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ORIGINAL RESEARCH

Analysis of interactions among the barriers to JIT production: interpretive structural modelling approach

J. R. Jadhav · S. S. Mantha · S. B. Rane

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Abstract 'Survival of the fittest' is the reality in modern global competition. Organizations around the globe are adopting or willing to embrace just-in-time (JIT) production to reinforce the competitiveness. Even though JIT is the most powerful inventory management methodologies it is not free from barriers. Barriers derail the implementation of JIT production system. One of the most significant tasks of top management is to identify and understand the relationship between the barriers to JIT production for alleviating its bad effects. The aims of this paper are to study the barriers hampering the implementation of successful JIT production and analysing the interactions among the barriers using interpretive structural modelling technique. Twelve barriers have been identified after reviewing literature. This paper offers a roadmap for preparing an action plan to tackle the barriers in successful implementation of JIT production.

Keywords Just-in-time (JIT) · Lean manufacturing · JIT production · Barriers · Interpretive structural modelling (ISM) · High performance manufacturing (HPM)

J. R. Jadhav (✉) · S. B. Rane
Mechanical Engineering Department, Sardar Patel College of Engineering, Bhavan's Campus, Munshi Nagar, Andheri (West), Mumbai 400 058, India
e-mail: jrjadhav70@gmail.com

S. B. Rane
e-mail: ranesantoshb@yahoo.co.in

S. S. Mantha
All India Council for Technical Education (AICTE), 7th Floor, Chanderlok Building, Janpath, New Delhi 110 001, India
e-mail: ssmantha@vjti.org.in

Introduction

Lean manufacturing is originated in Toyota with names 'Toyota production system (TPS)' or 'just-in-time (JIT)' manufacturing beginning back in 1960s (So 2010; Taj 2008; Reichhart and Holweg 2007; Bruun and Mefford 2004; Wu 2003). Considering the ability to do more with less, JIT manufacturing is referred as Lean manufacturing (So 2010; Bozarth and Handfield 2008). In many ways, Lean is an updated version of JIT (Näslund 2008). Lean production can be also considered as an extended JIT that includes participation of all parties involved in supply chain, intra- and inter-organization (Bakri et al. 2012; Enkawa and Schvaneveldt 2001). JIT is a production philosophy based on the elimination of all waste and on continuous improvement of productivity which is synonymous with lean production (So and Sun 2011; Cox and Blackstone 2002). JIT is part of the lean philosophy which aims to eliminate waste and increase quality and Profitability (Dowlatshahi et al. 2009). Hence, JIT and Lean are used as interchangeable concepts in this paper.

JIT has been a widely recognized production philosophy alternative since the early 1980s. JIT principles and techniques have been widely adopted in many manufacturing firms (Olhager 2002). JIT is a set of management practices aimed at continuous improvement through the elimination of all wastes and full utilisation of human resources (White et al. 2010; Shingo 1981).

Monden (1983) described JIT as an internally focused production system that produces parts on demand. It eliminates unnecessary elements in production, and its primary purpose is cost reduction (Koufteros et al. 1998; Tu et al. 2001). JIT aims to achieve on-time delivery and to minimise unnecessary inventory cost. To achieve JIT delivery, quality of the whole internal operations as well as that of the external partners must be assured (Vanichchinchai and Igel 2011).

JIT manufacturing has the capacity, when properly adapted to the organization, to strengthen the organization's competitiveness in the marketplace substantially by reducing wastes and improving product quality and efficiency of production (Altekar 2005). During the last two decades, many companies have implemented JIT to increase their competitiveness. In fact, inventory reduction is perhaps the most visible result that JIT brings about. JIT in reality is a philosophy of supply chain excellence (Roy and Guin 1999). Initially conceptualized as an approach to reduce lead time and decrease inventory within a manufacturing plant (Schonberger 1982), JIT has expanded to include a broader set of production and purchasing practices (Kaynak and Hartley 2006; Fullerton et al. 2003; White et al. 1999; Hahn et al. 1983; Schonberger and Ansari 1984; Schonberger and Gilbert 1983).

Lean Production System is based on Toyota Production System (TPS). JIT and Jidoka are the two main pillars of TPS. JIT looks after 'Quantity' aspect, whereas Jidoka takes care of 'Quality' aspect of lean systems. Supporting Lean practices like quick change over, standard work, visual management, etc. are absolutely necessary for successful implementation of JIT. Hence the author focused on one of the pillar of Lean system i.e. JIT production. Moreover, many researchers believe that Lean is the extended or updated version of JIT. Jidoka enables operations to 'build-in quality' at each process and to isolate human resource and machines for more efficient work. An informal survey of practitioners of lean in manufacturing revealed that changes to the production environment have only a 30 % success rate. In other words, 70 % of lean implementations experience decay and a return to the original way of doing business (Schipper and Swets 2010). JIT failure is more responsible than Jidoka for the majority of unsuccessful lean implementations. Active and timely participation of all stakeholders including internal (employees and top management) as well as external (suppliers and customers) is essential for successful implementation of JIT. Hence there is inherent complexity in JIT structure.

JIT deployment faces many challenges or barriers even though it offers tremendous benefits such reduction in inventory holding cost, reduction in space requirement and lead time reduction. To encourage the organizations for adoption of JIT production, significant barriers essentially need to be recognized, analysed and discussed. The JIT production barriers also influence one another. The understanding of the mutual relationship between JIT production is very important. Some barriers create a platform for other barriers. Some barriers are dependent, some are independent and some have interrelationship. The barriers which have high driving power and dependency need more consideration. The understanding of the ladder of barriers would be helpful for the senior management implementing JIT system.

Lot of research has been carried out in the field of analysing and Modelling JIT systems. Some researchers did empirical studies and presented conceptual or theoretical models. Various Modelling tools and techniques based on the mathematics, statistics, operation research (OR), computer simulation, structural equation Modelling, AHP, etc. were used. As far as authors' literature review on JIT is concerned, nobody used interpretive structural modelling (ISM) for JIT systems. Structural equation modelling (SEM) may not be used independently. SEM is only the statistical validation tool for ISM model. So ISM model has to build first.

Although from the view of integral whole, JIT production can enhance the performance of the organization, yet, little attention has been paid to the relationship between barriers to JIT production. In actual practice, managers may be interested in asking the questions like: what are the barriers to JIT production? are all barriers equally significant? If not, which barriers are more influential? What is the structure of these barriers?

This paper contributes to fill the research gaps by providing the answers to these questions. It will be very helpful for organization to focus on critical barriers for successful implementation of JIT production and achieve operational excellence.

The research is based on secondary data, which includes compilation of research articles, web articles, survey reports, thesis and books on JIT production in manufacturing industry. The main aspect of the paper is to expose the hidden structure of barriers to JIT production using ISM.

The salient features of the research are as follows:

1. It represents the collective wisdom of Lean/JIT practitioners in the form of interpretive structural model.
2. It offers prioritize structure of the barriers to JIT production based on ISM so that managers can prepare an action plan to tackle these barriers.

This paper is further organized as follows. Research methodology is described in "Research objectives and methodology" section. Barriers to JIT production are described briefly in "Literature review and hypotheses"section. Overview of interpretive structural modelling (ISM) and ISM for JIT production is discussed in "Interpretive structural modelling (ISM)" section. "MICMAC analysis" section discussed MICMAC analysis. "Discussion" section discussed the ISM model for barriers to JIT production. "Conclusions" section includes general conclusions with research findings, implications and contributions. Finally, limitations and suggestions for future research are mentioned in "Limitations and suggestions for future research" section.

Research objectives and methodology

Research objectives

The prime purpose of this paper is to offer a framework for sustainable implementation of JIT production in manufacturing industry.

The main objectives of this paper are as follows:

1. To identify critical barriers to JIT production.
2. To establish contextual relationship between each pair of critical JIT production barriers.
3. To analyse and prioritize the interactions among the barriers using interpretive structural modelling technique.
4. To carry out MICMAC analysis to classify the identified barriers to JIT production.
5. To developing a structural framework for successful implementation of JIT production.

This work may provide a roadmap for taking suitable actions for successful implementation JIT production system. The effective and sustainable implementation of JIT production assumes great significance in this context.

Research methodology

Published research papers have covered various domains of JIT. Research papers focused on identification of JIT elements, benefits of JIT implementation, simulation, implementation strategies, impact of JIT on competitive and financial performance of the organization, the relationship between JIT and other operational practices like information systems and technology, total quality management (TQM), total productive maintenance (TPM), supply chain management (SCM) and human resource management (HRM). However, papers were not found on the Modelling JIT barriers using interpretive structural modelling (ISM).

This work can be characterised as a theoretical concept, specifically for review of literature on barriers in JIT production. The approach of the research is exploratory in nature. First the relevant literature is reviewed. The authors focused on literature from 1994 to 2012.

Following criteria are used for inclusion of literature:

- Literature published on lean, JIT and ISM.
- Journals stating lean and JIT in their editorial scope.
- Web articles on lean and JIT.
- Articles published in reputed referred scholarly journals.
- Articles discussing issues and barriers in lean and JIT implementation in manufacturing sectors.
- Articles addressing issues related to the problems in lean and JIT implementation.
- Articles presenting a lean and JIT model or framework specifically in manufacturing sectors.

Figure 1 shows the flow chart of research methodology adopted in this paper.

The literature review was augmented by use of online computerized search engines like Science Direct, Emerald, Taylor and Francis, Google Scholar, Springer Link, Bing, etc. using primary keywords such as lean, JIT, ISM and secondary key words like JIT production, barriers, challenges, lack of and implementation strategy. The research is based on secondary data, which includes compilation of research articles. The ultimate list of articles reviewed for this paper covers articles published in reputed referred scholarly journals on JIT and lean. In this study, research factors are the barriers of JIT production. Twelve significant barriers for JIT production have been identified after reviewing literature. Five lean/JIT practitioners and experts have been consulted to identify the relationships between the identified barriers to JIT production for developing the ISM model for barriers to JIT production.

Literature review and hypotheses

A detailed description of barriers to JIT production and constructs for ISM model for JIT production is provided in the following subsections. Based on the existing literature, then we discuss and develop hypotheses about the dependency and independency of various barriers to JIT production and about the interactions among barriers to JIT production.

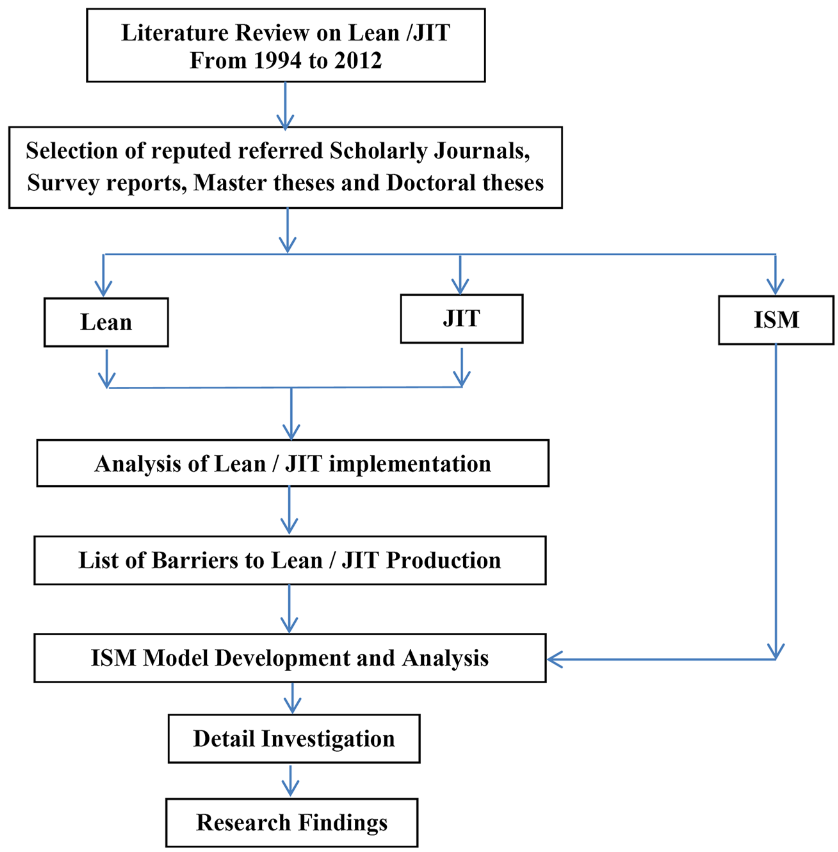
Barriers to JIT production

The JIT production implementation has provided impressive benefits, but some major problems are encountered. The barriers for JIT production and the best practices used to overcome them are described in this section.

- Lack of top management commitment and support

Many managers carry 'not suitable or applicable for us' syndrome for any initiative due to fear of failure or they do not want to come out of their comfort zone. Lack of top-management commitment may stem from various reasons like lack of experience and training, resistance to change and hesitation in initiating improvement programs (Talib

Fig. 1 Flowchart of research methodology



et al. 2011). Many mangers give up after experiencing lot of unexpected problems and/or erratic results during first stage of implementation. For any change to be successful, high-level management must be committed to making the change. They need to demonstrate their commitment to the work in a highly visible fashion—by what they do as well as what they say (Phelps et al. 2003). Ramarapu et al. (1995) conclude that management commitment and employee participation are critical success factors when implementing JIT (Sim and Rogers 2008). Successful development of a JIT production demands serenity, long-term commitment and focus leadership of top management.

- Lack of training and education

Newall and Dale (1990) and Ljungström and Klefsjö (2002) have also reported in their studies that poor education and training acts as a major barrier in the development and implementation of quality program (Talib et al. 2011). According to Im et al. (1994) and Jayaram et al. (1999), JIT training is one of the critical factors of JIT program success. In a survey, Zhu et al. (1994) found that over half of the cases reported cross training as a key element of JIT implementation. The first step to enhance operational excellence is the implementation of quality improvement practices. Lack of training roadmap is a pitfall hampering the improvement process (Houshmand and Jamshidnezhad 2006). According to survey carried out by Salaheldin (2005) in Egyptian manufacturing firms, lack of formal training/education for management and workers is the most important implementation problems reported by JIT Companies and limited knowledge about JIT is the biggest obstacle impeding the implementation of JIT based on the point of view of non-JIT companies.

- The lack of resources to invest/financial constraints

Finance and reasonable resources are indispensable for successful and effective execution of any improvement program. Poorly maintained and inadequate facilities/infrastructure are significant barriers for the adoption of JIT production. Progress rate is one of the principal pointers of leading organization. Leading organizations have better financial ability to invest along with intelligent human capabilities. However, small and medium scale firms may face financial crunch for paradigm shift from traditional production to JIT production. A commonly mentioned obstacle to the introduction of JIT in small companies is their lower availability of resources. Large companies usually enjoy more financial and human resources to innovate, and at the same time have better access to the knowledge necessary for the implementation of JIT (Doolen and Hacker 2005; Bayo-Moriones et al. 2008).

- Employees' resistance

A frequently encountered problem is lack of employee enthusiasm and support in JIT implementation. Employees do not want to embrace JIT production due to resistance for transformation. Employee thinks that improvement initiative may result into unemployment. This psychological fear is known as 'hazard to profession safety' in industrial circles. Difficulty in changing the mindset of employee with regard to quality and urgency among them are reasons which generally obstruct the movement of quality program (Talib et al. 2011). Benton and Shin (1998) mentioned that Young (1992) found that the JIT production system aggravates workers because they are expected to work continuously. There is no work in process to protect them. One of the problems encountered during JIT implementation is unwillingness of workers to perform multiple tasks (Yasin and Small 2003).

- Poor facility planning and layout

JIT emphasises on frequent production with small lot size. Availability of efficient, effective and reliable machines/equipment along with flexible factory layout is essential to meet demand variations. Su (1994) cautioned that superficial attempt to reorganize plant layout not matched by accompanying changes to manufacturing processes may lead to JIT failure. A poor layout may have several deteriorating effects such as high material handling costs, excessive work-in-process inventories and low or unbalanced equipment utilisation (Wong et al. 2009; Heragu 1997).

- Backsliding/lack of perseverance

The ultimate results of continuous improvements are reduction in lead time and cost. Reduction in the machine cycle time is one of the methods for productivity improvements. It often leads to unemployment if labour management is not plan properly by top management. If workers feel that employee reduction is the motive of productivity improvement programs then they will not support it in future. Lack of training of new work method to workers and failure of higher management to install the monitoring and control systems for new work methods entice the workers to slipback or resort to the old habits of working. Lack of perseverance and the propensity to revert to traditional practices when difficulties were encountered (Su 1994).

- Organizational cultural difference

Resistance to change is natural propensity of majority of employee. Very few employees are ready to venture out of their comfort zone. JIT deployment demands radical change in thinking and revamping the entire organization including the production system. JIT implementation requires a change in culture, attitude and habits of employees. Adherence to strict production schedule, complying with standards and shouldering widen responsibilities are some of the salient features of JIT system. A major constraint in JIT implementation is that there are no universally accepted JIT techniques, as they seem to vary from one culture to another and also from one industry to another (Sandanayake et al. 2008). Western firms are different from Japanese ones considering cultural, technological and industrial points of view (Alfieri et al. 2012).

- Absence of a sound action or planning system

The main objective of any production planning and inventory management system is to minimise the total system cost (Roy et al. 2012). JIT demands accurate production planning and execution in all respects. On time availability of necessary resources with specific quantity, specific quality, at specific location is essential for successful JIT implementation. Since there is less margin for error, the planner needs to be very familiar with the process capability in terms of changeover times, changeover patterns (the relative difficulty of switching from one specific product to another) and the true lead times of each product (Larson 2005). JIT production is a susceptible system as it does not favour the stocking inventories to fulfil customer requirements. If supplier and manufacturer are not sufficiently aligned through a JIT supply logic, delays in deliveries can occur, that can, in part, lessen the benefits of JIT production on delivery performance (Danese et al. 2012). The absence of a sound strategic planning by the top management has often contributed to ineffective quality improvement (Whalen and Rahim 1994; Talib et al. 2011).

- Lack of information sharing or communication with stakeholders

Zhu et al. (1994) conducted a critical review of published studies of key success factors in JIT implementation and found that communication of JIT-related goals was included in several articles (Jayaram et al. 1999). Material flow and information flow are two prime streams in JIT. Long lead time, variation and inaccuracies in either stream disrupt the smooth functioning of the JIT system. Good information flows among the operations is a critical aspect of JIT (Arogyaswamy and Simmons 1991; Helms 1990; Richeson et al. 1995; White and Pearson 2001). Olhager (2002) and Vokurka and Lummus (2000) emphasise that this external extension of the JIT philosophy to include suppliers and customers requires that information be openly shared among channel members (Green et al. 2007). In the JIT environment, a supplier needs to adjust the production schedule to match the buyer's demand (Mungan et al. 2010). Lack of real time information exchange between downstream customer and upstream supplier may have catastrophic effects on production.

- Cross-functional conflict

Formation of cross-functional teams is one of the best methods for achieving desired results in a JIT environment. The department representatives across the organization are the members of cross-functional teams. Each team member must have understanding of team structure, role and responsibilities. High interactions and accurate information sharing about customers' need are essential for successful implementation of JIT. Constructive conflicts may lead to improvements. However, any communication gap leads to destructive conflict among cross-functional team members which derail the JIT implementation. Poor coordination between departments is one of the critical barriers that an organization inhibits (Talib et al. 2011). Upadhye et al. (2010) reported that the lack of interdepartmental relationship and communication gap were responsible for many shop floor conflicts.

- Slow response to market

Some of the issues managers should be aware when implementing JIT are inability to respond rapidly to changes in product design, product mix, or large demand volumes (Su 1994), customer scheduling changes (Celley et al. 1986), inability to meet the schedule (Crawford et al. 1988) and unstable demand (Im 1989). These issues lead to slow response to market.

- Poor sales forecasting

Lower volume of demand and highly fluctuating/varying customer orders are the serious hurdles faced by the industries (Eswaramoorthi et al. 2011). Poor forecasting (Crawford et al. 1988) and lack of an accurate forecasting system (Yasin et al. 1997) might result in the inability of the company to make deliveries to customers as required.

Hypotheses

Based on the prevailing literature study, the team of five lean/JIT practitioners and experts discusses and develops hypotheses about the dependency and independency of various barriers to JIT production and about the interactions among barriers to JIT production.

Many resources like fund, space, man-efforts, material, etc. are required to bring about any desirable changes in the existing system/environment by overcoming the barriers to change process. The willing and commitment of employees to change are not sufficient. It should be timely supported by necessary funds to change the existing layout to facilitate JIT production. Many barriers to JIT Production are interrelated to each other and dependency or independency exists between them. The ultimate result of interaction of barrier to JIT Production may result in delays in delivery schedule which is indicated by slow response to market causing customer dissatisfaction. Hence the team of experts put forward following hypotheses.

Hypothesis 1 (H1) Financial constrain is the most independent barrier to JIT production.

Hypothesis 2 (H2) Lack of top management commitment and support as well as organizational cultural difference are the next two the most independent barrier to JIT production.

Hypothesis 3 (H3) Slow response to market is the most dependent barrier to JIT production.

Hypothesis 4 (H4) High interactions among barrier to JIT production exist.

Interpretive structural modelling (ISM)

Introduction to ISM

Original theoretical development of ISM is credited to J. W. Warfield. Farris and Sage (1975), Sage (1977) and Sage and Smith (1977) have contributed to the development and application of the ISM methodology for a variety of purposes—especially those concerned with decision analysis and worth assessment in large-scale systems. The ISM process transforms unclear, poorly articulated mental models of systems into visible, well-defined models useful for many purposes (Mishra et al. 2012; Ahuja et al. 2009). ISM provides an ordered, directional framework for complex problems, and gives decision makers a realistic picture of their situation and the variables involved (Wang et al. 2008; Chandramowli et al. 2011). ISM has been used by researchers for understanding direct and indirect relationships among various variables in different industries.

ISM readily incorporates elements measured on ordinal scales of measurement and thus provides a modelling approach which permits qualitative factors to be retained as an integral part of the model. In this it differs significantly from many traditional modelling approaches which can only cope with quantifiable variables (Janes 1988).

ISM is a systematic application of some elementary graph theory in such a way that theoretical, conceptual and computational advantage are exploited to explain the complex pattern of conceptual relations among the variables (Shahabadkar et al. 2012 and Charan et al. 2008). ISM uses words, digraphs and discrete mathematics to reveal the intrinsic structure of system/complex issues/

problem under consideration. ISM can be used for identifying and summarizing relationships among specific variables, which define a problem or an issue (Sage 1977; Warfield 1974). It provides us a means by which order can be imposed on the complexity of such variables (Jharkharia and Shankar 2005; Mandal and Deshmukh 1994).

The ISM process transforms unclear, poorly articulated mental models of systems into visible, well-defined models useful for many purposes (Mishra et al. 2012; Ahuja et al. 2009). ISM transforms absolutely instinctual process of model building into a more methodical and structural approach. Team members acquire much greater insight of the system by both individually and collectively. It also enhances the communication within heterogeneous groups during the process of model building.

ISM has been used by researchers for understanding direct and indirect relationships among various variables in different industries. ISM approach has been increasingly used by various researchers to represent the interrelationships among various elements related to the issue (Attri et al. 2013).

Assumptions used in ISM modelling:

1. The modellers possess the sufficient experience and knowledge of the issue/system under deliberation.
2. Unique *contextual* relationship exists between any pair of variables/parameters/factors of the issue/system under consideration out of four possible *contextual* relationships which is useful to develop Structural Self-Interaction Matrix (SSIM).
3. The contextual relation being modelled is transitive and multilevel.
4. *The data are acquired and organized into a form* (*reachability matrix*) which help to develop *a structural model.*

There are certain prerequisite conditions need to satisfy to apply ISM technique successfully. The critical points in the application of ISM techniques are discussed as follows:

1. ISM is an interpretive learning process needs involvement of the stakeholders/concern change agents/team members working collectively to solve the problem.
2. The identification of system variables and the interrelationship between variables are of prime importance to achieve the exact structural model.
3. Team members must have experience and the in-depth knowledge of the issue/system under consideration.

- The enrich sources of the wisdom are personal knowledge, active practical experiences and exposures to failed as well as successful attempts of Lean implementation in the organizations for an individual member as a part of implementation team. The lessons learned from successful and failed Lean implementation in the organization must be documented and shared through proper Knowledge Management (KM) System. Organizational knowledge management is absolutely necessary so that the organization is independent of any person—transfer to another department or not working in the particular organization during execution of improvement programs.
- The Lean consultants are the rich source of profound knowledge as they work on various projects across the industries and hence have diversified exposure and experience in the areas of their specialization. This profound knowledge must be tapped for developing a roadmap for sustainable Lean implementation. ISM used the collective wisdom of the team members which includes Lean practitioners and consultants to convert mental model into a structural model by considering the interrelationship of variables involved in the process or system.

The justification for selection of ISM technique for analysing the interaction among identified Lean practices bundles and modelling it discussed here. Interpretive structural modelling (ISM), analytic network process (ANP) and analytic hierarchy process (AHP) are three contemporary modelling techniques applied frequently in the literature. Thakkar et al. (2008) compared these three techniques, and extracts of that comparison are shown in Table 1. Table 1 presents the exceptional virtues of ISM over other modelling techniques.

Talib et al. (2011) analyse interaction among the barriers to total quality management implementation using ISM approach. Faisal et al. (2007) used ISM to analyse the enablers for Supply chain agility. ISM is a well-known technique, which can be applied in various fields. Wang

Table 1 Brief comparison between AHP, ANP and ISM

Analytical hierarchy process (AHP)	Analytic network process (ANP)	Interpretive structural modelling (ISM)
Discipline of hierarchy has to be strictly followed	Deals with loose networks	Involves a set of interconnected criteria
Assumes functional independence of an upper part of hierarchy from its lower one	Takes into account the interdependencies and non-linearity	Establishes the "leads to" relationships among the criteria
Fails in complex real life problems	Useful in real life non-linear problems	Captures the complexities of real life problems
Moderate ability for capturing dynamic complexity	Lower ability for capturing complexity	Higher ability for capturing dynamic complexity

Source Thakkar et al. (2008)

et al. (2008) used ISM to investigate the interactions among the major barriers which prevent the practice of energy saving in China. Barve et al. (2007) used ISM to analysis of interaction among the barriers of Third Party Logistics. Raj et al. (2008) utilised ISM to model the enablers of flexible manufacturing system. Soti et al. (2011) used ISM to model the barriers of Six Sigma. Aloini et al. (2012) applied ISM to ERP risks management. Sharma and Garg (2010) used ISM for enablers for improving the performance of automobile service centre.

Procedure for model development using ISM

A stepwise procedure is to be adopted to develop a model or framework using ISM. Ravi and Shankar (2005) described the various steps involved in the ISM methodology as follows:

Step 1 Variables affecting the system under consideration are listed, which can be objectives, actions, individuals, etc.
Step 2 From the variables identified in step 1, a contextual relationship is established among variables with respect to which pairs of variables would be examined.
Step 3 A structural self-interaction matrix (SSIM) is developed for variables, which indicates pairwise relationships among variables of the system under consideration.
Step 4 Reachability matrix is developed from the SSIM and the matrix is checked for transitivity. The transitivity of the contextual relation is a basic assumption made in ISM. It states that if a variable A is related to B and B is related to C, then A is necessarily related to C.
Step 5 The reachability matrix obtained in Step 4 is partitioned into different levels.
Step 6 Based on the relationships given above in the reachability matrix, a directed graph is drawn and the transitive links are removed.
Step 7 The resultant digraph is converted into an ISM, by replacing variable nodes with statements.
Step 8 The ISM model developed in Step 7 is reviewed to check for conceptual inconsistency and necessary modifications are made.

Figure 2 depicts a flow chart for preparing a model based on ISM which is adapted from Ravi and Shankar (2005).

Interpretive structural model (ISM) development

The interrelationships among barriers to JIT production for successful implementation have been achieved through these steps mentioned above.

Structural self-interaction matrix (SSIM)

Twelve barriers to JIT production were identified through literature review. The next step is to analyse the interrelationship between these barriers using ISM. ISM methodology proposes the use of the expert opinions based on various management techniques such as brainstorming and nominal group discussion technique in developing the contextual relationship between barriers. These experts from the industry and academia were well conversant with JIT production.

'Leads to' or 'influences' type of contextual relationship is chosen for analysing the barriers to JIT production. This means that a particular barrier influences another barrier. On the basis of this, contextual relationship between the identified barrier is developed.

Following four symbols were used to denote the direction of relationship between the barriers (*i* and *j*):

V barrier *i* influences barrier *j*
A barrier *i* influenced by barrier *j*
X barrier *i* and *j* influence each other
O barrier *i* and *j* do not influence each other since they are unrelated

Consultation and discussions with the five lean/JIT practitioners and experts helped in identifying the relationships between the identified barriers to JIT production. On the basis of contextual relationship between barriers, the SSIM has been developed. Final SSIM is presented in Table 2.

Development of the initial and final reachability matrix

The next step is to develop the initial and final reachability matrix from the SSIM.

(i) Initial reachability matrix

Obtain the initial reachability matrix from the SSIM format by transforming the information of each cell of SSIM into binary digits (i.e. 1 or 0 s). This transformation has been done by substituting V, A, X, O by 1 and 0 as per the following rules. Rules for transformation are given in Table 3.

Following these rules, initial reachability matrix is prepared as shown in Table 4.

(ii) Final reachability matrix

To get Final reachability matrix, the concept of transitivity is introduced, and some of the cells of the initial reachability matrix are filled in by inference. If a variable '*i*' is related to '*j*' and '*j*' is related to '*k*', then transitivity implies that variable '*i*' is necessarily related to '*k*'. The final reachability matrix is developed after incorporating the transitivity concept in Table 4 and is presented in Table 5 wherein entries marked † show the transitivity.

Level partitioning the final reachability matrix

After creating the final reachability matrix, the structural model was obtained. Warfield (1974) has presented a series of partitions, which are induced by the reachability matrix on the set and subset of different variables. From these partitions, one can identify many properties of the structural model (Farris and Sage 1975).

The reachability set and antecedent set for each barrier to JIT production are established from the final reachability matrix (Table 5). The reachability set for a particular barrier consists of the barriers itself and the other barrier, which it influences, whereas the antecedent set consists of the barrier itself and the other barrier which may influence it. Subsequently, the intersection of the reachability and antecedent sets is derived for all the barriers and levels of different barriers are determined. The barriers for which the reachability sets and the intersection sets are identical assigned the top level in the ISM hierarchy. The top-level barriers are those that will not lead the other barriers above their own level in the hierarchy. Once the top-level barrier is identified, it is discarded from further hierarchical analysis (i.e. that barrier from all the different sets) and other top-level barriers of the remaining sub-group are found.

For example, for the iteration no. 1, to determine the reachability set for barrier no. 1 (Lack of top management commitment and support), follow the row of barrier no. 1 in Table 5 and list of the elements (barriers) which are

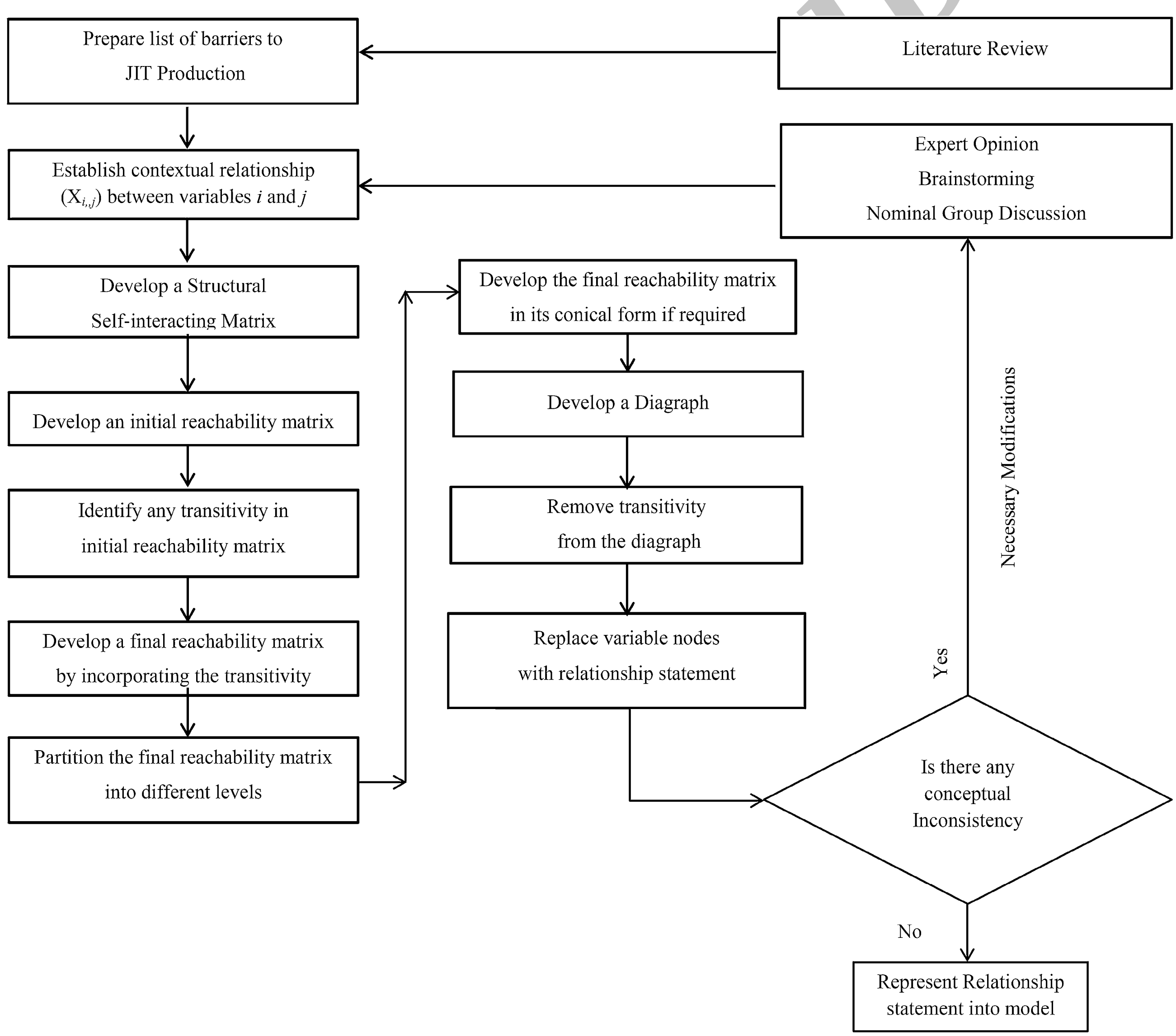


Fig. 2 Flow chart for preparing ISM

Table 2 Structural self-interaction matrix for barriers to JIT production

S. no.	Barriers to JIT production	12	11	10	9	8	7	6	5	4	3	2	1
1	Lack of top management commitment and support	O	V	V	X	V	A	V	V	V	A	X	
2	Lack of training and education	V	V	V	X	V	V	V	X	V	A		
3	Financial constraints	O	V	O	O	V	O	O	V	V			
4	Employees' resistance	O	V	X	X	V	A	V	X				
5	Poor facility planning & layout	O	V	A	A	V	O	O					
6	Backsliding	O	V	A	A	A	A						
7	Organizational cultural difference	O	V	V	X	V							
8	Absence of a sound action or planning system	A	V	A	A								
9	Lack of information sharing or communication with stakeholders	V	V	V									
10	Cross-functional conflict	V	V										
11	Slow response to market	A											
12	Poor sales forecasting												

influenced (indicated by 1) by barrier no. 1. Here all barriers are influenced by barrier no. 1, except barrier no. 3. Hence the reachability set consists of the barriers no. 1 to 12, except barrier no. 3 in Table 6. The procedure was repeated to determine reachability set for all other barriers and listed it in the column of reachability set. Now, to determine the antecedent set for barrier no. 1 (Lack of top management commitment and support), follow the column of barrier no. 1 in Table 5 and list of the elements (barriers) which may influence (indicated by 1) the barrier no.1. Here barrier nos. 1, 2, 3, 4, 5, 7 and 9 are having influence on the barrier no. 1. The procedure was repeated to determine antecedent set for all other barriers and listed in the column of antecedent set. The common elements in the reachability set and the antecedent set were listed for each barrier and then recorded it in the column of intersection set in Table 6. For barrier no. 1, the intersection set consists of the barrier nos. 1, 2, 4, 5, 7 and 9. The procedure was repeated to determine intersection set for each barrier. The barriers for which the reachability sets and the intersection sets are identical assigned the top level in the ISM hierarchy. In the iteration no. 1, only one barrier (barrier no. 11) is having identical reachability set and intersection set. Hence barrier no. 11 (Slow response to market) is assigned

Table 3 Rules for transformation

The (*i*, *j*) entry in the SSIM	Entry in the initial reachability matrix	
	(*i*, *j*)	(*j*, *i*)
V	1	0
A	0	1
X	1	1
O	0	0

Table 4 Initial reachability matrix for barriers to JIT production

S. no.	Barriers to JIT production	12	11	10	9	8	7	6	5	4	3	2	1
1	Lack of top management commitment and support	0	1	1	1	1	0	1	1	1	0	1	*1*
2	Lack of training and education	1	1	1	1	1	1	1	1	1	0	*1*	1
3	Financial constraints	0	1	0	0	1	0	0	1	1	*1*	1	1
4	Employees' resistance	0	1	1	1	1	0	1	1	*1*	0	0	0
5	Poor facility planning & layout	0	1	0	0	1	0	0	*1*	1	0	1	0
6	Backsliding	0	1	0	0	0	0	*1*	0	0	0	0	0
7	Organizational cultural difference	0	1	1	1	1	*1*	1	0	1	0	0	1
8	Absence of a sound action or planning system	0	1	0	0	*1*	0	1	0	0	0	0	0
9	Lack of information sharing or communication with stakeholders	1	1	1	*1*	1	1	1	1	1	0	1	1
10	Cross-functional conflict	1	1	*1*	0	1	0	1	1	1	0	0	0
11	Slow response to market	0	*1*	0	0	0	0	0	0	0	0	0	0
12	Poor sales forecasting	*1*	1	0	0	1	0	0	0	0	0	0	0

Table 5 Final reachability matrix for barriers to JIT production

S. no.	Barriers to JIT production	12	11	10	9	8	7	6	5	4	3	2	1	Driving power
1	Lack of top management commitment and support	†*1*	1	1	1	1	†*1*	1	1	1	0	1	*1*	11
2	Lack of training and education	1	1	1	1	1	1	1	1	1	0	*1*	1	11
3	Financial constraints	†*1*	1	†*1*	†*1*	1	†*1*	†*1*	1	1	*1*	1	1	12
4	Employees' resistance	†*1*	1	1	1	1	†*1*	1	1	*1*	0	†*1*	†*1*	11
5	Poor facility planning & layout	†*1*	1	†*1*	†*1*	1	†*1*	†*1*	*1*	1	0	1	†*1*	11
6	Backsliding	0	1	0	0	0	0	*1*	0	0	0	0	0	02
7	Organizational cultural difference	†*1*	1	1	1	1	*1*	1	†*1*	1	0	†*1*	1	11
8	Absence of a sound action or planning system	0	1	0	0	*1*	0	1	0	0	0	0	0	03
9	Lack of information sharing or communication with stakeholders	1	1	1	*1*	1	1	1	1	1	0	1	1	11
10	Cross-functional conflict	1	1	*1*	†*1*	1	0	1	1	1	0	†*1*	0	09
11	Slow response to market	0	*1*	0	0	0	0	0	0	0	0	0	0	01
12	Poor sales forecasting	*1*	1	0	0	1	0	†*1*	0	0	0	0	0	04
	Dependence	09	12	08	08	10	07	11	08	08	01	08	07	

Level I in first iteration. This indicates that barrier no. 11 (Slow response to market) is the most dependent barrier. Now discard barrier no. 11 (Slow response to market) from subsequent iterations. It is possible that in a particular iteration, more than one barrier (individually) may have identical reachability set and the intersection set. In such scenario, same level will be assigned to these barriers. For example, refer to iteration 5 (Table 10), barrier nos. 2, 4, 5, 9 and 10 have assigned Level 5 and they are discarded from subsequent iterations.

This iteration is repeated till the levels of each barrier are found out (Tables 6, 7, 8, 9, 10, 11, 12). Level identification process of these barriers is completed in seven iterations.

Final list of Level Partitions is given in Table 13. The identified levels aid in building the final model of ISM. First-level barriers are positioned at the top of model and so on.

Building the ISM-based model

The model developed with the identified barriers to JIT production is shown in Fig. 3. It is clear from the ISM model that the most important barriers that enable successful implementation of JIT production system is financial constraints, which form the base of ISM hierarchy, whereas slow response to market, backsliding, absence of a

Table 6 Level partition—iteration 1

Barrier no.	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 4, 5, 6,7, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 7, 9	1, 2, 4, 5, 7, 9	
2	1, 2, 4, 5, 6,7, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5,7, 9, 10	
3	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	3	3	
4	1, 2, 4, 5, 6,7, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5, 7, 9, 10	
5	1, 2, 4, 5, 6,7, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5, 7, 9, 10	
6	6, 11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12	6	
7	1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 7, 9	1, 2, 4, 5, 7, 9	
8	6, 8, 11	1, 2, 3, 4, 5, 7, 8, 9, 10,12	8	
9	1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5, 7, 9, 10	
10	2, 4, 5, 6, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 7, 9, 10	2, 4, 5, 9, 10	
11	1	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1	I
12	6, 8, 11, 12	1, 2, 3, 4, 5, 7, 9, 10, 12	12	

Table 7 Level partition—iteration 2

Barrier no.	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 4, 5, 6,7, 8, 9, 10, 12	1, 2, 3, 4, 5, 7, 9	1, 2, 4, 5, 7, 9	
2	1, 2, 4, 5, 6,7, 8, 9, 10, 12	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5,7, 9, 10	
3	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12	3	3	
4	1, 2, 4, 5, 6,7, 8, 9, 10, 12	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5, 7, 9, 10	
5	1, 2, 4, 5, 6,7, 8, 9, 10, 12	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5, 7, 9, 10	
6	6	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 2	6	II
7	1, 2, 4, 5, 6, 7, 8, 9, 10,12	1, 2, 3, 4, 5, 7, 9	1, 2, 4, 5, 7, 9	
8	6, 8	1, 2, 3, 4, 5, 7, 8, 9, 10,12	8	
9	1, 2, 4, 5, 6, 7, 8, 9, 10, 12	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5, 7, 9, 10	
10	2, 4, 5, 6, 8, 9, 10, 12	1, 2, 3, 4, 5, 7, 9, 10	2, 4, 5, 9, 10	
12	6, 8, 12	1, 2, 3, 4, 5, 7, 9, 10, 12	12	

Table 8 Level partition—iteration 3

Barrier no.	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 4, 5, 7, 8, 9, 10, 12	1, 2, 3, 4, 5, 7, 9	1, 2, 4, 5, 7, 9	
2	1, 2, 4, 5, 7, 8, 9, 10, 12	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5,7, 9, 10	
3	1, 2, 3, 4, 5, 7, 8, 9, 10, 12	3	3	
4	1, 2, 4, 5, 7, 8, 9, 10, 12	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5, 7, 9, 10	
5	1, 2, 4, 5, 7, 8, 9, 10, 12	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5, 7, 9, 10	
7	1, 2, 4, 5, 7, 8, 9, 10,12	1, 2, 3, 4, 5, 7, 9	1, 2, 4, 5, 7, 9	
8	8	1, 2, 3, 4, 5, 7, 8, 9, 10,12	8	III
9	1, 2, 4, 5, 7, 8, 9, 10, 12	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5, 7, 9, 10	
10	2, 4, 5, 8, 9, 10, 12	1, 2, 3, 4, 5, 7, 9, 10	2, 4, 5, 9, 10	
12	8, 12	1, 2, 3, 4, 5, 7, 9, 10, 12	12	

sound action or planning system and poor sales forecasting which are dependent on other barriers have been appeared on top of the hierarchy.

Table 9 Level partition—iteration 4

Barrier no.	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 4, 5, 7, 9, 10, 12	1, 2, 3, 4, 5, 7, 9	1, 2, 4, 5, 7, 9	
2	1, 2, 4, 5, 7, 9, 10, 12	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5,7, 9, 10	
3	1, 2, 3, 4, 5, 7, 9, 10, 12	3	3	
4	1, 2, 4, 5, 7, 9, 10, 12	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5, 7, 9, 10	
5	1, 2, 4, 5, 7, 9, 10, 12	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5, 7, 9, 10	
7	1, 2, 4, 5, 7, 9, 10,12	1, 2, 3, 4, 5, 7, 9	1, 2, 4, 5, 7, 9	
9	1, 2, 4, 5, 7, 9, 10, 12	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5, 7, 9, 10	
10	2, 4, 5, 9, 10, 12	1, 2, 3, 4, 5, 7, 9, 10	2, 4, 5, 9, 10	
12	12	1, 2, 3, 4, 5, 7, 9, 10, 12	12	IV

Table 10 Level partition—iteration 5

Barrier no.	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 4, 5, 7, 9, 10	1, 2, 3, 4, 5, 7, 9	1, 2, 4, 5, 7, 9	
2	1, 2, 4, 5, 7, 9, 10	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5,7, 9, 10	V
3	1, 2, 3, 4, 5, 7, 9, 10	3	3	
4	1, 2, 4, 5, 7, 9, 10	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5, 7, 9, 10	V
5	1, 2, 4, 5, 7, 9, 10	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5, 7, 9, 10	V
7	1, 2, 4, 5, 7, 9, 10	1, 2, 3, 4, 5, 7, 9	1, 2, 4, 5, 7, 9	
9	1, 2, 4, 5, 7, 9, 10	1, 2, 3, 4, 5, 7, 9, 10	1, 2, 4, 5, 7, 9, 10	V
10	2, 4, 5, 9, 10	1, 2, 3, 4, 5, 7, 9, 10	2, 4, 5, 9, 10	V

MICMAC analysis

Matrice d'Impacts croises-multipication applique' an classment (cross-impact matrix multiplication applied to classification) is abbreviated as MICMAC. The MICMAC principle is based on multiplication properties of matrices (Mudgal et al. 2010; Sharma and Gupta 1995). The objective of the MICMAC analysis is to analyse the driving power and the dependence of the variables (Faisal et al. 2006; Mandal and Deshmukh 1994).

Table 11 Level partition—iteration 6

Barrier no.	Reachability set	Antecedent set	Intersection set	Level
1	1, 7	1, 3, 7	1, 7	VI
3	1, 3, 7	3	3	
7	1, 7	1, 3, 7	1, 7	VI

Table 12 Level partition—iteration 7

Barrier no.	Reachability set	Antecedent set	Intersection set	Level
3	3	3	3	VII

Table 13 Final list of level partitions

Level	Barrier no.	Barrier to JIT production
I	11	Slow response to market
II	6	Backsliding
III	8	Absence of a sound action or planning system
IV	12	Poor sales forecasting
V	2	Lack of training and education
	4	Employees' resistance
	5	Poor facility planning & layout
	9	Lack of information sharing or communication with stakeholders
	10	Cross-functional conflict
VI	1	Lack of top management commitment and support
	7	Organizational cultural difference
VII	3	Financial constraints

The dependence and the driving power of each of these barriers to JIT production are shown in Table 5. In this table, an entry of '1' along the rows and columns indicates the driving power and the dependence, respectively. Subsequently, the driving-dependence power diagram is constructed as shown in Fig. 4. As an illustration, it is observed from Table 5 that barrier no. 6 (Backsliding) is having a driving power of 2 and a dependence of 11. Therefore, in this figure, it is positioned at a place corresponding to a driving power of 2 and a dependency of 11 in the driving-dependence power diagram.

In this analysis, the barriers to JIT production described earlier are classified into four clusters (Fig. 4):

1. Autonomous barriers
2. Dependent barriers
3. Linkage barriers
4. Independent barriers.

Independent barriers cluster consists of financial constraints (barrier no. 3). Finance is the key drivers for implementation of JIT production. Management has to pay maximum attention to financial constraints to get quick and sustainable results. Autonomous cluster has weak driving power and weak dependence. Absence of any barrier in autonomous cluster is observed. Autonomous cluster is relatively disconnected from the whole system and has very few links, which may be strong. It is observed from Fig. 4 that seven barriers to JIT production lie in linkage cluster. These barriers are unstable, in the sense that any action on these barriers will have an effect on others and also a feedback on themselves too. Very high interactions exist among these linkage barriers. Management has to look after linkage barriers with utmost care. Table 14 provides more details about clusters and its characteristics.

Discussion

ISM model

Manufacturing firms all over the world are facing tremendous pressure in present market conditions. Manufacturing firms are adopting lean or JIT production systems to remain competitive. The successful implementation of JIT production will ensure the survival and growth of a company in today's volatile and aggressive market. The JIT production has many benefits, however, also faces some challenging issues related to human, organizational, cultural, leadership and systems. Various challenges like employees resistance, cross-functional conflict, poor facility planning, poor sales forecast, etc. erupt during implementation of JIT production. Interpretive structural modelling (ISM) approach can be used to prioritize the barriers in implementation of JIT production.

Twelve barriers to JIT production have been identified and modelled. Interpretive structural Modelling of the barriers to implement JIT production throws some light on the behavioural characteristics of the barriers. The hierarchical structure of barriers provides platform to analyse the interactions among barriers and roadmap to tackle them in order of significance.

With reference to Fig. 3, ISM model for barrier to JIT production, financial constraints, appears at the final level VII. It indicates that financial constraint is the most important barrier. Change in existing manufacturing system is inevitable to adopt and implement JIT production. For example installation of latest information systems, modifications in shop floor layout and facilities, training for employees and formation of cross functional teams are necessary to implement JIT successfully. Merely willpower of top management is not enough to bring about transition

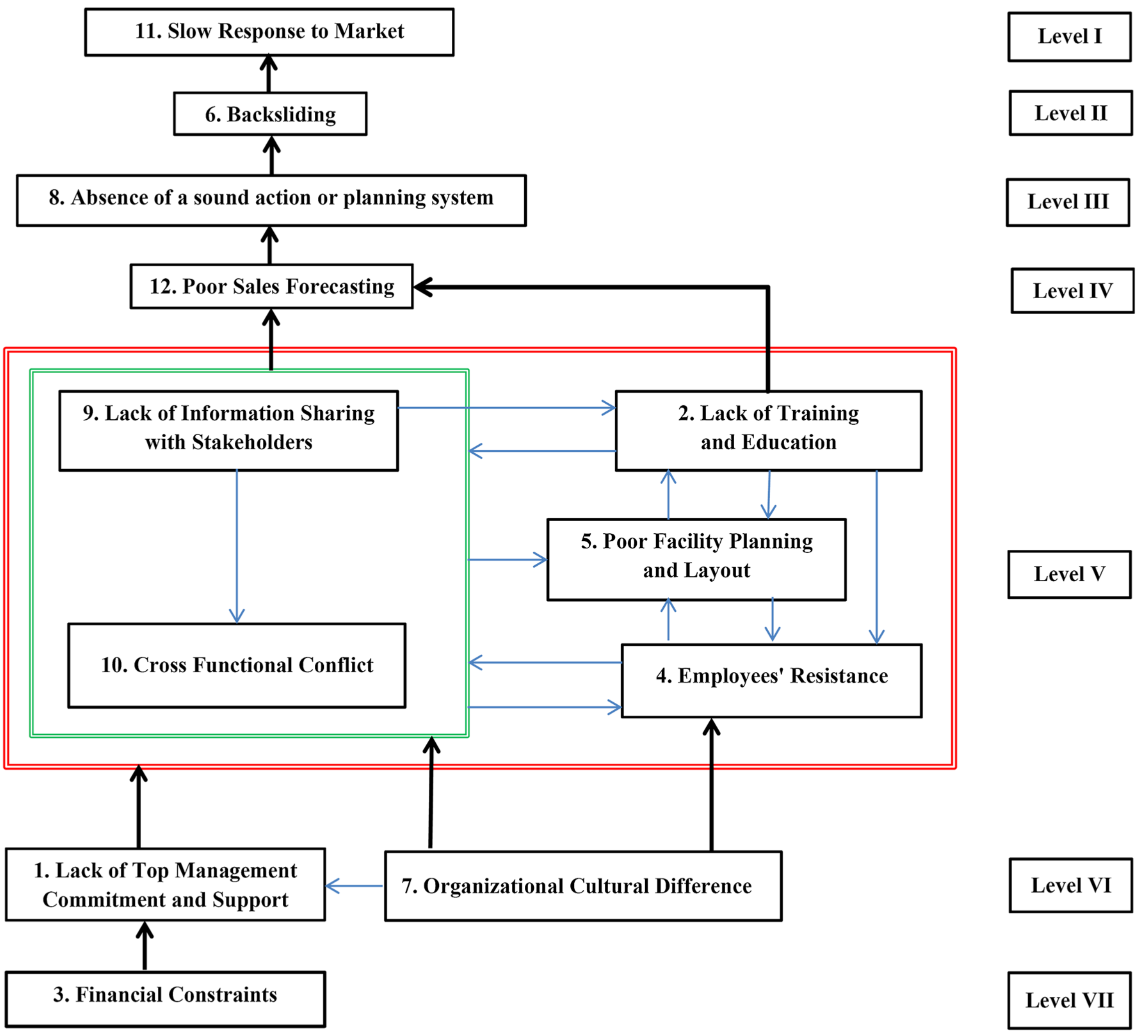


Fig. 3 ISM model for barrier to JIT production

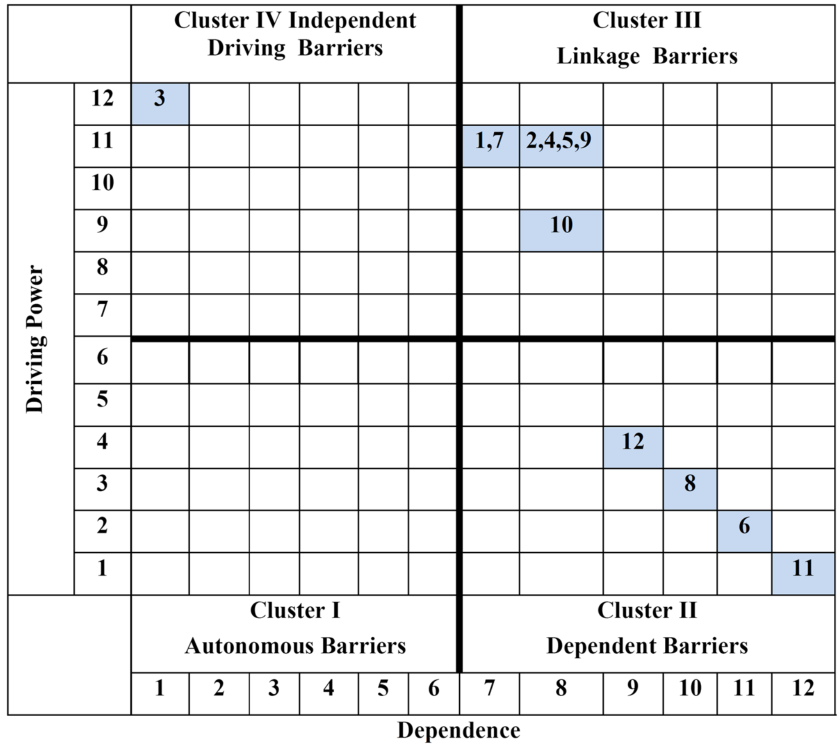
from old production system to JIT production system. Sufficient fund allocation is required to make the appropriate changes. The management has to make the provision of finance for JIT production implementation. Financial constraints influence the decisions of the top management. Hence financial constraint is the main barrier to JIT production implementation.

Nobody wish to come out of comfort zone. Change management comes into picture before implementation, during implementation and after implementation stages. Naturally employees resist changing process. Organizational cultural difference also leads to lack of top management commitment/support as well as employees resistance, cross-functional conflict and lack of information sharing with stakeholders. Lack of training and education has the most destructive effects on the human relationship management. Lack of training and education leads to harden resistance of the employees, inflame conflicts among cross-functional team members, lack of information sharing with stakeholders, poor facility planning and layout which in turn magnifies workers resistance multi-fold.

Linkage barriers contain all above-mentioned barriers which are the most unstable and influencing each other. Sales forecasting requires training and understanding of some statistical techniques as well as accurate inputs from marketing personnel. Effects of linkage barriers result into poor sales forecasting.

Lack of training and education for workers may end in poor knowledge management. It may be evident from the lack of information sharing among the stakeholders and cross-functional conflict. The cross-functional team members belong to various departments like marketing, design, manufacturing, distribution, etc. The cross-functional conflicts lead to poor communication and information sharing among the stakeholders and thus erroneous sales forecasting. Finally, it results into poor/absence of a sound

Fig. 4 Driving-dependence power diagram



action or planning system. As a consequence of these, catastrophic barriers give birth to Backsliding. Backsliding impedes the ability of quick response to the market. More time is consumed due to backsliding (resorting back to old ways of doing things). Slow response to market requirements leads to failure in meeting on-time, in-full delivery of the customer demands.

This paper explores and integrates prior researches on lean or JIT production. It also suggests that lean or JIT production is an effective methodology which offers lot of benefits. Top management and work culture of the organization play significant role in understanding the strategy, its implementation and effective deployment throughout the organization. ISM is used to develop a framework for JIT production.

Testing/Verification of Hypotheses

Four hypotheses were tested by analysing the barrier to JIT production using ISM and MICMAC Analysis. Refer to Fig. 3 (ISM model for Barrier to JIT Production) and Fig. 4 (Driving-Dependence Power Diagram).

(a) Financial constrain is the most independent barrier to JIT production which is at top level VII in ISM model (Fig. 3). The Financial constrain (barrier no. 3) is the most independent driving barrier as shown in Fig. 4 (supporting H1).

(b) Lack of top management commitment and support as well as organizational cultural difference are the next two of the most independent barrier to JIT production which is at level VI in ISM model (supporting H2).

(c) Slow response to market is the most dependent barrier to JIT production which is at level I in ISM model (supporting H3).

(d) High interactions among barrier to JIT production specifically employee resistance, poor facility layout and planning, lack of training and education to employees, lack of information sharing among stakeholders and cross-functional conflicts exist as depicted in at level V (Fig. 3). These barriers are placed in linkage barriers in Fig. 4 (supporting H4).

High performance manufacturing (HPM)

High performance manufacturing (HPM) indicates the capability of a manufacturing firm to accomplish continuous improvement through management of manufacturing practices and thus attain global competitiveness. HPM is a methodical international benchmarking study of manufacturing plants originated in 1989 in the United States under the name world class manufacturing (WCM) and is presently at its fourth round of data collection.

Table 14 Clusters and its characteristics

Cluster no.	Clusters	Characteristics	Driving power	Dependence	JIT barriers
I	Autonomous barriers	These barriers are relatively disconnected from the system, with which they have only few links, which may not be strong	Weak	Weak	
II	Dependent barriers	These barriers are the automatic followers of other barriers	Weak	Strong	Slow response to market Backsliding Absence of a sound action or planning system Poor sales forecasting
III	Linkage barriers	These barriers are unstable, in the sense that any action on these barriers will have an effect on others and also a feedback on themselves	Strong (key variable)	Strong	Lack of information sharing or communication with stakeholders Lack of training and education Employees' resistance Organizational cultural difference Cross-functional Conflict Lack of top management commitment and support Poor facility planning & layout
IV	Independent barriers	These barriers are the key drivers for implementation Management has to pay maximum attention to these barriers to get quick results	Strong (key variable)	Weak	Financial constraints

Since its induction, its main target has been to identify those practices that determine exceptional performance in manufacturing (Hammer 2006; Flynn et al. 1997). The aim of the project is to investigate high-performing plants in order to understand the practices and principles behind superior performance (Hallgren and Olhager 2009). The overall objective of HPM is to increase efficiency and quality of production processes associated with rapid and successful introduction on high-tech materials (Kopac et al. 2006). HPM strategy comprises new developments to reduce primary process times and lead times significantly by the means of enhanced cutting abilities, adapted tooling and machine concepts combined with integrated examination and optimization of the process chain (Herzig et al. 2014). Hence, an interdisciplinary project team comprising experts in the domain of material science, manufacturing technology and manufacturing processes is necessary to define standardised manufacturing HPM strategies though combining apt selections of reference materials (of specific characteristics), machining tools/methods and indicators (like tool wear, specific cutting force, feed, etc.) and optimized manufacturing processes. Figure 5 depicts the relationship among the standardised HPM strategies to define HPM.

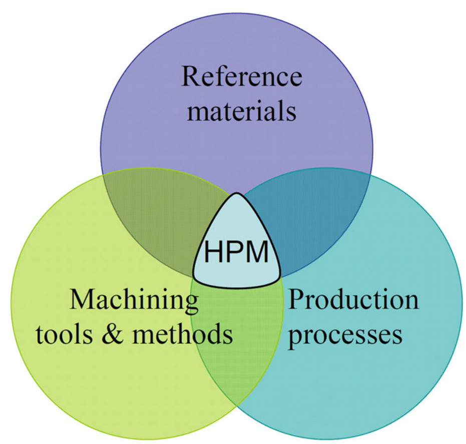


Fig. 5 Definition of standardised HPM strategies. *Source* Kopac et al. (2006)

The following advanced production practices (APPs) are being studied in 4th Round of the HPM project (Machuca et al. 2011): JIT/lean manufacturing (LM), information systems/information technology (IS/IT), total quality management (TQM), technology (T), human resources (HR), new product development (NPD), supply chain management (SCM), total productive maintenance (TPM)

Table 15 JIT/lean barriers and manufacturing practice areas (HPM model)

S. no.	JIT/lean barriers	Manufacturing practice areas (HPM model)
1	Organizational cultural difference	Just-in-time (JIT)/lean manufacturing (LM)
		Total quality management (TQM)
		Total productive maintenance (TPM)
2	The lack of resources to invest/ financial constraints	Theory of constraints (TOC)
	Poor facility planning and layout	
3	Lack of top management commitment and support	Human resources
	Lack of training and education	
	Employees' resistance	
	Backsliding/lack of perseverance	
	Cross-functional conflict	
4	Lack of information sharing or communication with stakeholders	Information systems/ information technology (IS/IT)s
5	Absence of a sound action or planning system	Technology management
6	Slow response to market	Business services (BS)
7	Poor sales forecasting	Supply chain management (SCM)
8	–	New product development (NPD)
9	–	Environment/sustainability (E/S)

and theory of constraints (TOC), environment/sustainability (E/S) and business services (BS).

Table 15 provides the details of JIT/Lean Barriers falling in related manufacturing practice areas of HPM Model.

HPM project offers a solid foundation to manufacturing firms to enhance the capability of their manufacturing processes, particularly processing of new materials to acquire competitive performance. Competitive performance is defined as a manufacturer's attainment of common competitive priorities relative to its competition (Ahmad et al. 2010). Competitive performance has been measured using different measures in the published literature. The most commonly cited measures were cost, quality, flexibility, and delivery (Al-Abdallah et al. 2014; Cua et al. 2001; McKone et al. 2001; Ahmad et al. 2010; Phan et al. 2011). In addition to these measures, we also considered "on time product launch" due to its importance in defining competitive performance in firms (Al-Abdallah et al. 2014; Phan et al. 2011).

The authors of this paper suggest three more operational performance dimensions i.e. creativity and product innovation, human (employees) resources as well as health and safety. These new dimensions have been added in operational performance because ultimately, it enhances the operational performance of the manufacturing system and have impact on other operational performance dimensions. Hence the authors advocate that these practices should be the foundation of HPM project. The suggestive internal performance measures and external performance measures are provided in Table 16. However, it needs more critical evaluation for refinement and enrichment through inclusion of other internal performance measures and external performance measures.

The following definitions are used in this paper.

1. Cost

An amount that has to be paid or given up in order to get something. In business, cost is usually a monetary valuation of (1) effort, (2) material, (3) resources, (4) time and utilities consumed, (5) risks incurred and (6) opportunity forgone in production and delivery of a good or service. (http://www.businessdictionary.com/definition/cost.html).

2. Quality

The process' ability to manufacture products in accordance with predefined reliability and consistency specifications (Ward et al. 1996; Slack and Lewis 2002; Hallgren 2007).

3. Delivery reliability and speed

The ability to make the delivery as planned (on-time delivery) and speed of delivery (Jiménez et al. 2009).

4. Flexibility

The ability to adjust volume and product mix. (Olhager 1993; Hallgren 2007; Hutchison and Das 2007).

5. Product launch

The product launch signifies the point at which consumers first have access to a new product. (http://www.businessdictionary.com/definition/product-launch.html).

6. Creativity and innovation

Creativity is the act of turning new and imaginative ideas into reality. Creativity is characterised by the ability to perceive the world in new ways, to find hidden patterns, to make connections between seemingly unrelated phenomena, and to generate solutions.

Innovation is the implementation of a new or significantly improved product, service or process that creates value for business, government or society.

(http://www.creativityatwork.com/2014/02/17/what-is-creativity/).

Table 16 Some measures of operational performance

Sr. no.	Operational performance dimension	Internal performance measures	External performance measures	Related JIT/lean barriers
1	Cost[a] Jiménez et al. (2009), Schroeder and Flynn (2001), Slack and Lewis (2002), Hallgren (2007)	Production cost per unit	Market price and product price	Poor sales forecasting
2	Quality[a]	Quality control costs and reprocessing costs	Products as per specifications Customer returns PPM (average per annum)	Absence of a sound action or planning system Lack of information sharing or communication with stakeholders Slow response to market
3	Delivery reliability and speed[a] Ward et al. (1996), Hallgren (2007)	'Operation leanness' Leung and Lee (2004), Wan and Chen (2008) Production execution time	On-time delivery, cycle time and fast delivery Original equipment efficiency (OEE) in %	The lack of resources to invest/financial constraints Poor facility planning and layout
4	Flexibility[a] Jiménez et al. (2009)	Lead time	Flexibility in changing product mix and flexibility in changing volume	
5	"On time product launch" Phan et al. (2011)	The speed with which new products are introduced (execution time/development lead time) in the market		The lack of resources to invest/financial constraints
6	Creativity and product innovation performance[b]	'New-value creativeness' Leung and Lee (2004), Wan and Chen (2008) Value added to employee cost ratio	Number of innovative products launched per year	
7	Human (employees) performance[b]	Absenteeism reduction In-process rejection in PPM		Organizational cultural difference Employees' resistance Lack of top management commitment and support Lack of training and education Backsliding/lack of perseverance Cross-functional conflict
8	Occupational Health and safety performance[b]	Fatal accident frequency rate Loss of production time due to accidents Injury severity rate Injury frequency and severity OSHA recordable injuries Lost workdays Worker's compensation costs		

[a] Based on the HPM project

[b] Suggested by the authors

Leung and Lee (2004) identify 'operation Leanness' and 'new-value creativeness' as the two principal competencies of manufacturing firms (Wan and Chen 2008).

7. Human (employees) performance

Accomplishment of a task in accordance with that agreed upon standards of accuracy, completeness and efficiency (http://www.businessdictionary.com/definition/human-performance.html).

Human performance is the valued result of the work of the people working within a System (Tosti and Donald 2006).

8. Occupational Health and safety

Occupational Health and safety is defined by World Health Organization (WHO) as "occupational health deals with all aspects of health and safety in the workplace and has a strong focus on primary prevention of hazards. (http://www.wpro.who.int/topics/occupational_health/en/).

Some measures of operational performance based on the HPM project and suggested by the authors are mentioned in Table 16.

Conclusions

Even though JIT production is one of the most powerful systems, it is not free from barriers. The barriers not only affect the effective implementation but also influence one another. The identification of the barriers which give birth to some more barriers and those which are most influenced by the others would be helpful for the top management to implement JIT production successfully and effectively. It is, therefore, important that researchers to study the interrelationships among these barriers determine the structural hierarchy of barriers.

JIT production can improve the operational performance of the organization. However, little attention has been given to the contextual relationship between pair of barriers to JIT production in the literature. The Lean/JIT practitioners may be interested in knowing the relative significance, influence and inherent structure of barriers to JIT production. This paper makes an attempt to fill the research gaps by providing the answers to the queries concerning the Lean/JIT practitioners. It will be very helpful for organization to focus on critical barriers for successful implementation of JIT production and achieve operational excellence.

Secondary data have been used in this research. It includes compilation of research articles, web articles, survey reports, thesis, books, etc. on JIT production in manufacturing industry. The prime objective of the paper is to expose the hidden structure of barriers to JIT production using ISM. ISM makes use of the collective acumen of Lean/JIT practitioners. It offers prioritize structure of the barriers to JIT production so that managers can prepare an action plan to tackle these barriers.

Twelve barriers to JIT production have been identified and analyse to expose the inherent structure in the order of independence using ISM. It indicates that financial constraint (barrier no. 3-cluster I) is the most independent barrier. Many shop floor modifications are necessary to implement JIT for which lot of fund is required. Financial constraints have tremendous impact on the decisions of the top management for JIT implementation. Hence financial constraint is the prime barrier to JIT production implementation. Lack of top management commitment and support (barrier no. 1) and organizational cultural difference (barrier no. 7) are next level barriers. Lack of top management commitment is dependent on the financial constraints and organizational cultural difference. Lot of interactions are taking place among barriers number 2, 4, 5, 9 and 10. It indicates that lot of interdependences are existing. All these barriers are Linkage barriers (Cluster III). Very high interactions exist among these linkage barriers. If these barriers are not handled properly then probability of JIT failure is very high. Barrier no. 12, 8, 6 and finally 11 (cluster II) are mentioned in the order of increasing dependence. Slow response to market (barrier no. 11) is the most dependent barrier. The ISM depicts the hierarchical structure of barriers to JIT production starting from the most independent barrier to most dependent barrier. The interpretive structural modelling and MICMAC analysis of barriers to JIT production provide a structural framework to prepare strategies to alleviate the adverse effects and impact of JIT barriers.

This paper makes three broad conceptual contributions. First, it identifies barriers for successful accomplishment of JIT production; second, it provides brief description of twelve barriers; and third, this research paper offers an interpretive structural model as a launching pad for taking appropriate action to deal with barriers in the successful JIT production. The success of global manufacturing strategies such as JIT production will not only be entirely based on application of proper tools and techniques alone but also on the interactions among top management, employees and environment or culture. Top management can play pivotal role in how the strategy is understood, implemented and deployed effectively throughout the organization.

Limitations and suggestions for future research

This paper primarily focused on JIT production in manufacturing segment and secondarily focused on other segments. The JIT implementation issues in other sectors may slightly differ from manufacturing segment. The issues may vary from country to country, work culture of the organization and geographic location within the country. The model is not statistically validated.

Once the barriers for JIT production are identified, the interaction among the barriers can be analysed using other modelling techniques like ANP or AHP. The ISM model can be statistically validated using Structural Equation

Modelling. Implementation strategy can be developed for successful and sustainable implementation of JIT production using tools like quality function deployment (QFD), failure mode and effect analysis (FMEA), Balance Score Card and Hoshin Kanari policy deployment, etc. Research work in this area may act as a roadmap for successful JIT implementation. It would be a light house to lean/JIT practitioners and researchers.

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J. R. Jadhav obtained his Bachelor of Engineering in Mechanical Engineering from Visvesvaraya Regional College of Engineering, Nagpur (India) in 1995. He completed his Master of Technology in Reliability Engineering from Indian Institute of Technology, Mumbai in 2007. He is a senior faculty in the Mechanical Engineering Department at K. J. Somaiya Polytechnic, Mumbai. He has more than 16 years of experience in Technical education. He is presently pursuing Ph.D. from Mumbai University, India. His current areas of research include lean, six sigma and innovation. He has specialization in Lean, Six Sigma, TRIZ, ISO, TQM, TPM, SPC, Kaizen and quality circles. He is practicing consultant and corporate trainer in quality. As a six sigma black belt and lean practitioner, he has trained over 500 professionals in lean, six sigma, quality and business excellence. He has also executed many quality improvement projects in Indian and multinational industries. Fifteen of his research papers have been accepted/published in International Journal, International Conferences and National Journals.

S. S. Mantha is the Chairman of All India Council for Technical Education (AICTE). His current areas of research include CAD/CAM/CAE, Robotics, Automation, Supply Chain Management, etc. He has more than 30 years of experience in Technical education. He has published number of papers in reputed national and international journals as well as conferences.

S. B. Rane is a Associate Professor in Mechanical Engineering Department, Sardar Patel College of Engineering. His current areas of research include Supply Chain Management, Lean, Six Sigma, Industrial Engineering, Manufacturing Management, etc. He has more than 19 years of experience in Technical education. He has published a more than 25 papers in National and International Conferences. He has also published paper in International Journal.