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Modeling the lean barriers for successful lean implementation: TISM approach

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Abstract

Purpose – Companies have been implementing lean manufacturing to improve their business performances. However, many of them have difficulties in the implementation because of various barriers, thus encountering failures. This paper aims to prioritize and analyze the lean barriers for better understanding and interpretation for successful lean implementation.

Design/methodology/approach – Extensive literature review has been carried out to identify the lean barriers. Subsequently, total interpretive structural modeling (TISM) has been adopted where lean experts' inputs have been sought to obtain the self-interaction and reachability matrix. Further, driving power and dependence of lean barriers have been derived, and TISM-based lean barrier model has been developed.

Findings – Insufficient management time, insufficient supervisory skills and insufficient senior management skills are the significant barriers with highest driving power and lowest dependence. With low driving power, cost- and funding-related barriers such as cost of the investment, internal funding and external funding are found to be less important barriers.

Practical implications – This model provides a more realistic approach to the problems faced by practitioners during lean implementation. Thus, it provides a roadmap to implement lean by focusing on reducing or eliminating important barriers.

Originality/value – The paper not only provides a TISM-based model of contextual relationships among lean barriers but also describes the validation of this model.

Keywords Lean manufacturing, Triangulation, Lean barriers, Interpretive structural modeling (ISM), Total interpretive structural modeling (TISM)

Paper type Research paper

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1. Introduction

The philosophy of manufacturing pioneered by Toyota was termed as *lean manufacturing* by James Womack and Daniel Jones (1991) in the book *The machine that changed the world* (Ramesh and Kodali, 2012). Lean manufacturing facilitates the production of artifacts in medium-to-large volume and a medium-to-large variety and hence enables to meet the requirements of a broad customer base. The basic concept of lean is to eliminate waste by addressing the material and information flow issues in a production system and makes it more efficient and competitive. Commonly referred wastes include overproduction, inventory, waiting, over-processing, transportation, motion and defects (Ramesh and Kodali, 2012; Hadid and Mansouri, 2014; Chaple and Narkhede, 2017). Lean manufacturing has been also viewed as a counter-intuitive alternative to the traditional and mass manufacturing models (Lewis, 2000). This is because the approach is able to create a better trade-off between two competitive priorities, namely, flexibility and cost. Benefits associated with lean manufacturing include reductions in lot sizes, lower inventories, improved quality, reduced waste, reduced rework, improved motivation, greater process yields, increased productivity, increased flexibility, reduced space requirements, lower overheads, decreased manufacturing costs, reduced lead-times, elimination of certain trade-offs (example cost versus quality) and increased problem-solving capabilities (Jayaram *et al.*, 2008).

In spite of all potential benefits of lean manufacturing, a very low lean implementation success rate has been recognized by the researchers (Yadav *et al.*, 2010; Bhasin, 2012; Kumar and Kumar, 2014). This is mainly because of various barriers, which are obstructing the successful implementation of lean manufacturing. It has been reported that at least 50 per cent of business improvement programs fail in longer run and up to 70 per cent fails to achieve their intended benefits (Found *et al.*, 2008). Similarly, less than 10 per cent of UK organizations have accomplished a successful lean implementation (Bhasin, 2012; Sim and Rogers, 2009). It is well known that principles, practices and tools form the backbone of lean manufacturing. However, mere implementation of tools, without establishing an integrative system (that acts as a precursor to lean implementation) is not sufficient (Yadav *et al.*, 2010). For example, 70 per cent of all manufacturing plants in the USA used some form of lean production project, but only one in four of them were satisfied with the outcome (Netland, 2015). Similarly, Yadav *et al.* (2010) reported that many automotive companies attempted to implement some or the other lean principles (like JIT, Kanban, Production leveling, team building, quality circle, etc.) independently; however, the approach did not bring them the kind of success these companies were expecting. Though lean has been principally accepted for sustainable growth by learning from the Toyota growth story, the available literature clearly highlights very less rate of successful lean implementation. Sharma *et al.* (2014) and Abolhassani *et al.* (2016) pointed out that an improper understanding or ignorance of lean barriers is a major reason for the implementation failures. As lean implementation requires systematic and continual efforts (Nordin *et al.*, 2010), it is deemed important to understand the barriers and their importance in implementation for a smooth transition (Kumar, 2014; Bhamu and Sangwan, 2014). The question therefore is, which are those all lean barriers reported in the literature and how they affect lean implementation. This research has been focused on addressing these issues.

The paper is organized as follows. An in-depth literature review has been carried out to identify the barriers in implementing the lean manufacturing and are summarized in the tabular format. In Section 3, total interpretive structural modeling (TISM) adopted in the work has been discussed by giving details of selection and prioritization of key lean barriers. Managerial implication of the systematic methodology developed in this work has been presented in Section 4. Finally, Section 5 concludes our findings.

2. Literature review

A large body of literature is available that presents various barriers in lean implementation. Sim and Rogers (2009) have explored the barriers while implementing lean production system. Similarly, Jadhav *et al.* (2014a) have identified 24 lean barriers, and Kumar (2014) has identified 20 lean barriers. Further, Kumar and Kumar (2014) have bundled 25 lean barriers in seven major areas. In addition, interpretive structural modeling (ISM) has been reported to analyze lean barriers specific to machine tool sector in India (Sharma *et al.*, 2014). The limitation of preceding study lies in the identification of less number of lean barriers (14) pertaining to machine tool sector, and author emphasized on the possibility of generalization. In-depth literature review helped us to identify 44 lean barriers. Researchers have classified them into ten different areas, namely, knowledge, conflict, management, resource, technology, employee, financial situation, customer, culture and past experience. Summary of these barriers has been presented in Table I. The frequency of each lean barrier that has been studied by the researches is different. For example, lean barriers, insufficient management time and employee attitude or resistance to change have been frequently referred in the literature, while lack of methodology or unwillingness to learn and lack of labor resources have been least referred. Literature suggests a large number of lean barriers; however, no study has been reported in selecting and prioritizing the lean barriers that are generic but not industry-specific.

This work presents TISM for prioritizing and analyzing the most generic lean barriers for their better understanding and interpretation for successful lean implementation. The TISM methodology is discussed next.

3. Methodology

The purpose of this research is to examine the relationships among key lean barriers and to understand interpretation between them. In this work, TISM has been used to examine the contextual relationships among lean barriers. TISM is the extension of ISM. TISM is a process that transforms unclear and poorly articulated mental models of systems into visible and well-defined models useful for many purposes (Prasad and Suri, 2011).

ISM, developed by Warfield (1974) and Sage (1977), is an adaptation of paired-comparison approach (Haleem *et al.*, 2012). ISM is a method for developing a hierarchy of system variables to represent, graphically, the system structure (Ramesh *et al.*, 2010). It is an interactive learning process in which a set of different and directly related elements is structured into a comprehensive systematic model (Ramesh *et al.*, 2010; Pandey and Garg, 2009; Haleem *et al.*, 2012). ISM helps to impose order and direction on the complex relationships among elements of a system (Thakkar *et al.*, 2007; Thakkar *et al.*, 2008; Pandey and Garg, 2009). An additional advantage of ISM is its ability of capturing dynamic complexity (Thakkar *et al.*, 2007). ISM is interpretive in the sense that judgments of the groups decide whether the variables are related and if yes, how they are related (Haleem *et al.*, 2012; Soti *et al.*, 2010).

ISM is very powerful methodology, and a number of applications of it can be found in the literature. It has been demonstrated in the application of vendor selection (Mandal and Deshmukh, 1994), third-party reverse logistics provider (Govindan et al, 2012), strategic decision-making (Bolaños *et al.*, 2005), analyzing success factors of world-class manufacturing practices (Haleem *et al.*, 2012), analyzing barriers for knowledge management (Singh and Kant, 2007), success factors for Indian R&D organizations (Jyoti *et al.*, 2010) and supply chain collaboration (Ramesh *et al.*, 2010). However, ISM remains quiet on interpreting relationships of the links, when it comes to the question "how" (Sushil, 2012; Singh and Sushil, 2013). Further to this, Sushil (2012) emphasized the need to

Areas	Lean barriers	Sohal and Egglestone (1994)	Beatty (2006)	Staudacher and Tantardini (2007)	Wong *et al.* (2009)	Nordin *et al.* (2010)	Singh *et al.* (2010)	Mirzaei (2011)	Bhasin (2012)	Cheah *et al.* (2012)	Jadhav *et al.* (2014a)	Kumar (2014)	Kumar and Kumar (2014)	Sharma *et al.* (2014)	Marchwinski (2015)
Knowledge	Lack of training							✓		✓	✓	✓	✓	✓	
	Insufficient understanding of the potential benefits				✓	✓			✓			✓		✓	
	Lack of implementation know-how		✓		✓								✓		✓
	Lack of understanding about lean			✓		✓		✓					✓		
	Insufficient supervisory skills to implement lean								✓						
	Insufficient senior management skills to implement lean								✓						
	Insufficient workforce skills to implement lean								✓						
	Lack of methodology											✓			
	Unwillingness to learn and see											✓			
Conflicts	Conflicts with other initiatives		✓								✓		✓	✓	
	Uncertainties in demand									✓	✓		✓	✓	
	Consultants' apathy							✓			✓		✓	✓	
	Frequent changes in design						✓					✓		✓	
	Lack of cooperation from suppliers						✓				✓			✓	
	Disparate manufacturing environments												✓	✓	
	Flavor of mouth" view		✓												✓
Resource	Insufficient investment cost			✓		✓			✓		✓		✓		✓
	Insufficient internal funding				✓		✓	✓	✓					✓	
	Lack of communication									✓	✓		✓		
	Lack of time				✓								✓		
	Insufficient external funding								✓						
	Lack of labor resources												✓		
	Lack of idea innovation												✓		

(*continued*)

Table I.
Lean barriers and their appearance in literature

Areas	Lean barriers	Sohal and Egglestone (1994)	Beatty (2006)	Staudacher and Tantardini (2007)	Wong *et al.* (2009)	Nordin *et al.* (2010)	Singh *et al.* (2010)	Mirzaei (2011)	Bhasin (2012)	Cheah *et al.* (2012)	Jadhav *et al.* (2014a)	Kumar (2014)	Kumar and Kumar (2014)	Sharma *et al.* (2014)	Marchwinski (2015)
Management	Insufficient management time		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	
	Lack of long term vision									✓			✓		
	Lack of strategic perspective										✓	✓			
	Lack of contingency											✓			
	Lack of organizational structure											✓			
	Pressure from top management									✓					
Technology	Lack of technological infrastructure											✓			
	High cost of advanced technology											✓			
	Technological advancements											✓			
	Requirement of alteration in process methodology											✓			
Employee	Employee attitude/resistance to change	✓	✓		✓	✓		✓	✓		✓	✓	✓	✓	✓
	Human aspects											✓			
	Non-lean behavior									✓					
	Lack of empowerment of employees										✓				
Financial situation	Financial benefits not recognized			✓									✓		✓
	No direct financial advantage												✓		
Culture	Cultural issues				✓			✓	✓		✓		✓		
	Social factor											✓			
Customer	Widening customer requirements									✓		✓			
	Pressure from customer									✓					
Past experience	Backsliding/lack of perseverance		✓		✓						✓			✓	✓

Table I.

interpret links in terms of clarifying the way in which the directed relationship is conceptualized or defined by the experts. TISM is, indeed, a technique in enhancing the interpretiveness in the structural modeling, thereby making the logic of the model much more transparent, rather than leaving it open to multiple interpretations by different users (Sushil, 2012; Singh and Sushil, 2013). TISM has been successfully used in the airline sector (Singh and Sushil, 2013), green procurement (Bag, 2016) and education sector (Prasad and Suri, 2011). TISM is the extension of ISM along with interpretations, and considering its advantages over ISM, this study has adopted TISM to model the lean barriers.

Overall methodology adopted for this research is shown in Figure 1. Initially, 44 lean barriers have been identified through the extensive literature review, and then based on the experts' opinion, the key 10 barriers have been selected for this study. In the second stage, contextual relationship between the lean barriers has been developed, which is then converted to a binary number to develop initial reachability matrix. In this matrix, the number "0" represents no relationship, while "1" represents the relationship between two barriers. The matrix is then subjected to transitivity check. In the presence of transitivity

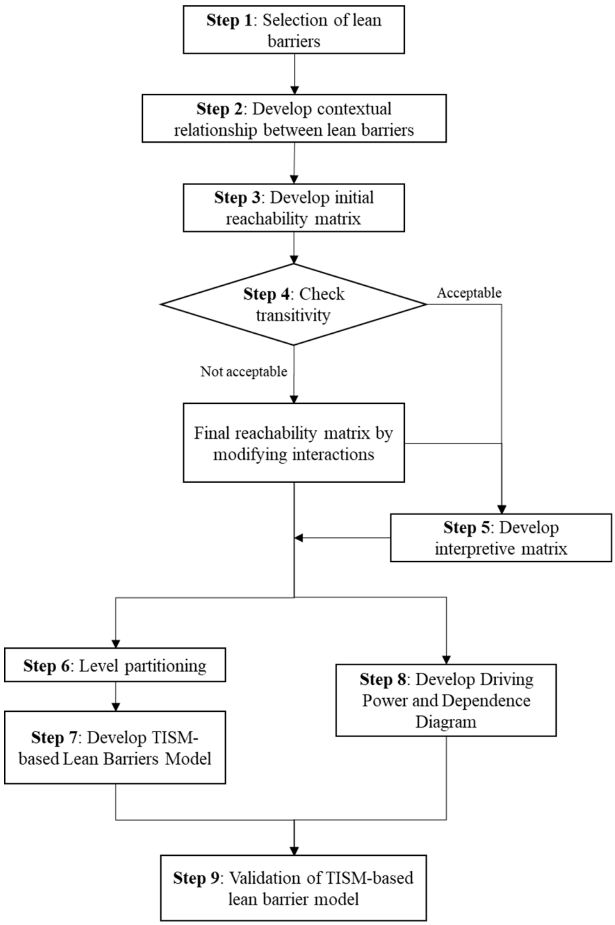

Figure 1.
Modeling lean barriers based on TISM

with any other barriers, the earlier relationships between lean barriers are modified. When all such links are modified, the final reachability matrix is developed. Subsequently, an interpretive matrix has been developed where relationships in the contextual matrix is interpreted based on the experts' opinion. The interpretive matrix helps in knowledge management for understanding the managerial implications. In subsequent iterations, levels of lean barriers have been obtained based on the partitioning. The steps involved in developing TISM model are described next.

3.1 Selection of lean barriers

A large number of lean barriers has been discussed in the literature, and it is difficult to investigate all these barriers in one study. Hence, to select the most important lean barriers to be investigated, we have used a dual approach of literature and experts' opinions.

To identify the key lean barriers, we have used opinions of five lean experts from Indian manufacturing companies. Each expert chosen had more than 15 years of experiences in the manufacturing domain, with minimum 5 years of experiences in consulting diverse lean implementation projects. Initially, ten key lean barriers were identified based on the frequency of the barriers that have been investigated by the researchers and reported in the literature. These barriers were then further subjected to experts' opinion. A group discussion technique was used to obtain the experts' opinions on importance of these ten lean barriers in successful lean implementation. Initially, a quick consensus was reached; six barriers were listed. These are insufficient investment cost, insufficient internal funding, insufficient management time, employee attitudes or resistance to change, cultural issues and insufficient understanding of the potential benefits. Remaining four lean barriers were further deliberated to understand their importance in successful lean implementation. Experts believed that these are also important and can also influence the lean implementation and therefore suggested to include them in the study. These are insufficient workforce skills, insufficient supervisory skills, insufficient senior management skills and insufficient external funding. Following representation has been used throughout the paper for these ten lean barriers (Table II).

3.2 Structural self-interaction matrix

The objective of this step is to identify and represent the contextual relationship between the lean barriers. ISM methodology suggests the use of experts' opinions based on various management techniques such as brainstorming and nominal techniques in developing the contextual relationship among variables (Govindan *et al.*, 2012). Thus, for identifying the contextual relationship among the lean barriers, same experts (as mentioned in Section 3.1)

Representation	Lean barrier
B1	Insufficient investment cost
B2	Insufficient internal funding
B3	Insufficient supervisory skills
B4	Insufficient management time
B5	Employee attitudes or resistance to change
B6	Insufficient external funding
B7	Insufficient senior management skills
B8	Insufficient workforce skills
B9	Cultural issues
B10	Insufficient understanding of the potential benefits

Table II.
Representation of selected lean barriers

were consulted for the above work. For expressing the relationship and direction of it between the lean barriers, four symbols (V, A, X and O) have been used to denote the relationship between the two lean barriers. The structured self-interaction matrix (SSIM) thus developed is shown in Table III. The symbols *V* and *A* indicate that a relationship is unidirectional or a one-way relation between lean barriers. In another word, *V* indicates that first lean barrier is leading to the second lean barrier. But, the second lean barrier is not leading to the first lean barrier. For example, "insufficient supervisory skills" (B3) leads to an "insufficient understanding of potential benefits" (B10); hence, B3 → B10 is represented by *V*. Similarly, *A* indicates that second lean barrier is leading to the first lean barrier; thus, it is reverse of *V*. For example, "insufficient internal funding" (B2) is a result of "insufficient understanding of potential benefits" (B10); hence, B2 ← B10 is represented by *A*. The symbol *X* indicates that a relationship is two-directional. That is, *X* indicates that first lean barrier is leading to the second lean barrier, and at the same time the second lean barrier is also leading to the first lean barrier. For example, "employee attitudes or resistance to change" (B5) and "insufficient workforce skills" (B8) are leading to each other; hence, B5 ↔ B8 is represented by *X*. The symbol *O* indicates the absence of a relationship between the barriers. For example, "insufficient workforce skills" (B8) and "cultural issues" (B9) are not related; hence, B8-B9 is represented by *O*.

3.3 Initial reachability matrix

In this step, SSIM is converted into an initial reachability matrix, which is a binary matrix. For this, *V*, *A*, *X* and *O* are replaced either by 1 or 0 based on the relationship. The cell value 1 indicates that a relationship exists between two lean barriers, and the cell value 0 indicates that no relationship exists. Thus, the cell value 0 indicates that the lean barrier does not lead to another lean barrier, while the cell value 1 indicates that the lean barrier leads to another lean barrier. The initial reachability matrix formed while carrying out this result is shown in Table IV. The substitution rule was followed while forming this initial reachability matrix.

The first case represents the unidirectional relationships, where the entry in the SSIM is indicated by *V*. For example, "insufficient supervisory skills" (B3) leads to achieve an "insufficient understanding of potential benefits" (B10). Thus, B3-B10 entry in the reachability matrix becomes 1 and the B10-B3 entry becomes 0. Similar approach is used for *A* symbol, which is opposite in relationship to *V*. For example, "insufficient internal funding" (B2) is a result of "insufficient understanding of potential benefits" (B10). Thus, B2-B10 entry in the reachability matrix becomes 0 and the B10-B2 entry becomes 1.

The second case represents the two-way relationship, which is denoted as *X* in the SSIM. For example, "employee attitudes/resistance to change" (B5) and "insufficient workforce

No.	Lean barriers	B10	B9	B8	B7	B6	B5	B4	B3	B2
B1	Insufficient investment cost	*O*	*O*	*O*	*A*	*A*	*O*	*O*	*A*	*A*
B2	Insufficient internal funding	*A*	*O*	*O*	*O*	*A*	*O*	*O*	*O*	–
B3	Insufficient supervisory skills	*V*	*O*	*V*	*A*	*O*	*V*	*O*	–	
B4	Insufficient management time	*O*	*V*	*O*	*V*	*O*	*V*	–		
B5	Employee attitudes/resistance to change	*V*	*V*	*X*	*A*	*O*	–			
B6	Insufficient external funding	*O*	*O*	*O*	*O*	–				
B7	Insufficient senior management skills	*V*	*V*	*V*	–					
B8	Insufficient workforce skills	*V*	*O*	–						
B9	Cultural issues	*V*	–							
B10	Insufficient understanding of the potential benefits	–								

Table III.
SSIM

skills" (B8) are the barriers leading to each other. Thus, both the entries B5-B8 and B8-B5 in the reachability matrix become 1.

The third case represents the absence of a relationship between both the barriers, and it is denoted by *O* in the SSIM. For example, "insufficient workforce skills" (B8) and "cultural issues" (B9) are the unrelated barriers. Thus, both the entries B8-B9 and B9-B8 in the reachability matrix become 0.

3.4 Transitivity check

The initial reachability matrix is subjected to transitivity check. That is, the interpretations of relationships developed in the initial reachability matrix are checked to determine if all relations are correctly assessed. For example, if barrier Bi leads to barrier Bj (Bi → Bj) and barrier Bj leads to barrier Bk (Bj→Bk), then barrier Bi must lead to barrier Bk (Bi → Bk) (i, j, k = 1, 2, 3 … 0.10). The process of bridging these gaps is known as transitivity check (Thakkar *et al.*, 2008). Transitivity of the contextual relation is a basic assumption in ISM (Singh and Sushil, 2013), and it is very critical to remove the same. In initial reachability matrix, B3-B10 is 1 and B10-B2 is 1; hence, B3-B2 must be 1. However, initial reachability matrix shows that B3-B2 is 0. All such gaps present in the initial reachability matrix has been examined and modified to obtain the final reachability matrix, shown in Table V.

Table IV. Initial reachability matrix

No.	Lean barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	Insufficient investment cost	1	0	0	0	0	0	0	0	0	0
B2	Insufficient internal funding	1	1	0	0	0	0	0	0	0	0
B3	Insufficient supervisory skills	1	0	1	0	1	0	0	1	0	1
B4	Insufficient management time	0	0	0	1	1	0	1	0	1	0
B5	Employee attitudes/resistance to change	0	0	0	0	1	0	0	1	1	1
B6	Insufficient external funding	1	1	0	0	0	1	0	0	0	0
B7	Insufficient senior management skills	1	0	1	0	1	0	1	1	1	1
B8	Insufficient workforce skills	0	0	0	0	1	0	0	1	0	1
B9	Cultural issues	0	0	0	0	0	0	0	0	1	1
B10	Insufficient understanding of the potential benefits	0	1	0	0	0	0	0	0	0	1

Table V. Final reachability matrix

No.	Lean barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	Driving power
B1	Insufficient investment cost	1	0	0	0	0	0	0	0	0	0	1
B2	Insufficient internal funding	1	1	0	0	0	0	0	0	0	0	2
B3	Insufficient supervisory skills	1	1*	1	0	1	0	0	1	1*	1	7
B4	Insufficient management time	1*	0	1*	1	1	0	1	1*	1	1*	8
B5	Employee attitudes/resistance to change	0	1*	0	0	1	0	0	1	1	1	5
B6	Insufficient external funding	1	1	0	0	0	1	0	0	0	0	3
B7	Insufficient senior management skills	1	1*	1	0	1	0	1	1	1	1	8
B8	Insufficient workforce skills	0	1*	0	0	1	0	0	1	1*	1	5
B9	Cultural issues	0	1*	0	0	0	0	0	0	1	1	3
B10	Insufficient understanding of the potential benefits	1*	1	0	0	0	0	0	0	0	1	3
	Dependence power	7	8	3	1	5	1	2	5	6	7	

Note: Numbers marked with * represent transitivity

3.5 Interpretive matrix

The value 1 represented in the final reachability matrix indicates the presence of a relationship between two lean barriers and hence must be interpreted. For this, experts' opinions have been sought to interpret the relationship, and based on the opinion, an interpretive matrix has been developed, where the value 1 in Table V has been replaced with the corresponding relationship interpreted. The interpretive matrix thus formed is shown in Table VI. For example, the value 1 between insufficient management time and cultural issue in the final reachability matrix indicates that "insufficient management time leads to the cultural issues" (in the interpretive matrix). The interpretive matrix provides new knowledge and helps practitioners better understand how lean barriers affect each other. Thus, this interpretative matrix can support practitioners with managerial decision-making on lean implementation.

3.6 Level partitioning

As suggested by Warfield (1974), the reachability and antecedent sets for each barrier are found out from the final reachability matrix. The reachability set consists of the barrier itself and other barriers, which it may help achieve. The antecedent set consists of the barrier itself and other barriers, which may help in achieving them. Then, the intersection set is derived for each barrier. The barriers for which the intersection set and the reachability set are found to be the same will be given the top-level barrier in the ISM hierarchy. These top-level barriers in the ISM hierarchy will not help to achieve any other barriers above their own level. Once the top-level barriers are identified, these are then removed from the rest of the barriers, and the process is repeated till all barriers are assigned their levels. In Table VII, the barrier B1 (cost of the investment) is at the top level of the ISM hierarchy. After removing barrier B1, the same process is repeated again to find out next level of barriers. These levels help in building the diagraph and the final model. The process has been completed in seven iterations giving seven levels in the ISM hierarchy (summary of the Iterations 2-7 is shown in Table VIII). From the iterations, we found that barrier B1 (cost of the investment) is at the top level of the ISM hierarchy and barriers B4 and B7 (insufficient management time and insufficient senior management skills, respectively) are at the bottom of the hierarchy, while all other barriers exist at various intermediate levels.

3.7 Total interpretive structural modeling-based lean barriers model

With the final reachability matrix in Table V, the TISM-based lean barrier model shown in Figure 2 has been developed. In developing this model, all the lean barriers are arranged in the ascending order of the levels (as shown in Table VIII). More specifically, B1 having the level I is placed at the top, whereas others are placed below it. Each arrow represents the relationship between two lean barriers. For example, B6 leads to B1. Interpretations of each relationship are provided along with the arrow.

3.8 Driving power and dependence diagram

At this stage, driving and dependence diagram is required to be developed. This diagram is also called as MICMAC analysis, which helps in analyzing and categorization of barriers of interest in terms of driving power and dependence (Mandal and Deshmukh, 1994; Singh and Sushil, 2013). In this regard, barriers are classified into four different clusters based on their driving power and dependence. The diagram drawn to depict the driving power and dependence of barriers is shown in Figure 3.

The first cluster is "autonomous barriers" that have weak driving power and weak dependence. These barriers are relatively disconnected from the system. In the current

Table VI.
Interpretive matrix

No.	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	–	–	–	–	–	–	–	–	–	–
B2	Insufficient internal funding affects investment cost	–	–	–	–	–	–	–	–	–
B3	Sufficient supervisory skills are necessary for sufficient investment cost for lean	Sufficient supervisory skills are necessary for sufficient internal funding	–	–	Insufficient supervisory skills are having impact on employee attitudes	–	–	Supervisory skills are essential to develop workforce skills	Insufficient supervisory skills lead to the cultural issues	Supervisory skills are necessary to understand the potential benefits
B4	Insufficient management time has discouraging effect on investment cost	–	Insufficient management time affects the supervisory skills to implement lean	–	Insufficient management time is having impact on employee attitudes	–	Insufficient management time affects the senior management skills	Insufficient management time affects the workforce skills	Insufficient management time leads to the cultural issues	Management time is essential to understand the potential benefits
B5	–	Resistance to change results into insufficient internal funding	–	–	–	–	–	Resistance to change is a hurdle for sufficient workforce skills	Employee attitude is main reason for Cultural issues	Employee attitude is hurdle to understand the potential benefits
B6	Insufficient external funding affects investment cost	Internal funding depends upon external funding	–	–	–	–	–	–	–	–
B7	Sufficient senior management skills are necessary for sufficient investment cost for lean	Sufficient senior management skills are necessary for getting internal funding	Sufficient senior management skills are essential to develop supervisory skills	–	Insufficient senior management skills are having impact on employee attitudes	–	–	Senior management skills are essential to develop workforce skills	Supervisory skills need to keep Cultural issues away	Senior management skills are necessary to understand the potential benefits

(*continued*)

No.	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B8	–	Insufficient workforce skills fail to get sufficient internal funding	–	–	Insufficient workforce skills lead to resistance to change	–	–	–	Workforce skills need to keep Cultural issues away	Workforce skills are necessary to understand the potential benefits
B9	–	Cultural issues are hurdles for getting sufficient internal funding	–	–	–	–	–	–	–	Cultural issues are hurdles to understand the potential benefits
B10	Sufficient understanding of benefits is required to justify investment cost	Insufficient understanding is required to decide sufficient internal funding	–	–	–	–	–	–	–	–

Table VI.

study, barrier B6 (insufficient external funding) is an autonomous barrier. The second cluster is "dependent barriers" that have weak driving power but strong dependence. In the current study, barriers B1, B2, B9 and B10 (insufficient investment cost, insufficient internal funding, cultural issues and insufficient understanding of the potential benefits, respectively) are dependent barriers. The third cluster is "linkage barriers" that have strong driving power and strong dependence. Any action on these barriers will have an effect on the others, as well as feedback effect on themselves. In the current study, barriers B5 and B8 (employee attitudes/resistance to change and insufficient workforce skills, respectively) are appearing on the midpoint of the matrix and could be part of any cluster. Hence, these barriers are considered in the third cluster with author's judgment. The fourth cluster is "driver barriers" that have strong driving power but weak dependence. In the current study, barriers B3, B4 and B7 (insufficient supervisory skills, insufficient management time and insufficient senior management skills, respectively) are driver barriers. Table IX shows the four clusters and its characteristics.

3.9 Validation of total interpretive structural modeling-based lean barrier model

It is essential to test and validate the model developed for its appropriateness (Jadhav *et al.*, 2014b); it also increases the confidence and acceptance of the study. Triangulation is one such approach adopted for this purpose. Triangulation is defined as "the combination of methodologies in the study of the same phenomenon" (Jonsen and Jehn, 2009). More specifically, triangulation aims to achieve convergence of methods producing more objective and valid results. The primary purpose of triangulation is to eliminate or reduce biases and

Table VII. Partitioning the final reachability matrix into different levels (Iteration 1)

Barriers	Reachability Set	Antecedent set	Intersection set	Level
B1	B1	B1,B2,B3,B4,B6,B7,B10	B1	I
B2	B1,B2	B2,B3,B5,B6,B7,B8,B9,B10	B2	
B3	B1,B2,B3,B5,B8,B9,B10	B3,B4,B7	B3	
B4	B1,B3,B4,B5,B7,B8,B9,B10	B4	B4	
B5	B2,B5,B8,B9,B10	B3,B4,B5,B7,B8	B5,B8	
B6	B1,B2,B6	B6	B6	
B7	B1,B2,B3,B5,B7,B8,B9,B10	B4,B7	B7	
B8	B2,B5,B8,B9,B10	B3,B4,B5,B7,B8	B5,B8	
B9	B2,B9,B10	B3,B4,B5,B7,B8,B9	B9	
B10	B1,B2,B10	B3,B4,B5,B7,B8,B9,B10	B10	

Table VIII. Partitioning the final reachability matrix into different levels (Iterations 2-7)

Barriers	Reachability Set	Antecedent set	Intersection set	Level
B1	B1	B1,B2,B3,B4,B6,B7,BB10	B1	I
B2	B1,B2	B2,B3,B5,B6,B7,B8,B9,BB10	B2	II
B3	B1,B2,B3,B5,B8,B9,BB10	B3,B4,B7	B3	VI
B4	B1,B3,B4,B5,B7,B8,B9,BB10	B4	B4	VII
B5	B2,B5,B8,B9,BB10	B3,B4,B5,B7,B8	B5,B8	V
B6	B1,B2,B6	B6	B6	III
B7	B1,B2,B3,B5,B7,B8,B9,BB10	B4,B7	B7	VII
B8	B2,B5,B8,B9,BB10	B3,B4,B5,B7,B8	B5,B8	V
B9	B2,B9,BB10	B3,B4,B5,B7,B8,B9	B9	IV
B10	B1,B2,BB10	B3,B4,B5,B7,B8,B9,BB10	B10	III

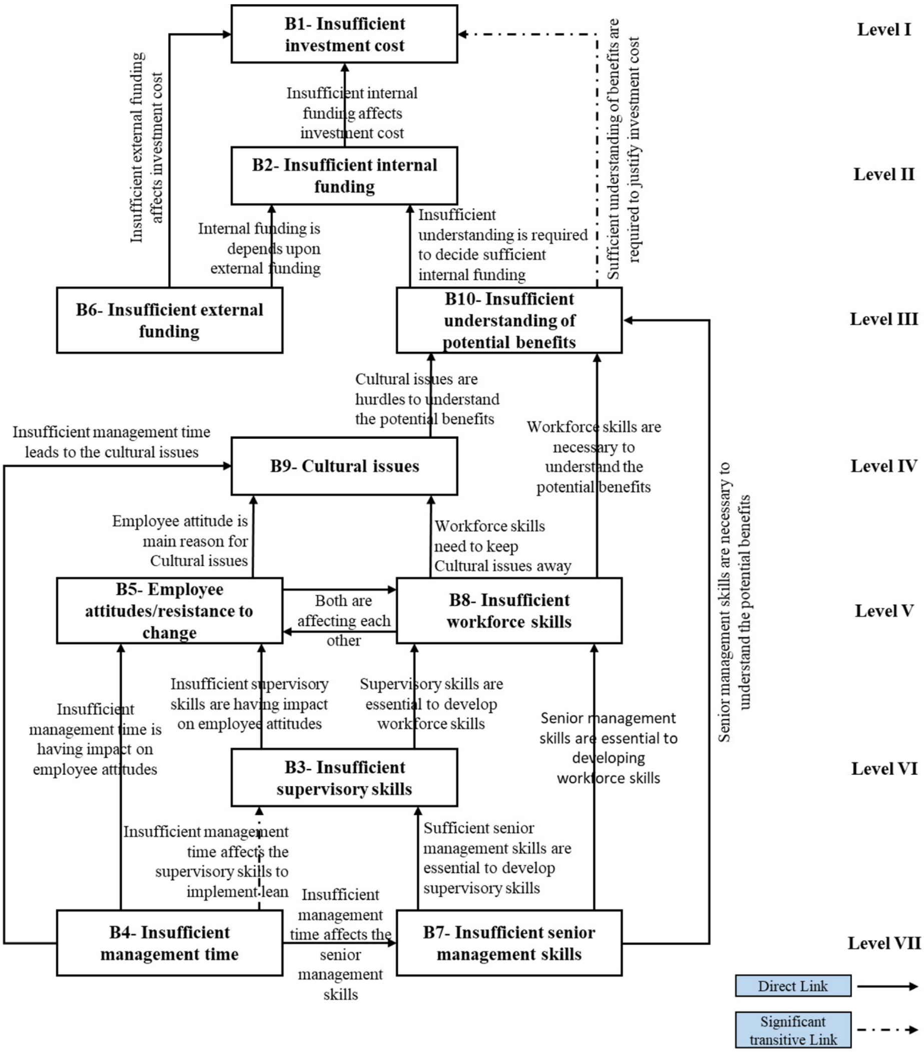

Figure 2.
TISM-based lean barriers model

increase validity of the study. The secondary purpose is to increase confidence regarding results that triangulation brings to the researchers. Triangulation has been recommended to become the researcher's way of thinking, which includes a constant cross-check on theories or explanations (Jonsen and Jehn, 2009). Thakkar *et al.* (2008) and Jadhav *et al.* (2014b) suggested to carry out validation qualitatively by comparing the already established and widely accepted theory, concepts or rules, which are adopted in the present study for validation. The details are as given below:

- The most important lean barrier that emerged in this study is insufficient management time (B4), having highest driving power and lowest dependence (Figure 3). This finding is in consistent with the previous studies proclaiming

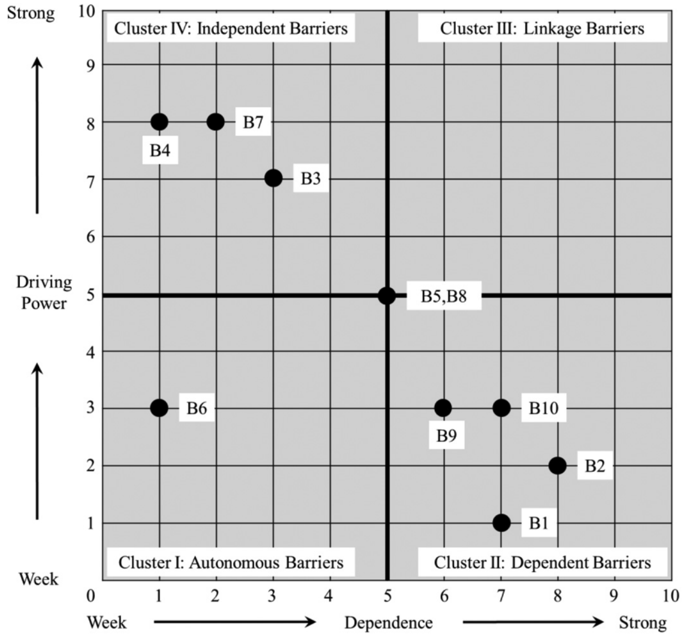

Figure 3.
Driving power and dependence diagram for lean barriers

Cluster No.	Clusters	Characteristics	Driving power	Dependence	Lean barriers
I	Autonomous barriers	Autonomous lean barriers are relatively disconnected from the system and may not be strong	Weak	Weak	B6. Insufficient external funding
II	Dependent barriers	Dependent lean barriers are mostly dependent on others and are weak	Weak	Strong	B1. Insufficient investment cost B2. Insufficient internal funding B9. Cultural issues B10. Insufficient understanding of the potential benefits
III	Linkage barriers	Any action on linkage barriers have effect on others and also get feedback on self	Strong	Strong	B5. Employee attitudes/ resistance to change B8. Insufficient workforce skills
IV	Independent barriers	Independent barriers are basic blocks of system and strong among all others. Paying maximum attention, gives quick desired results	Strong	Weak	B3. Insufficient supervisory skills B4. Insufficient management time B7. Insufficient senior management skills

Table IX.
Clusters and its characteristics

management commitment and involvement as the most important critical success factor for successful implementation of improvement projects (Netland, 2015; Brady and Allen, 2006). Being most driving barrier, it has an impact on other lean barriers. For example, to deal with employees' resistance to change, management requires to spend significant time and energy (Zahraee, 2016).

- Training of employees is an important part of developing skills to implement lean. Another driving barrier in our model is insufficient skill of employees. An organization cannot succeed in lean implementation without proper training of employees; even managers need training (Netland, 2015). Accumulating local knowledge is considered much more important than the use of outside consultants (Netland, 2015). This observation is in consistent with TISM-based model, which clearly shows the links between senior management skills to supervisory and workforce skills.
- In TISM-based model, there are links between employee skills and resistance to change, former leads to later. According to literature, one of the causes of resistance to change is a lack of essential skills in employees (Mirzaei, 2011; Hadid and Mansouri, 2014).
- Appropriate training of lean concepts and basic principles would give a greater level of understanding of lean and encourage the work culture and employee attitude (Zahraee, 2016). Finding of TISM-based model shows consistency with this, as an understanding of lean, cultural issues and employees attitude is driven by the skills of employees.
- Rose *et al.* (2011); Hu *et al.* (2015) and Zahraee (2016) insist organizations (specially small- and medium-sized enterprises) to focus in-house elements that require a less financial investment in lean implementation, such as 5S, quality circle, preventive maintenance and employee involvement. As cost is the uppermost consideration for smaller organizations, they need to secure the additional funding to a level whereby the savings from lean start to materialize (Bhasin, 2012). Literature clearly indicates that the lean transformation can be done with low investment and funding. The TISM-based model also shows that the cost of investment- and internal/external funding-related barriers are less important (due to low driving power and high dependence).

4. Discussions

The main objective of this research work is to identify and model lean barriers and further analyze the interactions among barriers in successful implementation of lean manufacturing. To achieve these objectives, TISM-based model has been developed to understand the interactions among different lean barriers so that practitioners may consider these barriers for effective implementation of lean manufacturing. This will certainly help organizations in realizing the real benefits of lean manufacturing in improving their performance and competitiveness in the market.

The driving power and dependence diagram helps classify and lean barriers in terms of driving power and dependence. This, along with TISM-based lean barriers model, gives valuable managerial insight and implications about the relative importance and the relations between the barriers of interest.

4.1 Analysis of total interpretive structural modeling-based lean barriers model

Figure 3 shows that there is only one autonomous barrier, which indicates that all other barriers which are identified as barriers play a significant role in the implementation of lean manufacturing. Therefore, management should pay attention to all other barriers, except insufficient external funding (B6), which is an autonomous barrier, to achieve successful lean implementation.

Barriers such as employee attitudes/resistance to change (B5) and insufficient workforce skills (B8) lie in the third quadrant exactly in the center part of the diagram; hence, these barriers have medium driving power and medium dependence. These barriers are relatively unstable and need the consistent attention of the management because any effect on these two barriers will affect others and themselves too.

Barriers such as insufficient supervisory skills (B3), insufficient management time (B4) and insufficient senior management skills (B7) are clubbed together into the fourth quadrant of the driving power and dependence diagram. All these barriers have strong driving power and weak dependence and are called independent or driver barriers. These barriers lie at the lower portion of the TISM hierarchy. Hence, to implement lean successfully, management must overcome these barriers. As these barriers lie at the bottom of TISM hierarchy and have the strongest driving power (Figure 2), these are the most important barriers for successful implementation of lean.

Barriers such as insufficient investment cost (B1), insufficient internal funding (B2), cultural issues (B9) and insufficient understanding of the potential benefits (B10) have weak driving power and strong dependence and hence come into the category of the dependent barriers. Hence, these barriers are seen at the top of the TISM hierarchy, and these are clubbed together into the second quadrant of the driving power and dependence diagram. These barriers are dependent on mid-level and bottom-level barriers. Hence, to implement lean successfully, management must focus on barriers having high driving power and should formulate strategies based on these results and findings.

4.2 Managerial implications

In accordance with the TISM-based lean barrier evaluation model (Figure 2), we discuss below some issues for a better lean implementation.

4.2.1 Provide sufficient management time and training. As shown in the model, insufficient management time is one among the independent barriers. It, thus, has the highest level of importance in achieving the targeted performance measures in lean implementation. As the lack of management time plays a vital role, the management team in any firm should commit themselves to lean projects by investing more time. In practice, a firm's management team has many issues/problems to solve and may deal with multiple projects in the same time. In this regard, the management team should prioritize the issues/projects to be handled such that enough time is allocated to lean projects. In addition, the management people may entrust certain responsibilities to the experienced, senior staff to have more time for lean projects. As shown in the model, the management and supervisory skills are also very important in lean implementation. These skills closely relate to the efficient communication between the management people (or supervisors) and employees. In this regard, the management people should pay attention to the way with which they communicate with the employees. They should communicate with the employees in such a way that the employees are happy to accept their instructions/suggestions, and that their employees feel more encouraged and empowered in carrying out lean projects.

As suggested by the model, insufficient workforce skills impede lean implementation. To improve workforce skills and knowledge about lean implementation, firms should provide the employees with more training and coaching. More specifically, firms should carry out mentor/mentee programs to engage employees in training by building trust and modeling positive behavior. In addition, firms may adopt some lean practices for a better training, e.g. group problem-solving and cross-functional team development. Applying well accepted practice in training may lead to better results.

4.2.2 Develop a right culture. In the traditional manufacturing environment, production activities take place all the time to fully utilize manufacturing resources even when there are no customer orders. Different with the traditional manufacturing, in lean manufacturing, production activities take place when there are customer orders, in the hope of eliminating waste. In this regard, successful lean implementation calls for many changes in the manufacturing environment and a different culture. With a fear of losing jobs, employees resist to the changes and are reluctant to cultivate a new culture. Management may, thus, create certain programs and inventive plans to provide employees with a safe feeling while improving their skills, thus developing the culture necessary for lean implementation. As social issues, e.g. legal pressures and environment pressures, affect the development of lean culture, management needs to address these issues well. At last, in developing the right culture, management may adopt different tools/practices, such as Kaizen, Kanban system and daily schedule adherence.

4.2.3 Develop effective communication, carry out low-cost production and obtain external funding. To tackle barriers such as insufficient understanding of the potential benefits, firms need to communicate well with employees about lean and its potential benefits so that they can have a clear understanding. There exist diverse approaches, tools and activities which may help develop the effective communication. Firms may have formal and/or informal meetings to clarify for the employees the firms' vision, lean implementation targets, strategies, plan, performance objectives, etc. Moreover, firms may adopt some well-recognized lean practice, including visual management, goal communication and reward/recognition plans, to communicate with the employees. Because of the limited financial resources, most firms lack investment costs and internal funding. This is especially true for SMEs. Thus, it is very important for firms to carry out activities and programs to overcome the high investment costs and insufficient internal funding. They may implement lean practices, e.g. low-cost automation, single piece flow, quick changeover, total productive maintenance, seven wastes elimination, on the shop floors. As external funding affects serious lean implementation (Figure 2), firms need to obtain sufficient external funding. There are a variety of different approaches which may help firms in securing external funding, such as developing collaboration, developing cooperative R&D and obtaining sponsors.

5. Conclusions

In the present research work, a TISM-based lean barrier model has been developed for successful implementation of lean manufacturing. This TISM-based lean barrier model is a structural model that can be interpreted and analyzed completely by interpreting the links, thereby making the logic more transparent. In this research work, an attempt has been made to identify barriers to lean implementation. Although a substantial literature is available on lean barriers, no study has been reported to understand the interactions among these barriers. The major contribution of this research work is the development of contextual relationships among selected lean barriers through a systematic framework. Another contribution of this research work is the validation of the outcome of this study through a triangulation technique.

In the present research work, only ten lean barriers have been identified, while more barriers can be identified to develop TISM model. TISM model may further be compared with other methodologies such as interpretive ranking process and analytical hierarchy process for better insights.

A major finding of this research work is that the insufficient management time, insufficient supervisory skills and insufficient senior management skills are significant barriers to lean implementation. These barriers have the strongest driving power and the weakest dependence and lie at the bottom of the TISM hierarchy. With low driving power, cost- and funding-related barriers such as cost of the investment, internal funding and external funding are found to be less important barriers. This can help the management in deciding on the priority and focus on those barriers that lead to the successful lean implementation. The proposed TISM-based lean barrier model provides a more realistic approach to the problems faced by practitioners during lean implementation.

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