

This analysis has sought to identify LSSEs and understand the dependencies that exist among these LSSEs. Based on the input obtained from a literature search and expert

opinions, 40 LSSEs were identified. An ISM model was developed to introduce the hierarchical dependencies existing among the identified LSSEs. Then fuzzy MICMAC analysis was carried out to cluster the identified LSSEs according to their driver-dependency power. The results of this analysis broadly show that the ISM network consisting 13 levels. Top-management commitment, involvement and support' is top level LSSE in the ISM hierarchy. The top-management commitment and support' helps in making proper strategic planning

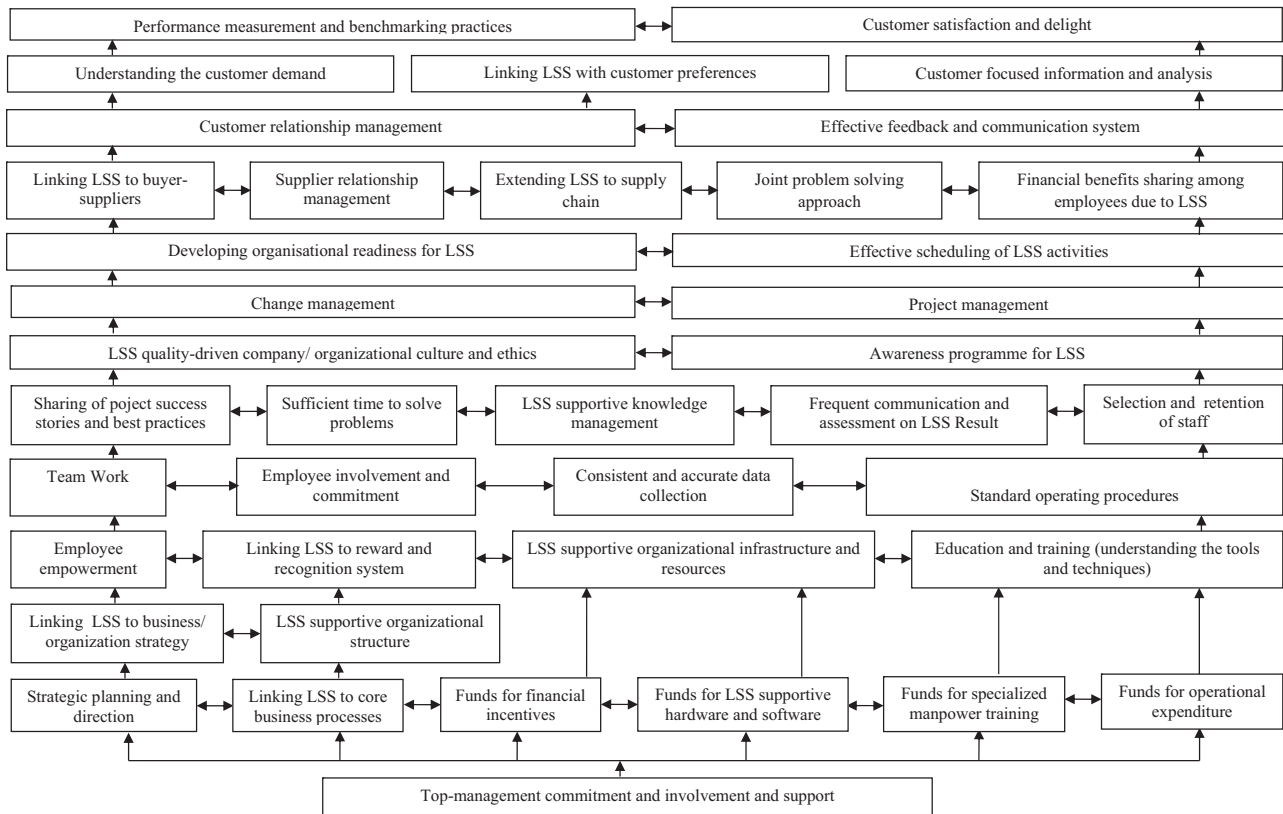


Figure 5. ISM-based model of LSSEs.

Table 9. Binary direct reachability matrix.

Sr. no.	LSSE code	1	2	3	...	14	...	38	39	40
1	LSSE1	0	1	1	...	1	...	1	1	1
2	LSSE2	0	0	1	...	1	...	1	1	1
3	LSSE3	0	0	0	...	1	...	1	1	1
...
6	LSSE6	0	0	0	...	1	...	1	1	1
...
38	LSSE38	0	0	0	...	0	...	0	1	1
39	LSSE39	0	0	0	...	0	...	0	0	0
40	LSSE40	0	0	0	...	0	...	1	1	0

Table 10. Linguistic assessment direct reachability matrix.

Sr. no.	LSSE Code	1	2	3	...	14	...	38	39	40
1	LSSE1	0	H	VH	...	H	...	VH	H	H
2	LSSE2	0	0	H	...	H	...	M	H	H
3	LSSE3	0	0	0	...	M	...	VH	VH	M
...
6	LSSE6	0	0	0	...	M	...	VH	VH	VH
...
38	LSSE38	0	0	0	...	0	...	0	H	VH
39	LSSE39	0	0	0	...	0	...	0	0	0
40	LSSE40	0	0	0	...	0	...	H	H	0

and direction and linking LSS to core business processes. Top-management commitment assures funds for specialised manpower training, financial incentives and operational expenditure for LSS supportive hardware and software. In the ISM model level three, LSS is linked to business/organisation strategy and LSS supportive organisational structure. Linking LSS to business/organisation strategy feeds the link between LSS projects and strategic goals. The LSS organisation structure defines the roles and responsibility and the flow of information among the different levels of management.

Linking LSS to business/organisation strategy and LSS supportive organisational structure mutually supports each other. Employee empowerment, linking LSS to reward and recognition system', LSS supportive organisational infrastructure and resources' and education and training (understanding the tools and techniques) are at fourth levels of ISM model. These four LSSEs help to cultivate the quality-focused environment and reciprocally assist one another. The ISM hierarchy level five constitutes the mutually supportive LSSEs

such as team work, employee involvement and commitment, standard operating procedures and consistent and accurate data collection to establish better work culture for the LSS initiatives. Whereas the level six of ISM model constitutes the frequent communication and assessment on LSS, sharing of project success stories and best practices, LSS supportive knowledge management, selection and retention of staff' and sufficient time to solve problems.

These periodic actions will guarantee that the LSS implementation programme remains on track and helps to motivate LSS initiative activities. The awareness programmes for LSS and organisational culture and ethics' mutually support each other (on level six in ISM hierarchy), by the overall employees involvement. Continuous improvements enforce change in organisational culture and ultimately help to satisfy the customer demands. The change management and project management assist each other and constitute at level eight.

The change management helps to achieve organisational readiness for LSS and project management helps to achieve

effective scheduling of LSS activities. All the nine levels of ISM model assist towards successful LSS implementation. The next level of ISM model assists the buyer and supplier with the LSS activities, namely linking LSS to buyer-suppliers, supplier relationship management, extending LSS to supply chain, joint problem-solving approach and sharing financial benefits among employees due to LSS. At level 11, the effective feedback communication system and customer relationship management are presented. These both LSSEs assist each other and help to improve the experience of the customer, add value, remove waste and construct long-term customer value. The level 12 constitutes understanding the customer demand, linking LSS with customer preferences and customer-focused information and analysis. All of these LSSEs ultimately help to archive customer satisfaction and delight and performance measurement and benchmarking practices.

Table 11. Fuzzy direct reachability matrix.

Sr. no.	LSSE code	1	2	3	...	14	...	38	39	40
1	LSSE1	0	0.7	0.9	...	0.7	...	0.9	0.7	0.7
2	LSSE2	0	0	0.7	...	0.7	...	0.5	0.7	0.7
3	LSSE3	0	0	0	...	0.5	...	0.9	0.9	0.5
...
6	LSSE6	0	0	0	...	0.5	...	0.9	0.9	0.9
...
38	LSSE38	0	0	0	...	0	...	0	0.7	0.9
39	LSSE39	0	0	0	...	0	...	0	0	0
40	LSSE40	0	0	0	...	0	...	0.7	0.7	0

Table 12. Fuzzy MICMAC stabilised matrix.

Sr. no.	LSSE Code	1	2	3	...	14	...	38	39	40	Driving
1	LSSE1	0	0.9	0.9	...	0.9	...	0.9	0.9	0.9	34.7
2	LSSE2	0	0	0.9	...	0.9	...	0.9	0.9	0.9	33.4
3	LSSE3	0	0	0	...	0.9	...	0.9	0.9	0.9	28.8
...
6	LSSE6	0	0	0	...	0.9	...	0.9	0.9	0.9	13.3
...
38	LSSE38	0	0	0	...	0	...	0	0.9	0.7	9.7
39	LSSE39	0	0	0	...	0	...	0	0	0	4.6
40	LSSE40	0	0	0	...	0	...	0.9	0.9	0	9.9
	Dependence	0	4.6	7	...	23.2	...	28.8	30.6	28.6	

From fuzzy MICMAC analysis, LSSEs were grouped into four dimensions: autonomous, dependent, linkage and independent (refer Figure 6). The autonomous LSSEs have weak driving power and weak dependence power. The cluster of dependent LSSEs has weak driving power but strong dependence power. The linkages LSSEs have strong driving power and strong dependence power. And the fourth cluster of independent LSSEs has strong driving power and weak dependence power. The results of fuzzy MICMAC analysis are presented in the following subsections.

5.1. Autonomous LSSEs

Autonomous LSSEs have weak driving power and also have weak dependence power. The autonomous LSSEs are relatively disconnected from the system, as they have only a few links, which may not be strong. Therefore, they do not have the huge effect on the system. The results indicate that no autonomous LSSEs exist in this analysis. No autonomous LSSEs show that all studied LSSEs are significant, that is, they are not disconnected from the system. All LSSEs considered in this analysis have influence on the successful LSS implementation.

5.2. Dependent LSSEs

The dependent LSSEs have weak driving power but strong dependence power. From cluster of LSSEs, project management (LSSE4), performance measurement and benchmarking practices' (LSSE5), change management (LSSE6), developing organisational readiness for LSS (LSSE8), awareness programme for LSS (LSSE13), effective scheduling of LSS activities (LSSE14), quality driven company/organisational culture and ethics' (LSSE18), financial benefits sharing among employee's due to LSS (LSSE29), linking LSS with customer preferences (LSSE31), customer satisfaction and delight (LSSE32), customer relationship management (LSSE33), customer focused information and analysis (LSSE34), understanding the customer demand (LSSE35), linking LSS to

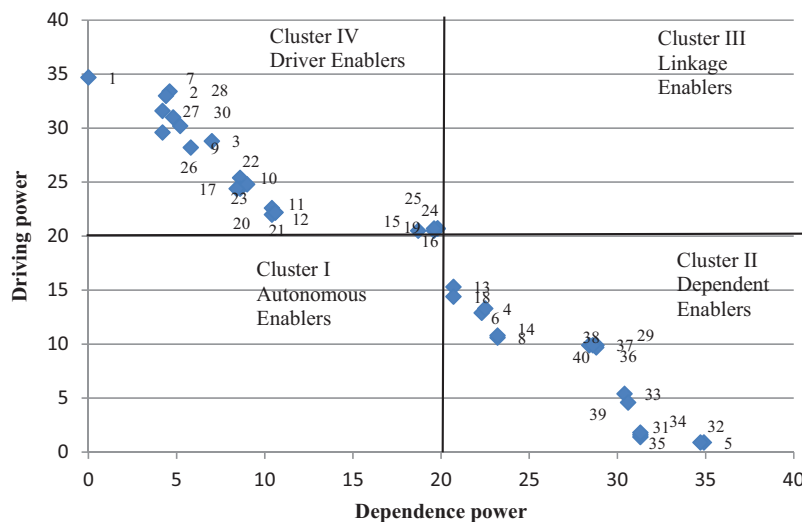


Figure 6. LSSEs cluster.

buyer-suppliers (LSSE36), supplier relationship management (LSSE37), extending LSS to supply chain (LSSE38), effective feedback and communication system (LSSE39) and joint problem solving approach (LSSE40), have weak driving power but strong dependence power on other LSSEs and are more performance orientated. They are seen at the top level of the ISM hierarchy (refer [Figure 5](#)), hence regarded as vital LSSEs. Their strong dependence power indicates that they require all other LSSEs to come together for overcoming the LSS implementation challenges. The model will be beneficial for the organisations which are striving LSS implementation. The top-management has to accord high priority in accomplishing these LSSEs.

5.3. Linkage LSSEs

Linkage LSSEs have high driving power and also have high dependence power. The linkage LSSEs are unstable, therefore any alteration occurring to these LSSEs will influence the other LSSEs and furthermore feedback affects themselves. The result of fuzzy MICMAC analysis shows (refer [Figure 6](#)) that there are no unstable LSSEs among all the 400 LSSEs adopted in this analysis. The linkage LSSEs are affected by lower level LSSEs and successively influence other LSSEs in the model, which may affect the successful LSS implementation in a positive or negative way. The special care has to be taken while dealing such LSSEs.

5.4. Independent LSSEs

Independent LSSEs have high driving power and low dependence power. These LSSEs are more strategic in orientation. The results show the top-management commitment, involvement and support' (LSSE1), strategic planning and direction' (LSSE2), linking LSS to business/organisation strategy (LSSE3), linking LSS to core business processes (LSSE7), LSS supportive organisational structure (LSSE9), LSS supportive organisational infrastructure and resources (LSSE10), consistent and accurate data collection (LSSE11), standard operating procedures (LSSE12), LSS supportive knowledge management (LSSE15), frequent communication and assessment on LSS result (LSSE16), Linking LSS to reward and recognition system (LSSE17), selection of staff and retention of staff (LSSE19), employee involvement and commitment (LSSE20), team-work (LSSE21), employee empowerment (LSSE22), education and training (understanding the tools and techniques) (LSSE23), sufficient time to solve problems (LSSE24), sharing of project success stories and best practices (LSSE25), funds for specialised manpower training (LSSE26), funds for financial incentives (LSSE27), funds for operational expenditure (LSSE28) and funds for LSS supportive hardware and software (LSSE30) have high driving power and low dependence power. The existing of strong dependence power indicating that change in these driving LSSEs has a significant effect on ISM network. The driving LSSEs are key variables for controlling the ISM hierarchy. In ISM network they are at the bottom level of ISM hierarchy as depicted in [Figure 5](#). These LSSEs are more strategic in orientation, a root cause of all LSSEs and

important and ever push the organisation to successful LSS implementation. The top-management should formulate the strategy to apply these driver LSSEs for the successful LSS implementation.

LSS is the method to realise the improvements. The top management's long term thinking (philosophy), process improvements and data management, employees and stakeholder involvement and their growth, continuous improvements, problem solving and learning are necessary for sustainable LSS implementation for both manufacturing and service industries (Piercy and Rich 2009; Geier 2011; Sony and Naik 2011). Recently, Arcidiacono et al. (2016) developed the AMSE (Assessment, Monitoring, Sustainability, Expansion) model to deal with the LSS sustainability over the time. The organisation needs to adopt the holistic view of the business, holistic improvement methods and establishing an integrated project management system to successfully pursue the LSS system. Holistic improvements define as 'An improvement system that can successfully create and sustain significant improvements of any type, in any culture for any business' (Snee 2008, 2009a, 2009b). When this holistic improvement embedded in the organisation's business, it can achieve better LSS sustainability. The critical components of this embedding are development of process management system, focus on operational excellence rather than only training, make communication as the key priority, cultivate the culture of continuous improvements by everyone's involvement, improvements, learning and innovation, align reward and recognition with LSS objective, make documents of LSS easy and simple to understand, involve the customer's voice and feedback for process improvements and measurement, make celebrating success a priority and revise job descriptions as per LSS goal and requirements (Kleindorfer, Singhal, and Wassenhove 2009; Sony and Naik 2011; Geier 2011; Arcidiacono et al. 2016).

6. Concluding remarks and managerial implications

The key objectives of this study are to determine and rank LSSEs and to examine the interactions among LSSEs which assist in the successful LSS implementation in the manufacturing organisations of India. The integrated ISM and fuzzy MICMAC framework have been built-up to identify the interactions among LSSEs so that management may lay stress on those LSSEs which are more effective for the successful LSS implementation. The driver-dependence diagram assists in clustering and collecting LSSEs together in terms of driving-dependence power. By carrying out literature review and gathering expert opinions, 40 LSSEs have been identified. LSS offers significant benefits to the organisations. However, the LSS initiatives are lower in developing country like India. The most significant 40 LSS implementation LSSEs have been identified in this study. The information of the vital LSSEs and the strategy to improve/archive these are of critical importance for organisations that are considering LSS implementation. Many of the organisations experience the scarcity of resources. The identification of most significant LSSEs assists managers to concentrate those scarce resources on the most imperative factors. In this analysis, 'Top-

management commitment, involvement and support' is identified as the most dominant LSSE. Top-management commitment, involvement and support' ensures the human resource support, financial support and fund availability, helps in removing obstacles and regularly reviewing LSS project progress, ensures recognition and rewards for participants. The transformation of the conventional manufacturing system to LSS system is the complex task. It is recommended that practitioners begin with small-scale LSS project and gradually adopt LSS on full-scale over time. Management requires teaching every associate about the benefits of LSS implementation for successful LSS implementation.

The LSS demands some substantial investment of organisation in creating various assets, generating resources, hardware and software purchase, preparation materials, consultation service, organisation rewards and reorganisation system, Master Black Belt (MBB), Black Belt (BB) and Green Belt (GB) training and others to build up and sustain the culture. All the LSS activities should be prioritised with organisation's other curricula and quality programmes by practising the strategic planning. To feed the link between LSS projects and strategic goals, continuous improvement principles need to be incorporated into the business strategy. Also, it is necessitated seeing the organisation's preparedness for LSS implement activities. The LSS champions and leaders need to prepare the customised roadmap and can guide the organisation about deployment and implementation process. Frequent communication will be required consistently at various levels, such as top-level management, leadership review and the state of every project.

As LSS should be observed as a cultural shift, in order to cultivate the quality-focused culture throughout the organisation, certain recognition and reward system shall be implemented. Effective LSS implementation requires providing training to employees to identify waste, focusing on team-work, determining the causes and empowering people to implement changes. The measurement of benefits in terms of performance, financial measurement before and after LSS implementation, quality practices, project success stories and benchmarking practice should be shared with employees to enhance the visibility of LSS activities and help in building the culture. Linking LSS to buyer-suppliers is needed for successful LSS implementation. Extending LSS to supply chain accomplished customer satisfaction relating delivery, quality and cost.

The outcomes suggest a tight interrelationship among many of listed LSS enablers and feature the multidimensional nature of LSS implementation. It is apparent that no single LSSE would lead to achieving LSS implementation; hence, it becomes more important to recognise the relationship of LSSEs with each other. In ISM frameworks, the association among the two LSSEs is indicated by a binary number. Nevertheless, the association among LSSEs cannot be constantly equivalent, a few relations might be strong, some might be very strong and some relations might be better. To beat this limitation of ISM method the fuzzy relationship is utilised to forecast the association among LSSEs. ISM framework (Figure 5) recognises the hierarchy of actions to be taken by

practitioners to maximise the impact of these LSSEs for successful LSS implementation. The practitioners require focusing on these LSSEs more cautiously during LSS implementation in their organisations. The fuzzy MICMAC analysis demonstrated the clusters of LSSEs which consideration by practitioners as per their driving and dependence power. No autonomous, no linkage, 18 dependent and 22 independent LSSEs have been determined in the fuzzy MICMAC analysis. The diagram appeared in Figure 6 has identified the key LSSEs associated with high driving power and thus influence over other enablers in the framework. These are situated at the lower level of the ISM model. The practitioners should focus on those LSSEs which have higher driving power because these LSSEs should be emphasised for successful LSS implementation. The driver LSSEs are the root cause for other LSSEs which have higher dependence power. These key driver LSSEs assist top management to formulate the strategy for enhancing their effects during successful LSS implementation. By putting more efforts towards improving independent LSSEs, other enablers may be worked upon and will play a vital role in the successful LSS implementation. The dependent enablers are located at the top level in the digraph. In practice, it implies that these enablers will be easily achieved if the linked enablers lower in the model are subject to successfully achieved.

The key contribution of this analysis is the development of LSSEs' contextual relationships through a systematic framework. The results of this study can help to make the strategic and tactical decisions in organisations to move from a traditional manufacturing system to LSS system.

7. Limitation and future scope

One major limitation of this study is the exploratory nature of this study and a single case example. The developed model is highly judgmental based on the experts' opinions. Hence, any bias in judgment will influence the final result. The ISM methodology does not consider the relationship strength in a quantitative way. Rather, it is intended at identifying the dependent/independent factors of a complex problem. To overcome these limitations, the scope for future research can be mainly the quantitative way, to gauge the strength of the relationship in place. Also, measurement of these LSSEs and their interrelationships possibly may be carried with future by selecting Analytical Hierarchy Process (AHP), Analytical Network Process (ANP), SWOT analysis and decision-making trial and evaluation laboratory (DEMATEL) methodology within multiple industrial sectors. Also, statistical validation may be carried out with the help of a questionnaire-based survey concentrating on a particular sector. Furthermore, the suggested model validity can be tested using Structural Equation Modeling (SEM) or Systems Dynamics Modeling (SDM).

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors



S. J. Raval has about 10 years of teaching experience at graduate and post graduate levels. She has completed her graduation in Production Engineering and post-graduation in Advance Manufacturing Systems. She is pursuing her Ph.D. in the area of Lean Six Sigma from Department of Mechanical Engineering, Sardar Vallabhbhai National Institute of Technology, Surat, India. Her interests of areas are Lean Six Sigma, Advanced Manufacturing and Optimisation.



Dr. Ravi Kant is Assistant Professor at the Department of Mechanical Engineering, Sardar Vallabhbhai National Institute of Technology, Surat, India. His areas of research interest include Knowledge Management, Operations & Supply Chain, Lean & Six Sigma. He has about 11 years of experience in industry, teaching and research. He has co-authored more than 150 research papers in international journals and conferences and three books.



Dr. Ravi Shankar is the 'Amar S. Gupta Chair Professor of Decision Science' at Department of Management Studies, Indian Institute of Technology (IIT) Delhi, India. He is also the Honorary Visiting Professor of Decision Science at School of Economics and Management, Loughborough University, UK. His areas of interest include Decision Sciences, Business Analytics and Big Data, Operations and Supply Chain Management, Sustainable Freight Transportation, Project Management, Total Quality Management and Six Sigma, Strategic Technology Management, etc. He has co-authored more than 400 research papers and six books.

References

- Abu Bakar, F. A., K. Subari, and M. A. Mohd Daril. 2015. "Critical Success Factors of Lean Six Sigma Deployment: A Current Review." *International Journal of Lean Six Sigma* 6 (4): 339–48. doi:10.1108/IJLSS-04-2015-0011
- Agarwal, S., J. J. Gallo, A. Parashar, K. K. Agarwal, S. G. Ellis, U. N. Khot, R. Spooner, E. M. Tuzcu, and S. R. Kapadia. 2016. "Impact of Lean Six Sigma Process Improvement Methodology on Cardiac Catheterization Laboratory Efficiency." *Cardiovascular Revascularization Medicine* 17 (2): 95–101. doi:10.1016/j.carrev.2015.12.011
- Agi, M. A., and R. Nishant. 2017. "Understanding Influential Factors on Implementing Green Supply Chain Management Practices: An Interpretive Structural Modelling Analysis." *Journal of Environmental Management* 188: 351–63. doi:10.1016/j.jenvman.2016.11.081
- Akbulut-Bailey, A. Y., J. Motwani, and E. M. Smedley. 2012. "When Lean and Six Sigma Converge: A Case Study of a Successful Implementation of Lean Six Sigma at an Aerospace Company." *International Journal of Technology Management* 57 (1/2/3): 18–32. doi:10.1504/IJTM.2012.043949
- Albliwi, S., J. Antony, S. Abdul Halim Lim, and T. van der Wiele. 2014. "Critical Failure Factors of Lean Six Sigma: A Systematic Literature Review." *International Journal of Quality & Reliability Management* 31 (9): 1012–30. doi:10.1108/IJQRM-09-2013-0147
- Ali, N. K., C. W. Choong, and K. Jayaraman. 2016. "Critical Success Factors of Lean Six Sigma Practices on Business Performance in Malaysia." *International Journal of Productivity and Quality Management* 17 (4): 456–73. doi:10.1504/IJMQM.2016.075251
- Anderson, N. C., and J. V. Kovach. 2014. "Reducing Welding Defects in Turnaround Projects: A Lean Six Sigma Case Study." *Quality Engineering* 26 (2): 168–81. doi:10.1080/08982112.2013.801492
- Antony, J. 2014. "Readiness Factors for the Lean Six Sigma Journey in the Higher Education Sector." *International Journal of Productivity and Performance Management* 63 (2): 257–64. doi:10.1108/IJPPM-04-2013-0077
- Antony, J., N. Krishan, D. Cullen, and M. Kumar. 2012. "Lean Six Sigma for Higher Education Institutions (HEIs) Challenges, Barriers, Success Factors, Tools/Techniques." *International Journal of Productivity and Performance Management* 61 (8): 940–8. doi:10.1108/17410401211277165
- Antony, J., D. Setijono, and J. J. Dahlgaard. 2016. "Lean Six Sigma and Innovation – An Exploratory Study among UK Organisations." *Total Quality Management & Business Excellence* 27 (1-2): 124–40. doi:10.1080/14783363.2014.959255
- Arcidiacono, G., N. Costantino, K. Yang, and J. Antony. 2016. "The AMSE Lean Six Sigma Governance Model." *International Journal of Lean Six Sigma* 7 (3): 233–66. doi:10.1108/IJLSS-06-2015-0026
- Assarlind, M., I. Gremyr, and K. Bäckman. 2013. "Multi-Faceted Views on a Lean Six Sigma Application." *International Journal of Quality & Reliability Management* 30 (4): 387–402. doi:10.1108/02656711311308385
- Bhat, S., E. Gijo, and N. Jnanesh. 2014. "Application of Lean Six Sigma Methodology in the Registration Process of a Hospital." *International Journal of Productivity and Performance Management* 63 (5): 613–43. doi:10.1108/IJPPM-11-2013-0191
- Bhat, S., and N. Jnanesh. 2014. "Application of Lean Six Sigma Methodology to Reduce the Cycle Time of Out-Patient Department Service in a Rural Hospital." *International Journal of Healthcare Technology and Management* 14 (3): 222–37. doi:10.1504/IJHTM.2014.064257
- Bhosale, V. A., and V. R. Kant. 2016. "An Integrated ISM Fuzzy MICMAC Approach for Modelling the Supply Chain Knowledge Flow Enablers." *International Journal of Production Research* 54 (24): 7374–99. doi:10.1080/00207543.2016.1189102
- Chang, T.-H., and T.-C. Wang. 2009. "Using the Fuzzy Multi-Criteria Decision Making Approach for Measuring the Possibility of Successful Knowledge Management." *Information Sciences* 179 (4): 355–70. doi:10.1016/j.ins.2008.10.012
- Chen, M., and J. Lyu. 2009. "A Lean Six-Sigma Approach to Touch Panel Quality Improvement." *Production Planning and Control* 20 (5): 445–54. doi:10.1080/09537280902946343
- Clegg, B., M. Pepper, and T. Spedding. 2010. "The Evolution of Lean Six Sigma." *International Journal of Quality & Reliability Management* 27 (2): 138–55.
- Dubey, R., A. Gunasekaran, T. Papadopoulos, S. J. Childe, K. Shihin, and S. F. Wamba. 2017. "Sustainable Supply Chain Management: framework and Further Research Directions." *Journal of Cleaner Production* 142: 1119–30. doi:10.1016/j.jclepro.2016.03.117
- Dubois, D., and H. Prade. 1978. "Operations on Fuzzy Numbers." *International Journal of Systems Science* 9 (6): 613–26. doi:10.1080/00207727808941724
- Duperrin, J., and M. Godet. 1973. "Methode de hierarchisation des elements d'un systeme." *Rapport Economique Du CEA* 1 (2): 49–51.
- Eriksson, N., and N. Eriksson. 2017. "Hospital Management from a High Reliability Organizational Change Perspective: A Swedish Case." *International Journal of Public Sector Management* 30 (1): 67–84. doi:10.1108/IJPSM-12-2015-0221
- Fadly Habidin, N., and S. R. Mohd Yusof. 2013. "Critical Success Factors of Lean Six Sigma for the Malaysian Automotive Industry." *International Journal of Lean Six Sigma* 4 (1): 60–82. doi:10.1108/20401461311310526
- Farris, D., and A. P. Sage. 1975. "On the Use of Interpretive Structural Modeling for Worth Assessment." *Computers & Electrical Engineering* 2 (2–3): 149–74. doi:10.1016/0045-7906(75)90004-X
- Franchetti, M., and P. Barnala. 2013. "Lean Six Sigma at a Material Recovery Facility: A Case Study." *International Journal of Lean Six Sigma* 4 (3): 251–64. doi:10.1108/IJLSS-05-2013-0026
- Furterer, S., and A. K. Elshennawy. 2005. "Implementation of TQM and Lean Six Sigma Tools in Local Government: A Framework and a Case Study." *Total Quality Management & Business Excellence* 16 (10): 1179–91. doi:10.1080/14783360500236379

- Garza-Reyes, J. A., M. Al-Balushi, J. Antony, and V. Kumar. 2016. "A Lean Six Sigma Framework for the Reduction of Ship Loading Commercial Time in the Iron Ore Pelletising Industry." *Production Planning & Control* 27 (13): 1092–111. doi:10.1080/09537287.2016.1185188.
- Geier, J. 2011. "Embedding Lean Six Sigma into Everyday Use Ensures Sustainable Culture Change at Xerox." *Global Business and Organizational Excellence* 30 (6): 17–26. doi:10.1002/joe.20402
- Gnanaraj, S. M., S. Devadasan, R. Muruges, and C. Sreenivasa. 2012. "Sensitisation of SMEs towards the Implementation of Lean Six Sigma – An Initialisation in a Cylinder Frames Manufacturing Indian SME." *Production Planning & Control* 23 (8): 599–608. doi:10.1080/09537287.2011.572091
- Gupta, V., P. Acharya, and M. Patwardhan. 2012. "Monitoring Quality Goals through Lean Six-Sigma Insures Competitiveness." *International Journal of Productivity and Performance Management* 61 (2): 194–203. doi:10.1108/17410401211194680
- Hilton, R. J., and A. Sohal. 2012. "A Conceptual Model for the Successful Deployment of Lean Six Sigma." *International Journal of Quality & Reliability Management* 29 (1): 54–70. doi:10.1108/02656711211190873
- Hughes, D. L., Y. K. Dwivedi, N. P. Rana, and A. C. Simintiras. 2016. "Information Systems Project Failure–Analysis of Causal Links Using Interpretive Structural Modelling." *Production Planning & Control* 27 (16): 1313–33. doi:10.1080/09537287.2016.1217571
- J. Thomas, A., K. Ringwald, S. Parfitt, A. Davies, and E. John. 2014. "An Empirical Analysis of Lean Six Sigma Implementation in SMEs – A Migratory Perspective." *International Journal of Quality & Reliability Management* 31 (8): 888–905. doi:10.1108/IJQRM-04-2013-0070
- Janes, F. 1988. "Interpretive Structural Modelling: A Methodology for Structuring Complex Issues." *Transactions of the Institute of Measurement and Control* 10 (3): 145–54. doi:10.1177/014233128801000306
- Jayaraman, K., T. Leam Kee, and K. Lin Soh. 2012. "The Perceptions and Perspectives of Lean Six Sigma (LSS) Practitioners: An Empirical Study in Malaysia." *The TQM Journal* 24 (5): 433–46. doi:10.1108/17542731211261584
- Jeyaraman, K., and L. Kee Teo. 2010. "A Conceptual Framework for Critical Success Factors of Lean Six Sigma: Implementation on the Performance of Electronic Manufacturing Service Industry." *International Journal of Lean Six Sigma* 1 (3): 191–215. doi:10.1108/20401461011075008
- Jourabchi, S. M., T. Arabian, Z. Leman, and M. Y. B. Ismail. 2014. "Contribution of Lean and Six Sigma to Effective Cost of Quality Management." *International Journal of Productivity and Quality Management* 14 (2): 149–65. doi:10.1504/IJPM.2014.064473
- Kandasamy, W. V., F. Smarandache, and K. Ilanthenral. 2007. *Elementary Fuzzy Matrix Theory and Fuzzy Models for Social Scientists*. Infinite Study.
- Kant, R., and M. Singh. 2009. "Knowledge Management Implementation: Modelling the Variables." *International Journal of Innovation and Learning* 6 (3): 342–61. doi:10.1504/IJIL.2009.023295
- Kleindorfer, P. R., K. Singhal, and L. N. Wassenhove. 2009. "Sustainable Operations Management." *Production and Operations Management* 14 (4): 482–92. doi:10.1111/j.1937-5956.2005.tb00235.x
- Kumar, M., J. Antony, C. N. Madu, D. C. Montgomery, and S. H. Park. 2008. "Common Myths of Six Sigma Demystified." *International Journal of Quality & Reliability Management* 25 (8): 878–95. doi:10.1108/02656710810898658
- Kumar, S., N. Kumar, and A. Haleem. 2015. "Conceptualisation of Sustainable Green Lean Six Sigma: An Empirical Analysis." *International Journal of Business Excellence* 8 (2): 210–50. doi:10.1504/IJBEX.2015.068211
- Kumar, S., S. Luthra, K. Govindan, N. Kumar, and A. Haleem. 2016. "Barriers in Green Lean Six Sigma Product Development Process: An ISM Approach." *Production Planning & Control* 27 (7–8): 604–20. doi:10.1080/09537287.2016.1165307
- Laureani, A., and J. Antony. 2018. "Leadership—a Critical Success Factor for the Effective Implementation of Lean Six Sigma." *Total Quality Management & Business Excellence* 29 (5–6): 502–23. doi:10.1080/14783363.2016.1211480.
- Laureani, A., M. Brady, and J. Antony. 2013. "Applications of Lean Six Sigma in an Irish Hospital." *Leadership in Health Services* 26 (4): 322–37. doi:10.1108/LHS-01-2012-0002
- Lertwattanapongchai, S., and F. William Swierczek. 2014. "Assessing the Change Process of Lean Six Sigma: A Case Analysis." *International Journal of Lean Six Sigma* 5 (4): 423–43. doi:10.1108/IJLSS-07-2013-0040
- Leseure, M., M. Hudson-Smith, C. Delgado, M. Ferreira, and M. Castelo Branco. 2010. "The Implementation of Lean Six Sigma in Financial Services Organizations." *Journal of Manufacturing Technology Management* 21 (4): 512–23.
- Majstorovic, D. V. D., P. Prof. Dr Numan, M. Durakbasa, V. Spasojevic Brkic, and B. Tomic. 2016. "Employees Factors Importance in Lean Six Sigma Concept." *The TQM Journal* 28 (5): 774–85.
- Malone, D. W. 1975. "An Introduction to the Application of Interpretive Structural Modeling." *Proceedings of the IEEE* 63 (3): 397–404. doi:10.1109/PROC.1975.9765
- Manville, G., R. Greatbanks, R. Krishnasamy, and D. W. Parker. 2012. "Critical Success Factors for Lean Six Sigma Programmes: A View from Middle Management." *International Journal of Quality & Reliability Management* 29 (1): 7–20. doi:10.1108/02656711211190846
- Mi Dahlgaard-Park, S., R. Andersson, H. Eriksson, and H. Torstensson. 2006. "Similarities and Differences between TQM, Six Sigma and Lean." *The TQM Magazine* 18 (3): 282–96.
- Mi Dahlgaard-Park, S., and T. Bendell. 2006. "A Review and Comparison of Six Sigma and the Lean Organisations." *The TQM Magazine* 18 (3): 255–62.
- Michael, G., D. Rowlands, and B. Kastle. 2004. *What Is Lean Six Sigma?* New York, NY: McGraw-Hill.
- Näslund, D. 2008. "Lean, Six Sigma and Lean Sigma: Fads or Real Process Improvement Methods?" *Business Process Management Journal* 14 (3): 269–87. doi:10.1108/14637150810876634
- Panahifar, F., P. Byrne, and C. Heavey. 2014. "ISM Analysis of CPFR Implementation Barriers." *International Journal of Production Research* 52 (18): 5255–72. doi:10.1080/00207543.2014.886789
- Piercy, N., and N. Rich. 2009. "Lean Transformation in the Pure Service Environment: The Case of the Call Service Centre." *International Journal of Operations & Production Management* 29 (1): 54–76. doi:10.1108/01443570910925361
- Psychogios, A. G., J. Atanasovski, and L. K. Tsironis. 2012. "Lean Six Sigma in a Service Context: A Multi-Factor Application Approach in the Telecommunications Industry." *International Journal of Quality & Reliability Management* 29 (1): 122–39. doi:10.1108/02656711211190909
- Psychogios, A. G., and L. K. Tsironis. 2012. "Towards an Integrated Framework for Lean Six Sigma Application: Lessons from the Airline Industry." *Total Quality Management & Business Excellence* 23 (3–4): 397–415. doi:10.1080/14783363.2011.637787
- Purohit, J. K., M. Mittal, S. Mittal, and M. K. Sharma. 2016. "Interpretive Structural Modeling-Based Framework for Mass Customisation Enablers: An Indian Footwear Case." *Production Planning & Control* 27 (9): 774–86. doi:10.1080/09537287.2016.1166275
- Ranjan Debata, B., K. Sree, B. Patnaik, and S. Sankar Mahapatra. 2013. "Evaluating Medical Tourism Enablers with Interpretive Structural Modeling." *Benchmarking: An International Journal* 20 (6): 716–43. doi:10.1108/BJJ-10-2011-0079
- Raut, R. D., B. Narkhede, and B. B. Gardas. 2017. "To Identify the Critical Success Factors of Sustainable Supply Chain Management Practices in the Context of Oil and Gas Industries: ISM Approach." *Renewable and Sustainable Energy Reviews* 68: 33–47. doi:10.1016/j.rser.2016.09.067
- Sage, A. 1977. *Interpretive Structural Modeling: Methodology for Large-Scale Systems*, 91–164. New York: McGraw-Hill.
- Salah, S., A. Rahim, and J. A. Carretero. 2010. "The Integration of Six Sigma and Lean Management." *International Journal of Lean Six Sigma* 1 (3): 249–74. doi:10.1108/20401461011075035
- Saraph, J. V., P. G. Benson, and R. G. Schroeder. 1989. "An Instrument for Measuring the Critical Factors of Quality Management." *Decision Sciences* 20 (4): 810–29. doi:10.1111/j.1540-5915.1989.tb01421.x

- Setijono, D., A. Laureani, and J. Antony. 2012. "Critical Success Factors for the Effective Implementation of Lean Sigma: Results from an Empirical Study and Agenda for Future Research." *International Journal of Lean Six Sigma* 3 (4): 274–83.
- Shokri, A., T. Waring, and F. Nabhani. 2016. "Investigating the Readiness of People in Manufacturing SMEs to Embark on Lean Six Sigma Projects: An Empirical Study in the German Manufacturing Sector." *International Journal of Operations and Production Management* 36 (8): 850–78. doi:10.1108/IJOPM-11-2014-0530
- Singh, A. K., and Sushil. 2013. "Modeling Enablers of TQM to Improve Airline Performance." *International Journal of Productivity and Performance Management* 62 (3): 250–75. doi:10.1108/17410401311309177
- Singh, M., R. Shankar, R. Narain, and A. Agarwal. 2003. "An Interpretive Structural Modeling of Knowledge Management in Engineering Industries." *Journal of Advances in Management Research* 1 (1): 28–40. doi:10.1108/97279810380000356
- Snee, R. D. 2008. "W. Edwards Deming's 'Making a New World': A Holistic Approach to Performance Improvement and the Role of Statistics." *The American Statistician* 62 (3): 251–5. doi:10.1198/000313008X335572
- Snee, R. D. 2009a. "Digging the Holistic Approach: Rethinking Business Improvement to Improve the Bottom Line." *Quality Progress* 42 (10): 52–4.
- Snee, R. D. 2009b. "Get Moo-Ving." *Six Sigma Forum Magazine* 8 (3): 30–1.
- Snee, R. D. 2010. "Lean Six Sigma-Getting Better All the Time." *International Journal of Lean Six Sigma* 1 (1): 9–29. doi:10.1108/20401461011033130
- Sony, M., and S. Naik. 2011. "Successful Implementation of Six Sigma in Services: An Exploratory Research in India Inc." *International Journal of Business Excellence* 4 (4): 399–419. doi:10.1504/IJBEX.2011.041059
- Sunder, M. V. 2016. "Rejects Reduction in a Retail Bank Using Lean Six Sigma." *Production Planning & Control* 27 (14): 1131–42.
- Tsironis, L. K., A. Psychogios, and M. Al-Mashari. 2016. "Road towards Lean Six Sigma in Service Industry: A Multi-Factor Integrated Framework." *Business Process Management Journal* 22 (4): 812. doi:10.1108/BPMJ-08-2015-0118
- Venkatesh, V., S. Rathi, and S. Patwa. 2015. "Analysis on Supply Chain Risks in Indian Apparel Retail Chains and Proposal of Risk Prioritization Model Using Interpretive Structural Modeling." *Journal of Retailing and Consumer Services* 26: 153–67. doi:10.1016/j.jretconser.2015.06.001
- Vinodh, S., S. V. Kumar, and K. Vimal. 2014. "Implementing Lean Six Sigma in an Indian Rotary Switches Manufacturing Organisation." *Production Planning & Control* 25 (4): 288–302. doi:10.1080/09537287.2012.684726
- Wang, F.-K., and K.-S. Chen. 2012. "Application of Lean Six Sigma to a Panel Equipment Manufacturer." *Total Quality Management & Business Excellence* 23 (3–4): 417–29. doi:10.1080/14783363.2011.593876
- Warfield, J. N. 1974. "Developing Interconnection Matrices in Structural Modeling." *IEEE Transactions on Systems, Man, and Cybernetics* SMC-4 (1): 81–7. doi:10.1109/TSMC.1974.5408524
- Watson, R. H. 1978. "Interpretive Structural Modeling—a Useful Tool for Technology Assessment?" *Technological Forecasting and Social Change* 11 (2): 165–85. doi:10.1016/0040-1625(78)90028-8
- Zadeh, L. A. 1965. "Fuzzy Sets." *Information and Control* 8 (3): 338–53. doi:10.1016/S0019-9958(65)90241-X