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Application of interpretive structural modelling for analysing the factors influencing integrated lean sustainable system

S. Vinodh[1] · K. Ramesh[1] · C. S. Arun[1]

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Abstract The modern manufacturing systems recognize the importance of adopting lean and sustainable manufacturing principles. Especially, Indian automotive component manufacturing organizations are interested in adopting the integrated lean sustainable manufacturing system. An appropriate methodology is required for enabling the organizations to identify the dominant factors. In this context, this article presents the interpretive structural modelling approach for identifying the mutual relationship among factors influencing the integrated lean sustainable manufacturing system. From the literature study and survey conducted among Indian automotive component manufacturing organizations, 25 influencing factors have been identified. Based on the study, top-management commitment in adopting integrated lean sustainable manufacturing and environmental knowledge occupy the bottom level of model which shows that it has more driving power. Efforts are being taken to implement the factors in the surveyed organizations.

Keywords Lean manufacturing · Sustainable manufacturing · Interpretive structural modelling (ISM) · Automotive component

Introduction

The manufacturing systems witnessed a paradigm shifts over the years from craft manufacturing to mass manufacturing, then lean manufacturing. Lean manufacturing principles are characterized by elimination of waste and value addition, ensuring streamlined processes (Seth and Gupta 2005). Lean manufacturing intend to maximize capacity and re-utilization and minimize buffer inventories through minimization of system variability (Singh et al. 2005).

Sustainable development has become an important issue across the globe because of rapid increase in consumption of natural resources, greenhouse gas emissions, landfill problems, and unhealthy degradation of soil and water (Mittal and Sangwan 2011). The manufacturing sector consumes a significant portion of the energy and resources; thus, government starts to force organizations to adopt practices that are designed in a manner to minimize resource utilisation and maintain environment safety (Yagi and Halada 2001). Lean manufacturing emphasis on reducing seven types of wastes that usually occur in any manufacturing process (as accepted in the Toyota Production System). Lately, underutilization of creativity of employees and environmental waste is considered as eighth and ninth waste respectively (Kuriger and Chen 2010). Environmental waste implies the unnecessary or excessive usage of resources as well as substances released to air, water, or land that could harm human health or environment (Robert 2000). Thus, in this competitive marketplace, now strategies are formulated for profit enhancement and environmental stewardship.

In countries like USA, Environmental Protection Agency (EPA) conducts environmental assessment, research, and education. It has the responsibility of maintaining and enforcing national standards under a variety of environmental laws, in consultation with state, tribal, and local governments. In Germany, The Federal Environment Agency is responsible for protecting the environment and human well-being from adverse environmental hazards. The

✉ S. Vinodh
vinodh_sekar82@yahoo.com

[1] National Institute of Technology, Tiruchirappalli, Tiruchirappalli, Tamil Nadu, India

Agency advises governmental institutions on environmental matters and informs the general public on almost every kind of question concerning environmental protection. Likewise, although Indian government has been spreading awareness and support for sustainable manufacturing, implementation organizations often lack the initiatives, skills, expertise, and finance to bring the required changes within the organization. So it is important to identify the dominant factors that influence implementation of any new strategies. While lean and green manufacturing strategies share similar implementation strategies, they differ only in the standards to which implementation is evaluated (Miller et al. 2010). Implementation of integrated system will provides combined benefits in terms of waste elimination, value enhancement, streamlined process, and minimizing environmental impacts in comparison to conventional manufacturing processes.

For implementing a new integrated system, management must understand the major factors that influence them and their linkages. So a decision making tool is introduced to fully identify and analyse the factor relationships. The technique is known as interpretive structural modelling (ISM). It is a tool that for understanding of complex situations and is very effective for planning exercises (Sarkis et al. 2006). In this article, Mechanics of the tool is applied to understand the possible organizational factors and their relationships that influence the implementation of lean sustainable system. Based on the literature review and experts opinion, 25 variables/factors governing the integrated lean sustainable system have been identified. The novel aspect of the study is that it presents a modelling approach for systematically prioritizing the factors influencing the performance of integrated lean sustainable manufacturing system. A structural model has been developed using ISM approach.

Literature review

The literature has been analysed from the perspectives of factors influencing the implementation of integrated lean sustainable manufacturing systems.

Identification of factors influencing the lean system implementation

Upadhye et al. (2011) developed a systematic relationship among lean manufacturing implementation issues and identified the driving and dependent issues using ISM approach. Cheah et al. (2012) applied ISM to develop hierarchical model for challenges of lean manufacturing implementation. They considered nine factors among which knowledge, training, and project implementation are identified as important factors. Grover et al. (2012) applied ISM approach to model enablers in the implementation of total productive maintenance (TPM). TPM is one of the important tools of lean manufacturing. They selected 10 enablers and prioritized it using ISM approach. They found that 'top management commitment and support' and 'integration of TPM goals and objectives into business plans' are top most enablers and 'cultural change' and 'total employee involvement' as least enablers. Kumar et al. (2013) formed a structural model of variables that is important to implement lean manufacturing system in Indian Automobile Industry using ISM. They identified 18 variables, out of which relative cost benefits has been identified as top level dependent and Top-management commitment as bottom level independent variable.

Identification of factors influencing the sustainable system implementation

Green/sustainable manufacturing is the process of manufacturing products that minimize negative environmental impacts, conserve energy and natural resources. Although sustainable manufacturing is widely regarded as a business strategy, few researchers have concentrated on the validation of its positive link with business performance (Singh et al. 2006; Detty and Yingling 2000). Sarkis et al. (2006) developed ISM model for evaluating environmentally conscious manufacturing (ECM) barriers considering 11 factors. They also identified top-management commitment as important independent factor. Tseng (2010) developed framework for modelling production indicators. 21 factors are proposed as main sustainable product indicators and prioritized them using ISM approach. Vinodh and Joy (2012) have done a study on the sustainable manufacturing practices across industrial sectors and to identify the critical factors for its success implementation and shown the correlation between sustainable manufacturing practices and organizational performance among the industries being surveyed. Govindan et al. (2014) analysed the drivers of sustainable manufacturing. They considered 12 factors among which compliance with regulation is proved essential. Mittal and Sangwan (2014) developed a hierarchy and interrelationship among barriers to ECM adoption. They identified five levels of hierarchies and classified them into three categories-internal barriers, economy barriers and policy barriers using an ISM technique.

Review on integrated lean sustainable research studies

King and Lenox (2001), desired an investigation of 17,499 U.S. plants, found that lean production, in terms of quality improvement and lower inventory, is associated with lower pollutant emissions. Moreover, they showed that the adoption of the ISO 14001 standard is more likely to occur when the ISO 9000 quality management standard has been already implemented. Vinodh et al. (2011) have done a study on exploration of various issues of sustainability using lean initiatives. Also, they presented some of the strategies/techniques that would enable the achievement of sustainability objectives using lean initiatives. Dües et al. (2013) compared the attributes of lean production and green management to identify their similarities and differences. By explaining various literature studies, they highlighted that lean and green practices share a focus on reduction techniques, lead time reduction, people and organization, supply chain relationships, key performance indicators (KPIs), and common tools and practices. Because of these overlapping attributes, they conclude that lean and green practices impart benefits to firm performance. Pampanelli et al. (2014) applied lean and green concepts together in production cell level then presented findings from an application of the model in a major international engineering corporation. Such findings applied in a major international engineering corporation reduced resource usage from 30 to 50 % on average and have the potential to reduce the total cost of mass and energy flows in a cell by 5–10 %. The relationships between lean and environmental aspects are influenced by various factors such as top-management commitment, and that they also vary depending on the Lean principles under consideration. Some implementation schemes have been initiated since 2008, but few frameworks exist. A concrete general outline to simultaneously implement lean and sustainable paradigms is still lacking (Verrier et al. 2013). Vinodh et al. (2015) presented a method for value stream mapping integrated with life-cycle assessment for ensuring sustainable manufacture which provides insights to practitioners to visualize process performance from traditional and environmental perspectives.

By grouping the factors obtained from literature study and from expert's opinion, 25 major factors influencing implementation of integrated system have been identified. The factors were identified from literature review and are validated with opinion from experts with reference to Indian scenario. ISM procedure is applied to develop a general hierarchical relationship of factors and their interrelationship.

The important factors for implementation of integrated lean sustainable system are listed in Table 1.

Solution methodology

The procedure followed is as shown in Fig. 1. It starts with the identification of the variables in the implementation of lean sustainable system in Indian automobile industry, which is followed by the discussion of the ISM methodology to model the identified factors. MICMAC analysis has been carried out subsequently to understand the driving power and dependence of the variables.

In this article, ISM method is used to achieve the objective of prioritizing integrated lean sustainable manufacturing system implementation.

ISM methodology

ISM is a communication tool in which set of independent and dependent variables are structured into a comprehensive model (Singh and Kant 2013). The fundamental concept of ISM is to use experts' practical experience and knowledge to decompose a complicated system into several sub-systems (elements) and construct a multilevel structural model to highlight the dominance factors involves in implementation of a particular system. The model developed depicts the structure of a complex issue or problem in a carefully designed pattern (Raj et al. 2008). Features of the ISM method include (1) incorporating the subjective judgments and the knowledgebase of experts systematically, (2) to provide ample opportunity for revision of judgments, and (3) computational efforts involved are far less for criteria ranging from 10 to 25 numbers as well as used as a handy tool for real-life applications (Thakkar et al. 2005). These features make this method more suitable for this present analysis compared with all other methods.

Some of the important characteristics of ISM include:

1. This methodology is interpretative as it helps to decide whether and how different factors are related.
2. It is a modelling technique as relationships are represented in digraph model.
3. It is also a structural as the structure is developed from complex sets.
4. It facilitates both group and individual learning process.
5. It creates order and direction on relationship among various elements of a system.

Various steps involved in the ISM technique (Kannan et al. 2009) include:

1. Analyse the problem. Identify the various factors relevant to the problem. This can be done by group problem solving technique or a survey. In the present study, various factors involved in the implementation of integrated lean sustainable system in an Indian industry are considered.
2. From the variables identified, contextual relationship among factors is examined.
3. Develop a structural self-interaction matrix (SSIM) of elements. This matrix indicates the pair-wise relationship among factors.

Table 1 Factors used and their description

S. no.	Factors	Description	Research studies
1	Top-management commitment in adopting integrated lean sustainable manufacturing	Top-management commitment implies how senior leaders and management core group guide the organization and assess the organizational performance. Without the support of top management, the desired goal cannot be achieved	Kumar et al. (2013), Grover et al. (2012), Govindan et al. (2014), Sarkis et al. (2006), Teh et al. (2008)
2	Government support to adopt Environmental friendly policies	Legislation and regulation provide guidelines and certain standards that are needed for the proper governance of business enterprises in, turn it also considers the environment in which they operate. Environmental laws and regulations should be strictly followed in order to control pollution	Scupola (2003), Alkhidir and Zailani (2009)
3	Training courses/consultancy/ institutions to train, monitor and mentor the progress specific to each industry	Top management must provide training to develop the employee competencies by updating their skills, knowledge and attitude enable higher productivity and achieve highest standards of quality, to eliminate product defects, equipment failure and accidents, to develop a multi skilled workforce, and to create a sense of pride and belonging among all employees	Bowen et al. (2001), Carter and Dresner (2001), Tseng et al. (2008), Ahuja and Khamba (2008)
4	Acquisition of the cleanest technologies by the company	The organization should be ready to acquire the developing technologies which have less environmental effects	Perron (2005), Tseng et al. (2008), Vinodh et al. (2011), Mukherjee et al. (2015)
5	Effective scheduling to reduce waiting time	Appropriate scheduling methods should be selected and followed in order to eliminate the waiting time throughout the process. Reduction in waiting time increases the uptime and thereby productivity and profit of the organization	Poppendieck (2002), Heizer and Render (2006)
6	Standardization to reduce complexity and excessive processing	Every process involved in the organization should be standardized, so that it avoids confusion and complexity of the process. And also this standardization becomes as a reference for the future	Liker (2004), Vinodh et al. (2011)
7	Efficient use of newer, more efficient technology	As the developing technologies are mostly pollution free and environmentally conscious, efficient technologies should be utilized in the process. Not only on the equipment, but also on other aspects that indirectly contributes to the reduction in wastes and productivity improvement	Edwards (1996), Singh et al. (2014)
8	Control over defects	Whenever defect is identified in a product, the root cause of that problem should be identified, and corrective action should have to be taken which in turn eliminates defective products produced by that machine. Predicted and scheduled maintenance of equipment reduces the occurrence of defect	Lei (2003), Singh et al. (2014)
9	Effective measures to reduce environmental impact (fuel economy and air emissions)	Environmental impacts need to be systematically pertaining to this assessment measures need to be developed and deployed	Rao and Holt (2005), Vinodh (2011), Mukherjee et al. (2015)
10	Internal expertise	There should be experts to effectively implement the integrated lean sustainable system in an organization to rectify the problems	Hemel and Kramer (2002), Hillary (2000), Ofori et al. (2000)

Table 1 continued

S. no.	Factors	Description	Research studies
11	Complexity in design to reduce, reuse, recycle, or reclaim materials, components or energy	Design should be made in consultation with manufacturing department. DFMA concept should be followed. This will enable the repairing and recycling actions on the product	Mathiyazhagan et al. (2013), Mukherjee et al (2015)
12	Product designs that avoid or reduce toxic or hazardous material use	Organizations should consider all parameters during planning for the product and service design processes like understanding fully the customer requirements and service requirements, clarity of the specification, involving all related departments in design reviews and emphasizing the fitness of use	Kannan et al. (2014), Vinodh (2011), Motwani (2001)
13	Appropriate quality of manufacturing facilities	The quality level of manufacturing facilities should be high which in turn enhance the product quality	Vinodh et al. (2011)
14	Effective visual control	The visual control concept aims to increase the efficiency and effectiveness of a process by making the steps in that process more visible to employees working in that area	Pattanaik and Sharma (2009)
15	Effective safety and ergonomics measures	Safety aspects should be clearly defined, and it should be instructed to all employees in the organization. All the process involved should be ergonomically designed so that the employees are free from fatigue	Walder et al. (2007)
16	Collaborative decision making	Brainstorming sessions should be conducted at all levels of organization and decision should be integrated with their suggestions which improve the employee morale and belief over the organization. In turn, it motivates the employees	Ahuja (1996), Govindan et al. (2014)
17	Employee involvement in adopting sustainable manufacturing	Total employee involvement is indeed a pre-requisite for successful lean sustainable implementation and can be ensured by enhancing the competencies of employees towards jobs, evolving the environment of equipment and system ownership by the employees, adequate employee counselling, union buy-in, effective appropriate suggestions schemes and deploying encouraging and safe work environment in the organizations	Perron (2005), Tseng et al. (2008)
18	Proper utilization of floor space	Workplace has to be properly maintained. There should be a place for everything, and everything should be in its place. And unwanted movement of people to be minimized	Singh et al. (2014)
19	Environmental Knowledge	Knowledge about environmental impacts provides a great path way for sustainable system, and it provides a clear knowledge upon designing the whole process of product life cycle	Bhanot et al. (2015), Maniatis (2015), Bowen et al. (2001), Shen and Tam (2002)
20	Compliance with legal environmental requirements and auditing programs	Upon implementing the lean sustainable system, the legal environmental requirements should also be met. Auditing program has to be done periodically which enables continuous improvement of the organization	Kannan et al. (2014)

Table 1 continued

S. no.	Factors	Description	Research studies
21	Proper Value addition	Organization should provide a right value for the customer money. The product should add more value, and it should meet the given requirements	Vinodh and Chintha (2011)
22	Reduction in unnecessary inventory	Appropriate management of inventory is also a key for successful business process. Inventory stock of products should be made according to market demand. So appropriated forecasting has to done	Liker (2004), Singh et al. (2014)
23	High investments and less Return-on Investments	Implementing green concept needs high investment, but return-on-investment is low. But in turn, it has a huge positive impact on the environment	Mathiyazhagan et al. (2013), Singh et al. (2014), Mukherjee et al. (2015)
24	Customer involvement in quality program	Participation of customers in quality evaluation program gives a detailed and clear idea about the product quality. It creates a good relationship too between suppliers and customers of the product	Panizzolo (1998), Tseng et al. (2008)
25	Customer awareness and pressure about sustainable manufacturing	The customer is the key factor for any business. Businesses must design and manufacture products and provide services that meet customers' needs and expectations. Environmental consciousness of consumers is one of the most significant driving forces for companies to engage in environmental management	Chen et al. (2006), Jose (2008), Roarty (1997), Orsato (2006)

4. Develop a Reachability matrix from SSIM matrix and transitivity is checked. Reachability matrix previously obtained is partitioned into different levels.
5. Draw a digraph representing relationship among factors assigned in Reachability matrix.
6. Group various factors using MICMAC analysis.
7. Review the model to check inconsistency and make necessary modifications.

Case study

A survey has been conducted among 25 Indian automotive component manufacturing organization's experts who are presently working with the organization for more than ten years. These experts have key role in implementing lean and sustainable manufacturing strategies in the organizations, and they have shown good interest on implementing lean sustainable system. This survey was done through online, by electronic mail and messages. Based on the expert opinion, the relationship between factors has been identified, and the result of this survey is shown in Table 2. The experts provided their opinion based on complete understanding of the factors and based on the interrelationships. Hence, the inputs are found to have practical validity. The consensus opinion of the experts has been used as inputs. A sample question formulated for collecting expert opinion is

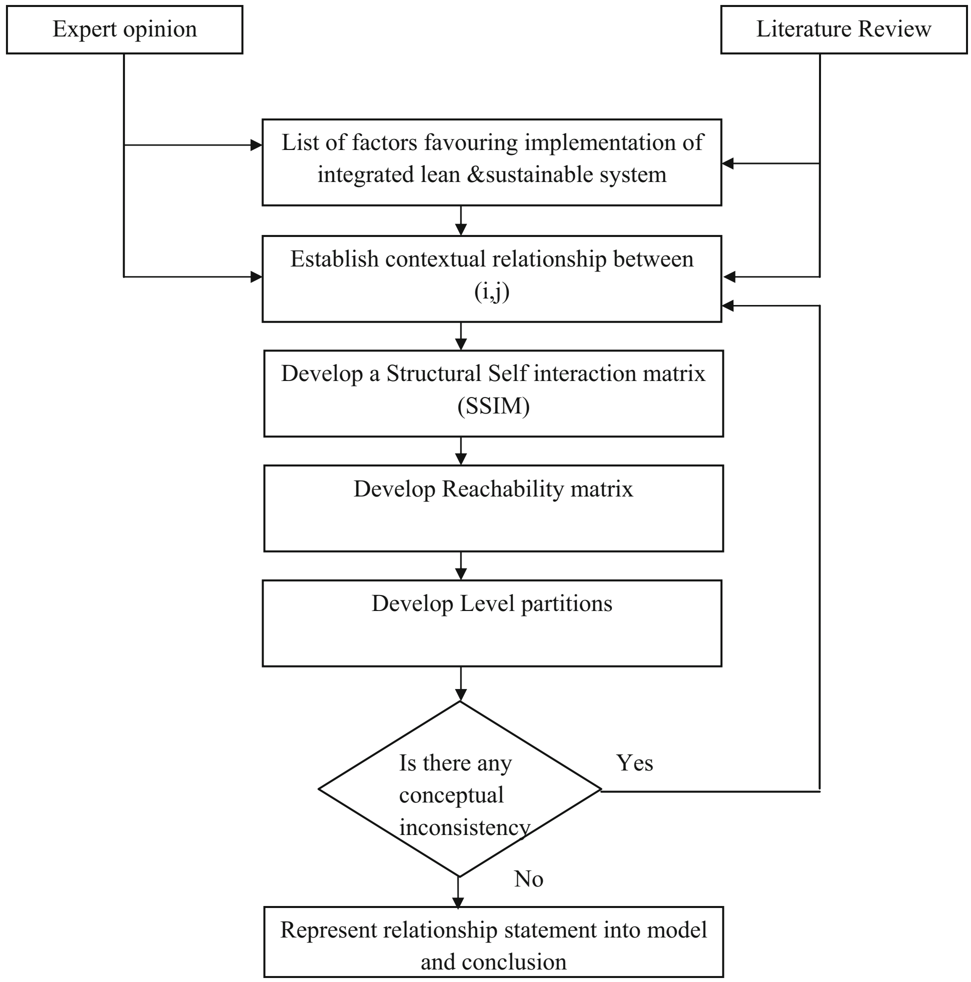
1. What is the relation (V/A/X/O) between Top-management commitment in adopting integrated lean sustainable manufacturing and Customer awareness and pressure about sustainable manufacturing?

Structural self-interaction matrix

Following four symbols have been used to denote the direction of the relationship between two factors (i and j):

V: factor i will help achieve factor j;	A: factor j will help achieve factor i;
X: factors i and j will help achieve each other;	O: factors i and j are unrelated

Fig. 1 Flow diagram for process model of ISM



Based on this contextual relationship, the SSIM has been developed.

Reachability matrix

SSIM is transformed into a Reachability matrix format by transforming the information in each entry of SSIM into 1s and 0s in the Reachability matrix (Talib et al. 2011). The substitution of 1s and 0s are as per the following rules:

1. If (i, j) entry in SSIM is V, then (i, j) entry in the Reachability matrix becomes 1 and the (j, i) entry becomes 0.
2. If (i, j) entry in SSIM is A, then (i, j) entry in the matrix becomes 0 and the (j, i) entry becomes 1.
3. If (i, j) entry in SSIM is X, then (i, j) entry in the matrix becomes 1 and the (j, i) entry also becomes 1.
4. If (i, j) entry in SSIM is O, then (i, j) entry in the matrix becomes 0 and the (j, i) entry also becomes 0.

Value in driving power column of each factor signifies its influence over other factors and value in dependence power row of each factor signifies its influence by other factors.

In the final reachability matrix, 1* is included to enter transitivity and practical variations. Transitivity implies, if A related to B and B related to C, then A must be related to C (Tables 3, 4).

Level partitions

From the reachability matrix, reachability and antecedent sets are developed for each factor. The reachability set consist of factors that it will impact and its factor itself. The antecedent set consists of factors that impact it and is factor itself. The intersection of these set is determined, which represents that both impact each other.

The variables with fewer factors in reachability and intersection sets occupy top level in the ISM hierarchy. The top level factors are those factors which will not lead to other factors. The factors once identified are removed and the same process is repeated for next levels.

These levels are used to build the digraph ISM model.

Table 2 Structural self-interaction matrix (SSIM)

	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	A	V	V	V	V	A	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	X	V	0	
2	X	V	X	X	V	X	A	X	V	V	X	O	V	V	V	A	V	X	V	O	O	V	X		
3	A	O	A	V	V	V	V	V	V	V	V	V	V	V	V	X	X	V	V	X	X	V			
4	A	A	V	V	V	V	A	V	A	A	V	V	V	X	X	A	V	X	V	X	O				
5	O	O	V	V	V	O	O	V	O	A	V	A	A	O	O	O	O	V	V	X					
6	O	A	A	V	V	A	A	V	V	A	V	A	V	V	V	A	X	V	A						
7	A	A	A	V	V	V	A	V	A	A	V	V	V	V	A	A	V	V							
8	A	A	O	V	V	A	A	V	A	A	A	A	V	X	A	O	A								
9	V	V	V	X	V	V	A	O	A	A	X	O	V	V	V	A									
10	V	A	V	V	V	A	A	O	X	A	V	V	V	V	V										
11	V	A	O	V	V	A	A	O	A	A	A	A	X	X											
12	A	A	A	O	X	A	A	O	A	A	X	A	A												
13	A	A	A	V	V	A	A	V	V	A	A	A													
14	X	O	O	V	V	A	X	V	A	A	V														
15	O	A	A	A	V	A	A	A	O	A															
16	A	X	O	V	V	O	X	V	A																
17	A	A	O	V	V	V	A	V																	
18	O	O	V	V	V	A	A																		
19	V	O	V	V	V	V																			
20	A	V	V	X	V																				
21	A	A	A	A																					
22	O	O	O																						
23	A	O																							
24	A																								
25																									

Representation of factors as ISM based model

From level partitions, a structural model known as digraph is developed. After removing the transitivity links and replacing nodes by factor statements, the ISM model is formed.

It is been observed that, 'Top management commitment in adopting integrated lean sustainable manufacturing' has been a very significant factor in the implementation of integrated system. 'Proper value addition' has been noted as the top level factor in the model (Table 5; Fig. 2).

Results and discussions

The results are presented as follows.

MICMAC analysis

The objective of MICMAC is to analyse and group the factors based on its driving and dependence powers. A graph is plotted with driving power along *X*-axis and dependence power along *Y*-axis.

In MICMAC analysis, factors are classified as follows:

1. *Autonomous enablers* These factors have weak driving and weak dependence power. They are represented in Quadrant III. They are relatively disconnected with few links.
2. *Dependent enablers* These factors have weak driving power but strong dependence power. They are represented in Quadrant IV. They are greatly affected by many factors.
3. *Linkage enablers* These factors have strong driving as well as strong dependence power. They are represented in Quadrant I. These variables are very important. Their action affects others and also possesses back effect on themselves.
4. *Driving variables* They have strong driving power but weak dependence power. They are represented in Quadrant II. They have greater driving power over many factors.

From Fig. 3, we can infer that:

There are no factors come under linkage variables. Four factors fall under Autonomous variables. Eight factors under dependant variables and remaining 13 fall under driving variables.

Table 3 Initial reachability matrix

	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Driving power
1	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	22
2	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	0	1	1	1	0	0	1	1	1	0	19
3	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	20
4	0	0	1	1	1	1	0	1	0	0	1	1	1	1	1	0	1	1	1	1	0	1	0	0	1	16
5	0	0	1	1	1	0	0	1	0	0	1	0	0	0	0	0	0	1	1	1	1	0	1	0	0	10
6	0	0	0	1	1	0	0	1	1	0	1	0	1	1	1	0	1	1	0	1	1	1	1	0	0	14
7	0	0	0	1	1	1	0	1	0	0	1	1	1	1	0	0	1	1	1	1	0	0	0	0	0	12
8	0	0	0	1	1	0	0	1	0	0	0	0	1	1	0	0	0	1	0	0	0	1	0	1	0	8
9	1	1	1	1	1	1	0	0	0	0	1	0	1	1	1	0	1	1	0	1	0	0	1	0	0	14
10	1	0	1	1	1	0	0	0	1	0	1	1	1	1	1	1	1	0	1	1	0	1	1	1	0	17
11	1	0	0	1	1	0	0	0	0	0	0	0	1	1	1	0	0	1	1	0	0	1	0	0	0	9
12	0	0	0	0	1	0	0	0	0	0	1	0	0	1	1	0	0	1	0	0	0	1	0	0	0	6
13	0	0	0	1	1	0	0	1	1	0	0	0	1	1	1	0	0	0	0	0	1	0	0	0	0	8
14	1	0	0	1	1	0	1	1	0	0	1	1	1	1	1	0	0	1	0	1	1	0	0	0	0	12
15	0	0	0	0	1	0	0	0	0	0	1	0	1	1	1	0	1	1	0	0	0	0	0	1	0	8
16	0	1	0	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	18
17	0	0	0	1	1	1	0	1	1	1	0	1	0	1	1	1	1	1	1	0	0	1	0	0	0	14
18	0	0	1	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	6
19	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	0	21
20	0	1	1	1	1	1	0	1	0	0	1	1	1	1	1	1	0	1	0	1	0	0	0	1	1	16
21	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2
22	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	5
23	0	0	1	0	1	0	0	0	0	0	1	0	1	1	0	0	0	0	1	1	0	0	1	1	0	9
24	0	1	0	0	1	0	0	0	1	1	1	0	1	1	1	1	0	1	1	1	0	1	0	0	0	13
25	1	1	1	0	1	1	0	0	1	1	0	1	1	1	0	0	0	1	1	0	0	1	1	1	1	16
Dependence	7	7	11	19	25	9	5	15	10	8	19	11	19	22	17	8	13	19	14	14	7	14	9	10	4	

Table 4 Final reachability matrix

	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Driving power
1	1*	1	1	1	1	1*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	24
2	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1*	1	1	1	0	0	1	1	1	0	20
3	1*	0	1*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1*	0	23
4	0	1*	1	1	1	1	0	1	1*	0	1	1	1	1	1	0	1	1	1	1	0	1	0	0	1	18
5	0	0	1	1	1	0	0	1	0	0	1	0	1*	0	0	0	0	1	1	1	1	0	1	0	0	11
6	0	1*	0	1	1	0	0	1	1	0	1	1*	1	1	1	0	1	1	1*	1	1	1	1	0	0	17
7	0	0		1	1	1	0	1	0	0	1	1	1	1	1*	0	1	1	1	1	1*	0	0	0	0	15
8	0	0	0	1	1	0	0	1	0	0	1*	0	1	1	0	0	0	1	0	0	0	1	0	1	0	9
9	1	1	1	1	1	1	0	0	0	0	1	0	1	1	1	0	1	1	1*	1	0	0	1	0	0	15
10	1	1*	1	1	1	1*	0	0	1	0	1	1	1	1	1	1	1	0	1	1	0	1	1	1	0	19
11	1	0	0	1	1	0	0	0	0	0	0	0	1	1	1	0	0	1	1	0	0	1	0	0	0	9
12	0	0	0	0	1	0	0	0	0	0	1	0	0	1	1	0	0	1	0	0	0	1	0	0	0	6
13	0	0	0	1	1	0	0	1	1	0	1*	0	1	1	1	0	0	1*	0	0	1	0	0	0	0	10
14	1	0	0	1	1	0	1	1	0	0	1	1	1	1	1	0	0	1	1*	1	1	0	0	0	0	13
15	0	0	0	1*	1	0	0	1*	0	0	1	0	1	1	1	0	1	1	0	0	0	0	0	1	0	10
16	1*	1	0	1	1	0	1	1	1*	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	20
17	0	1*	0	1	1	1	0	1	1	1	0	1	1*	1	1	1	1	1	1	1*	0	1	0	0	0	17
18	0	0	1	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	6
19	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1*	1	0	22
20	0	1	1	1	1	1	0	1	1*	0	1	1	1	1	1	1	1*	1	1*	1	0	1*	0	1	1	20
21	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2
22	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	5
23	0	0	1	0	1	0	0	1*	0	0	1	0	1	1	0	0	0	0	1	1	0	0	1	1	0	10
24	0	1	0	0	1	0	0	0	1	1	1	0	1	1	1	1	0	1	1	1	0	1	0	0	0	13
25	1	1	1	0	1	1	0	0	1	1	0	1	1	1	1*	0	1*	1	1	0	0	1	1	1	1	18
Dependence	10	11	13	20	25	11	5	17	13	8	21	12	21	22	19	9	15	20	18	15	8	15	10	11	4	

In the above Table, 1* entries are included to incorporate transitivity

Table 5 Level partitions table

Variables	Reachability set	Antecedent set	Intersection	Level
1	1,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25	1,3,25	1,3,25	XVI
2	2,3,4,7,8,9,10,11,12,13,15,16,17,18,20,21, 22,23,24,25	2,3,8,10,15,18,19,20,22,23,25	2,3,8,10,15,18,20,23,25	XIII
3	2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17, 18,19,20,21,22,23,25	1,2,3,5,6,9,10,19,23,25	2,3,5,6,9,10,19,23,25	XIV
4	1,4,6,7,8,9,11,12,13,14,15,17,18,20,21,22,23,24	1,2,3,4,6,8,10,11,12,16,17,19,20,25	1,4,6,8,11, 12,17,20,24	X
5	3,5,6,7,8,13,15,18,21,22,23	1,3,5,6,7,13,14,16,	3,5,6,7,13	VI
6	3,4,5,6,7,8,9,11,12,13,14,15,17,18,21,22,24	1,3,4,5,6,7,9,10,14,16,17,19,20,23,24	3,4,5,6,7,9,14,17,24	IX
7	5,6,7,8,9,11,12,13,14,15,18,20,21,22,23	1,2,3,4,5,6,7,9,10,11,14,15,16,18,20,23,24,25	5,6,7,9,11,14,15,18,20,23	VII
8	2,4,8,12,13,15,18,21,22	1,2,3,4,5,6,7,8,9,11,12,13,14,15,16,17,19,20,24,25	2,4,8,12,13,15	IV
9	3,6,7,8,9,11,12,13,15,20,21,22,23,24,25	1,2,3,4,6,7,9,10,15,16,17,19,20, 22,25	3,6,7,9,15,22,20,25	IX
10	2,3,4,6,7,9,10,11,12,13,,14,15,17,20,21,22,23,24,25	1,2,3,10,16,17,19,20,24	2,3,10,17,20,24	XI
11	4,7,8,11,12,13,21,22,25	1,2,3,4,6,7,9,10,11,12,13,14,15,16,17,19,20,24,25	4,7,11,12,25	V
12	4,8,11,12,15,21	1,2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,19,20,21,23,24,25	4,8,11,12,15,21	III
13	5,8,11,12,13,15,17,18,21,22	1,2,3,4,5,6,7,8,9,10,11,13,14,15,16,17,19,20,23,24,25	5,8,11,13,15,17	IV
14	5,6,7,8,11,12,13,14,15,18,19,21,22,25	1,3,4,6,7,10,14,16,17,19,20,25	6,7,14,19,25	VII
15	2,8,9,11,12,13,15,18,21,22	1,2,3,4,5,6,7,8,9,10,12,13,14,15,16,18,19,20,22,23,24	2,8,9,12,13,15,18,22	IV
16	4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,21,22,24,25	1,2,3,16,17,19,24,25	16,17,19,24,25	XII
17	4,6,7,8,9,10,11,12,13,14,16,17,18,20,21,22,24	1,2,3,4,6,10,13,16,17,19,20,24,25	4,6,10,13,16,17,20,24	IX
18	2,15,18,21,22,23	1,2,3,4,5,6,7,8,13,14,15,16,17,18,19,20,23	2,15,18,23	III
19	2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,25	1,3,14,16,19	3,14,16,19	XV
20	1,2,4,6,7,8,9,10,11,12,13,14,15,17,18,20,21,22,23,24	1,2,3,4,7,9,10,17,20,25	1,2,4,7,9,10,17,20	X
21	12,20	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	12,20	I
22	2,9,15,21,22	1,2,3,4,5,6,7,8,9,10,11,13,14,15 16,17,18,19,20,22	2,9,15,22	II
23	2,3,6,7,12,13,15,18,21,23	1,2,3,4,5,7,9,10,18,19,20,23,25	2,3,6,7,18,23	V
24	4,6,7,8,10,11,12,13,15,16,17,21,24	1,2,4,6,9,10,16,17,20,24,25	4,6,10,16,17,24	VIII
25	1,2,3,4,7,8,9,11,12,13,14,16,17,20,21,23,24,25	1,2,3,9,10,11,14,16,19,25	1,2,3,9,11,14,16,25	X

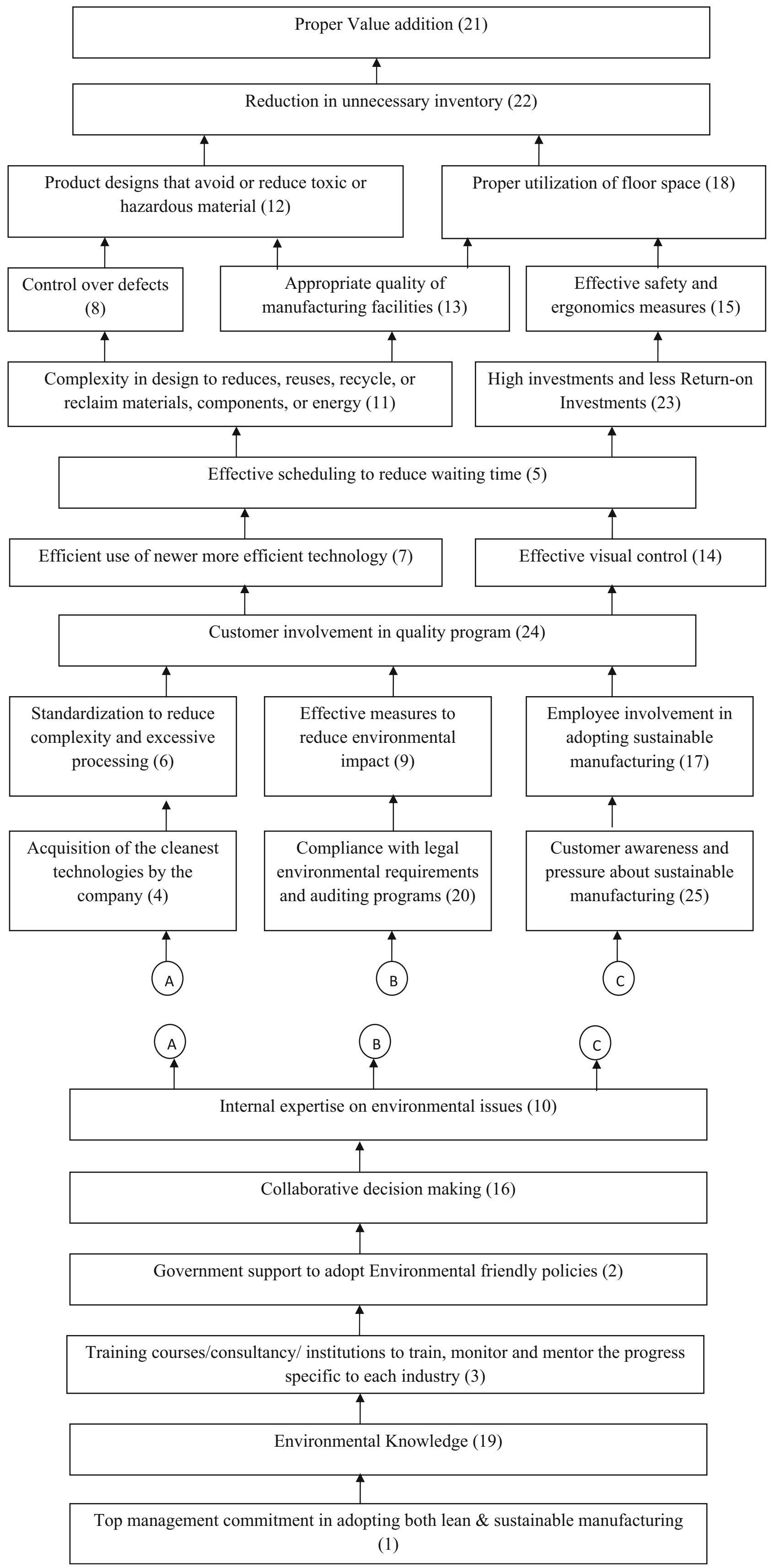


Fig. 2 ISM model for the implementation of integrated lean sustainable manufacturing system

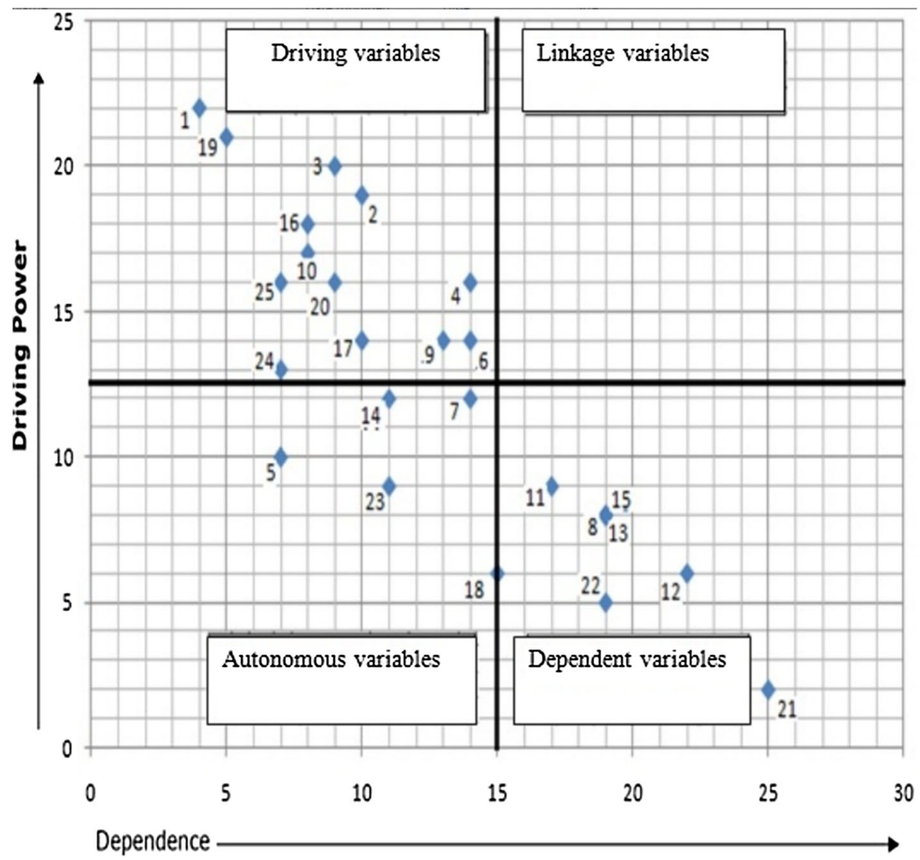


Fig. 3 Results of MICMAC analysis

Table 6 Comparison of results of present study with prior studies

Research studies	Focus of study	Dominant factors	Methodology
Present study	Lean sustainability	Top-management commitment in adopting both lean and sustainable manufacturing	ISM
Sarkis et al. (2006)	Barriers of environmentally conscious manufacturing (ECM)	Inappropriate evaluation and appraisal approaches	ISM
Kumar et al. (2013)	Lean implementation	Top-management commitment	ISM

Practical implications

By diagnosing the dominant factors for the adoption of lean sustainable system, the fear of implementing lean sustainable in manufacturing industries can be eliminated. This also leads to the manufacture of eco-friendly products in the industries, and their ability to sustain in the market is increased. While implementing the lean sustainable system, factors in the lower level have to be concentrated more and implemented first. As it drives all the other factors, then it will be easy to implement all other factors. Result shows that organization must have top-management support, commitment and involvement to undergo any cultural change. Both top management and employees must develop suitable knowledge on environmental issues. Environmental knowledge provides the key insight to all members of the organization and creates the awareness and importance of implementing the lean sustainable system. Training and consultancy must be provided for employees to enhance their knowledge and their commitment. Training provides continuous learning and thereby continuous improvement in the individual performance. Proper government support should be obtained before implementing this system; because government will provide certain rules and regulations that have to strictly compile which protects the environment considerably from release of toxic gases, wastes like environmental pollutants. Proper decision making is the next factor to be considered. An appropriate action needs to be taken by considering all the factors. A right decision at the right time using the right people will always bring great success to the organization. Organization should have internal expertise to take an immediate action against the crisis rising over time by time. Acquisition of cleanest technology, customer awareness and pressure, and compliance with legal requirements are the other important independent and bottom level factors. Action over these factors can create significance benefits to the organization. Proper value addition, reduction in unnecessary inventory, product design that avoid or reduce toxic or hazardous material and proper utilization of floor space are at the top level of the ISM model, and it has less impact on the lean sustainable system compared with all other factors. It shows that the organizations feel these factors have less impact and easy to eradicate. All other factors have average driving power as well as dependence power.

Managerial implications

The conduct of the study enabled the managers to systematically develop the model for integrated lean sustainable system. The categorization of factors enabled the identification of dominant factors. The practicing managers felt that the modelling approach would help them to implement the integrated lean sustainable system in an effective manner. The developed model act as a logical approach through which factors and their interrelationships are captured which would enable them to prioritize and allocate the resources in an effective way (Table 6).

Conclusions and future research

Increasingly, many organizations are beginning to recognize the importance of becoming green in the era of environmental responsibility. Unlike lean manufacturing, which focuses on ways to improve productivity and minimize waste from customer's perspective, Green initiatives look at ways to eliminate waste from the environment perspective (Verrier et al. 2013). Bringing lean and sustainable system together can benefit not only to manufacturers and customers, but the environment as well. With today's competitive market, scarcity of raw materials, high price of transportation, global warming and high competition and integration of lean and green manufacturing can provide competitive advantage and profitability that many organizations are aiming for.

Automotive component manufacturing organizations contribute significantly to gross domestic product (GDP) of India. Such organization recognizes the potential of applying integrated lean sustainable manufacturing system. A survey was conducted among experts who are working in this area and based on literature review 25 factors which influence the implementation of lean sustainable system were identified. Based on the inputs, a structural self-interaction matrix (SSIM) was formed, and factors are iterated into 16 levels, and MICMAC analysis was used to classify the factors into driving, dependent, autonomous, linkage factors. 13 factors have been identified as driving, 4 factors as autonomous and 8 factors as dependent variables. Understanding these factors and their relationships, through a logical structure, will help managers to better prioritize and target their resources in a more effective way. This prioritization helps management to make appropriate decision. The outcome of this study is communicated to the experts who are involved in this process and they found the results to be useful for further implementation in the organization.

The research and managerial implications provide numerous directions for further research and pursuit in this research stream. Additional factors could be considered to improve the effectiveness of the study. Simulation and system dynamics modelling may also be used to identify how these factors will influence various organizational performance results.

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