Int J Syst Assur Eng Manag
DOI 10.1007/s13198-012-0122-9

ORIGINAL ARTICLE

Analysis of barriers of total productive maintenance (TPM)

Rajesh Attri · Sandeep Grover · Nikhil Dev · Deepak Kumar

Received: 28 January 2012 / Revised: 31 July 2012

Abstract In the highly competitive environment, to be successful and to achieve world-class-manufacturing, organizations must possess both efficient maintenance and effective manufacturing strategies. A strategic approach to improve the performance of maintenance activities is to effectively adapt and implement strategic TPM initiatives in the manufacturing organizations. Total productive maintenance (TPM) is not easy to adopt and implement, due to presence of many barriers. The purpose of this paper is to identify and analyse these barriers. A questionnaire based survey was conducted to rank these barriers. The results of this survey and interpretive structural modelling approach have been used to model and analyse key barriers and drive managerial insights.

Keywords TPM · Total productive maintenance · Barriers · ISM · Interpretive structural modelling

1 Introduction

In the highly competitive environment, to be successful and to achieve world-class-manufacturing, organizations must possess both efficient maintenance and effective manufacturing strategies. A strategic approach to improve the performance of maintenance activities is to effectively adapt and implement strategic TPM initiatives in the manufacturing organizations. TPM has been accepted as the most promising strategy for improving maintenance performance in order to succeed in a highly demanding market arena (Nakajima 1988; Ahuja and khamba 2008c).

TPM is a structured equipment-centric continuous improvement process that strives to optimise production effectiveness by identifying and eliminating equipment and production efficiency losses throughout the production system life-cycle through active team-based participation of employees across all levels of the operational hierarchy. The goal of the TPM program is to markedly increase production while at the same time increasing employee morale and job satisfaction. TPM has emerged as a potent means to improve overall company performance (Ahuja and Kumar 2009).

TPM is a partnership between maintenance and production functions in the organization to improve product quality, reduce waste, reduce manufacturing cost, increase equipment availability, and improve the company's state of maintenance (Rhyne 1990). Though TPM provides a lot of benefits but implementation of TPM is not an easy task. Mora (2002) has stated that though in recent years, many companies have attempted to implement TPM programs, <10 % of companies succeed in implementing TPM as it requires the change of the organizational culture and change of existing behaviours of all employees, operators, engineers, maintenance technicians, and managers. Hartmann (2000) has stated that at least every second attempt of installation of total productive maintenance (TPM) has resulted in failure.

Moreover in several articles the reasons for TPM failure are discussed (Ljungberg 1998; Ireland and Dale 2001;

R. Attri (✉) · S. Grover · N. Dev
Department of Mechanical Engineering,
YMCA University of Science & Technology,
Faridabad 121006, India
e-mail: rajeshattri2005@gmail.com

D. Kumar
Department of Mechanical Engineering,
Advanced Institute of Technology & Management,
Palwal 121105, India

Published online: 14 August 2012

Bamber et al. 1999; Bakerjan 1994; Davis 1997; Cooke 2000; Ahuja and Khamba 2008a, b; Crawford et al. 1988; Becker 1993; Riis et al. 1997; Patterson et al. 1995; Lawrence 1999; Rodrigues and Hatakeyama 2006; Maggard and Rhyne 1992; Fredendall et al. 1997; Chan et al. 2005) and suggestions for implementing TPM are developed (Wang 2006; Sharma et al. 2006; Joeng and Phillips 2001; Cooke 2000; Blanchard 1997; Cigolini and Turco 1997; Hartmann 1992; Kaizen 1997; Suzuki 1992; McAdam and Duffner 1996; Ahuja and Khamba 2008a; Chan et al. 2005; Park and Han 2001).

Furthermore, the literature review suggest that no study has been taken that investigate explicitly the interactions among the barriers of TPM and proposes an interpretive structural modelling (ISM) based model for the TPM barriers. This paper attempts to identify the barriers of TPM through literature review and expert opinions and further develops the contextual relationships among these identified barriers using ISM approach. It also proposes a hierarchy of TPM barriers model that would help the managers of organizations to understand and to pay attention to the identified barriers for the successful implementation of TPM.

The main objectives of this paper are as follows:

- To identify and rank the barriers in the implementation of TPM in India.
- To find out the interaction among identified barriers using ISM.
- To discuss managerial implication of this research and suggest directions for future research.

This paper is further organised as follows. The next section represents the identification of various TPM barriers through the findings of literature survey and discussion with experts. This is followed by discussion of ISM methodology and development of the relationships model using ISM. Finally, the discussion and conclusion of this research study are presented, which is followed by scope for future work.

2 Identification of barriers in TPM implementation

Literature review and experiences of maintenance and production managers and academicians reveal that implementation of TPM is not an easy task by any means as it requires establishing new cultures (Patterson et al. 1996), changing attitudes (Turbide 1995), creating new work environment's (Maggard and Rhyne 1992), accomplishing paradigm shifts (Jeszenka 1993) and shifting the responsibility of the maintenance department to being everyone's responsibility (Lawrence 1999). The purpose of this paper is to identify and analyse these barriers and develop strategies to tackle them effectively.

Bakerjan (1994), Adam et al. (1997), Co et al. (1998), Jostes and Helms (1994), Chan et al. (2005), Davis (1997), Rodrigues and Hatakeyama (2006) have attributed lack of top management support and understanding as the major obstacle for the failure of TPM implementation. The lack of management support is attributed to management not completely understanding the true goal of the TPM program. For example if management consider that TPM is a means to reduce maintenance staff, they have failed to understand the true goal and purpose of the program. The real goal is to increase the equipment's effectiveness, not reduce the labour head-count (Bamber et al. 1999). In order to successfully implement TPM, companies must have top management support, understanding and commitment, along with training and motivation of everyone in the organization (Patterson et al. 1996; Park and Han 2001). The role of top management's commitment and leadership has been frequently emphasized in many literatures to have the decisive influence over successful TPM implementation (Tsang and Chan 2000). Patterson et al. (1995) explained that to successfully implement TPM, an organization must be led by top management that is supportive understanding and committed to the various kinds of TPM activities.

Lack of training and education has been considered as the major obstacle for the failure of TPM implementation by Bakerjan (1994), Chan et al. (2005), Adam et al. (1997), Co et al. (1998), Rodrigues and Hatakeyama (2006). Davis (1997) has outlined lack of education and training as the main reason for TPM failure within UK manufacturing organizations. Lack of training will inevitably lead to a decrease in overall equipment effectiveness and result in failure to adopt new and improved methods. To make TPM become a successful part of factory life will take considerable effort to change mindsets from a traditional maintenance approach (Bamber et al.1999). Ahuja and Khamba (2008b), Crawford et al. (1988), Becker (1993) have also specified lack of training as the prominent problem in TPM implementation. Maggard and Rhyne (1992) stated that training and education is crucial to the success of TPM. The importance of training is also highlighted by Turbide (1995) and Moore (1997). Swanson (1997) has emphasized upon worker training as a key component for successful implementation of TPM in an organization. Blanchard (1997) pointed out that training and educational issues had become one of the critical factors to establish successful TPM implementation, where proper education begin as early as during the TPM introduction and initial preparation stages. Chan et al. 2005 have also found training as the critical success factor in implementation of TPM in an electronics manufacturing company.

Bamber et al. (1999) have found motivation of management and workforce as a factor affecting successful implementation of TPM in UK manufacturing organizations. Ahuja and khamba (2008a, b) have stated that lack of motivation on part of employees to contribute effectively towards organizational development and sustainability efforts as the behavioural obstacle affecting the successful TPM implementation in Indian manufacturing organizations.

Ahuja and Khamba (2008b) have stated that companies that have experienced failure in the TPM implementation programs have often neglected the total employee involvement. Riis et al. (1997), Cooke (2000) has also attributed reluctance of individuals as a significant contributor for the failure of TPM implementation program. In TPM, maintenance goes from being the responsibility of the maintenance department to being everyone's responsibility. Such change is often resisted by both production and maintenance personnel. Production employees and managers are reluctant to accept responsibility for maintenance activities due to concerns about whether or not production employees have sufficient skill and/or time to perform maintenance tasks. Maintenance workers, likewise, are reluctant to give maintenance responsibilities to production employees out of fear that production employees will not perform maintenance tasks appropriately and that the maintenance department will be forced to "fix" the problems that production employees create (Lawrence 1999).

Lawrence (1999) has stated that many TPM programs fail because the organizations are unable to change their culture. The biggest challenge before the organization is to be able to make radical transformation in the organization's culture for ensuring overall employee participation towards the maintenance and manufacturing performance improvement through TPM initiatives. The focused and concerted efforts have to be made by the top management to bring about motivating organization culture by creating awareness to the employees about the true potential of TPM and by communicating to the employees about the contributions of TPM towards the employees in particular (Ahuja and Khamba 2008a, b). Crawford et al. (1988), Becker (1993) has also specified cultural resistance as the prominent problem in TPM implementation.

Failure to allow sufficient time for evolution has been considered as the major obstacle for the failure of TPM implementation by Bakerjan (1994). The time required to change from a reactive program to a proactive approach will be considerable by some estimates it may be a three to 5 year venture before achieving a competitive venture for the TPM program. TPM must be seen as a long-term commitment to strive for zero losses and not a way of obtaining short-term fixes (McCarthy 1997; Bamber et al. 1999).

Ahuja and Khamba (2008a, b) have found that low synergy and coordination between maintenance and production department as the important obstacle affecting successful implementation in Indian manufacturing organizations. Employee relations and coordination/relations between departments influence the performance of the organizational system and consequently determine the nature and extent of TPM implementation.

Ahuja and Khamba (2008b), Crawford et al. (1988), Becker (1993) have specified lack of organizational communication as the prominent problem in TPM implementation. Lack of communication will result into less employee participation in the TPM activities which in turn results into TPM failure.

Ahuja and Khamba (2008a) have reported financial obstacle as a significant factor affecting the successful TPM implementation in Indian manufacturing organizations. Baglee (2008) conducted a survey in England SMEs regarding maintenance strategy development for SMEs, founded that, majority of responses (80 %) claimed that the adoption of a new maintenance initiative is usually constrained by the lack of finances.

Ahuja and Khamba (2008b) have stated that the failure of the organizations to successfully harness the true potential of TPM can also be attributed to confusion over what exactly constitutes TPM, understanding the importance of knowledge, inconsistent and unclear expectations, neglecting the basics. Due to lack of knowledge of TPM, workers fear that the only drive is to improve production efficiency, reduce labour, and increase employee workload. Many operators do not want additional responsibility and are happy with the situation the way it is. In addition the skilled trades enjoy feeling indispensable and think that the autonomous maintenance activity threatens their job security (McAdam and Duffner 1996).

Based on the extent literature review and discussions with experts (both from industry and academia), the barriers were identified and used in questionnaire survey. In this paper, barriers with high mean score in questionnaire survey were included for analysis by ISM approach. Besides this, some barriers like lack of structural format, lack of sustained momentum, no delegate person, inexperienced consultants/trainers were excluded from the study due to very low mean score in the survey. These barriers are enlisted in Table 1 along with their references/sources.

Moreover, the barriers like no associates training on TPM know-how, lack of sufficient training, lack of personal training, lack of education and training for employees, lack of management support, lack of top management and understanding, lack of commitment of top management, lack of top management involvement, lack of awareness of TPM principles which are often cited with different names and headings are covered in this paper under a common barrier name like lack of training and education, lack of top management commitment and support, lack of understanding

Table 1 TPM barriers and their references/sources

S. No	TPM barriers	Notation	References/sources
1	Lack of top management commitment and support	B_1	Bakerjan (1994), Adam et al. (1997), Co et al. (1998), Jostes and Helms (1994), Chan et al. (2005), Davis (1997), Rodrigues and Hatakeyama (2006), Bamber et al. (1999)
2	Lack of training and education	B_2	Bakerjan (1994), Chan et al. (2005), Adam et al. (1997), Co et al. (1998), Rodrigues and Hatakeyama (2006), Davis (1997), Bamber et al. (1999), Ahuja and Khamba (2008b), Crawford et al. (1988), Becker (1993)
3	Lack of motivation	B_3	Bamber et al. (1999), Ahuja and Khamba (2008a, b)
4	Employee resistance	B_4	Ahuja and Khamba (2008b), Riis et al. (1997), Cooke (2000), Lawrence (1999)
5	Cultural resistance	B_5	Lawrence (1999), Ahuja and Khamba (2008a, b), Crawford et al. (1988), Becker (1993)
6	Failure to allow sufficient time for the evolution	B_6	Bakerjan (1994), McCarthy (1997), Bamber et al. (1999)
7	Poor relation between production and maintenance department	B_7	Ahuja and Khamba (2008a, b)
8	Lack of communication	B_8	Ahuja and Khamba (2008b), Crawford et al. (1988), Becker (1993)
9	Financial constraints	B_9	Ahuja and Khamba (2008a), Baglee (2008)
10	Lack of understanding and knowledge of TPM	B_{10}	Ahuja and Khamba (2008b), McAdam and Duffner (1996)

and knowledge of TPM. Hence, these 10 barriers are assumed to be major barriers that hinder the successful implementation of TPM.

3 Methodology

In this research, questionnaire-based survey and ISM approach have been used to achieve the research objectives. These methodologies and the respective results are separately discussed in the following sections.

3.1 Questionnaire-based survey

The main purpose of the questionnaire-based survey was to facilitate experts in developing a relationship matrix as a first step towards developing an ISM-based model. The questionnaire was designed on a five-point Likert scale and respondents were asked to indicate the importance of 10 listed barriers on this five-point Likert scale. On this scale, '1' and '5' correspond to 'very low' to 'very high', respectively.

The questionnaire was administered to companies from Indian manufacturing industries. In total, questionnaires were sent to 108 Indian companies. Out of the 108 questionnaires, 28 completed questionnaires were received. This gives a response rate of 25.92 %. Whereas higher response rates are better, response rates below 20 % are extremely undesirable for survey findings (Yu and Cooper 1983). Malhotra and Grover (1998) have suggested a response rate of 20 % for positive assessment of the surveys. On the basis of responses, the company data of 28 respondents is presented in Table 2 and the barriers are presented in the decreasing order of their significance in Table 3.

Table 2 Data of the responding companies

S. No	Description of data	Range	Percentage of firms
1.	Number of employees	<100	3
		101–500	25
		501–1,000	40
		1,001–3,000	17
		>3,000	15
2.	Turnover (US $ million)	<10	8
		10–20	39
		20–100	31
		100–200	10
		200–400	7
		>400	5

3.2 ISM approach

ISM is a qualitative tool that was developed by Warfield with the objective of understanding the complex relationships

Table 3 Rank and mean score of Barriers in the implementation of TPM

S. No	Barriers in the implementation of TPM	Mean score	Rank
1	Lack of top management commitment and support (B_1)	3.53	1
2	Lack of training and education (B_2)	3.41	2
3	Lack of motivation (B_3)	3.29	3
4	Employee resistance (B_4)	3.01	4
5	Cultural resistance (B_5)	2.56	5
6	Failure to allow sufficient time for the evolution (B_6)	2.14	6
7	Poor relation between production and maintenance department (B_7)	2.11	7
8	Lack of communication (B_8)	1.98	8
9	Financial constraints (B_9)	1.67	9
10	Lack of understanding and knowledge of TPM (B_{10})	1.62	10

among elements related to a subject (Sahney 2008; Borade and Bansod 2011). The ISM is a process that enables individuals or groups to develop a map of the complex relationships among elements in a complex situation and to calculate binary matrix, called adjacency matrix, to present the relations of the elements (Huang et al. 2005). Its basic idea is to use expert's practical experience and knowledge to decompose a complicated system into several subsystems (elements) and to construct a multilevel structural model (Warfield 1974a, b; Lee and Lin 2011). ISM helps to impose order and direction on the complex relationships among the variables of the system (Warfield 1974a; Sage 1977).

The ISM methodology is interpretive from the fact that as the judgment of the group decides whether and how the variables are related. It is structural too, as on the basis of relationship; an overall structure is extracted from the complex set of variables. It is a modeling technique in which the specific relationships of the variables and the overall structure of the system under consideration are portrayed in a digraph model. ISM is primarily intended as a group learning process, but it can also be used individually (Borade and Bansod 2011; Singh and Kant 2008; Ravi and Shankar 2005; Raj and Attri 2011; Mandal and Deshmukh 1994; Pandey et al. 2005; Singh et al. 2007).

The various steps involved in ISM modelling are as follows.

Step 1 Different elements (or variables), which are related to defined problems, are identified and enlisted by a survey or group problem-solving technique. After this, a contextual relationship is established among elements with respect to whom the pairs of barriers would be examined.

Step 2 A structural self-interaction matrix (SSIM) is developed for elements. This matrix indicates the pairwise relationship among elements of the system. This matrix is checked for transitivity. Transitivity of the contextual relation is basic assumption in ISM, which states that if an element X is related to Y and Y is related to Z, then X is necessarily related to Z.

Step 3 A Reachability Matrix is developed from the SSIM.

Step 4 The Reachability Matrix is partitioned into different levels.

Step 5 The Reachability Matrix is converted into its conical form.

Step 6 Based upon the above, a directed graph (digraph) is drawn and transitivity links are removed.

Step 7 Digraph is converted into an ISM model by replacing nodes of the elements with statements.

Step 8 Finally, the ISM model is checked for conceptual inconsistency and necessary modifications are incorporated.

ISM can be used at a high level of abstraction such as needed for long range planning. It can also be used at a more concrete level to process and structure details related to a problem or activity such as process design, career planning, strategic planning, engineering problems, product design, process re-engineering, complex technical problems, financial decision making, human resources, competitive analysis and electronic commerce (Chidambaranathan et al. 2009; Li et al. 2003; Banwet and Arora 1999; Rajesh et al. 2007). ISM is used by a number of researchers (Talib et al. 2011; Lee and Lin 2011; Borade and Bansod 2011; Raj and Attri 2011; Kuo et al. 2010; Pramod and Banwet 2010; Georgakopoulos 2009; Chidambaranathan et al. 2009; Singh and Kant 2008; Thakkar et al. 2007, 2008; Qureshi et al. 2007; Faisal et al. 2006, 2007a, b; Singh et al. 2003, 2007; Rajesh et al. 2007; Raj et al. 2007; Agarwal et al. 2006; Ravi et al. 2005; Ravi and Shankar 2005; Jharkharia and Shankar 2004, 2005; Bolanos et al. 2005; Banwet and Arora 1999; Sharma et al. 1995; Mandal and Deshmukh 1994; Saxena et al. 1990, 1992) to develop a better understanding of the systems under consideration.

The various steps, which lead to the development of an ISM model, are illustrated below.

3.2.1 Structural Self-Interaction Matrix (SSIM)

ISM methodology suggests the use of the expert opinions based on various management techniques such as brain storming, nominal group technique, etc. in developing the contextual relationship among the variables (Ravi and

Shankar 2005; Hasan et al. 2007; Barve et al. 2007). In this research, experts from the industry and academia were consulted in identifying the nature of contextual relationship among the barriers of TPM implementation. These experts from the industry and academia were well conversant with maintenance practices of the industrial organisations. For analysing the barriers, a contextual relationship of 'leads to' or 'influences' type is chosen. This means that one barrier influences another barrier. On the basis of this, contextual relationship between the identified barriers is developed.

Keeping in mind the contextual relationship for each barrier and the existence of a relationship between any two barriers (*i* and *j*), the associated direction of the relationship is questioned. The following four symbols have been used to denote the direction of relationship between two barriers (*i* and *j*):

- *V* for the relation from barrier *i* to barrier *j* (i.e., barrier *i* will influence barrier *j*)
- *A* for the relation from barrier *j* to barrier *i* (i.e., barrier *i* will be influenced by barrier *j*)
- *X* for both direction relations (i.e., barriers *i* and *j* will influence each other)
- *O* for no relation between the barriers (i.e., barriers *i* and *j* are unrelated).

Based on the contextual relationships, the SSIM is developed. To obtain consensus, the SSIM was further discussed by a group of experts. On the basis of their responses, SSIM has been finalised and it is presented in Table 4.

3.2.2 Reachability matrix

The next step in ISM approach is to develop an initial reachability matrix from SSIM. For this, SSIM is converted into the initial reachability matrix by substituting the four symbols (i.e., V, A, X or O) of SSIM by 1 or 0 s in the initial reachability matrix.

The rules for this substitution are as follows:

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

Following these rules, the initial reachability matrix is prepared as shown in Table 5.

1* entries are included to incorporate transitivity to fill the gap, if any, in the opinion collected during development of structural self-instructional matrix. After incorporating the transitivity concept as described above, the final reachability matrix is obtained and is presented in Table 6.

3.2.3 Level partitions

From the final reachability matrix, for each barrier, reachability set and antecedent sets are derived. The reachability set consists of the barrier itself and the other barrier that it may impact, whereas the antecedent set consists of the barrier itself and the other barrier that may impact it. Thereafter, the intersection of these sets is derived for all the barriers and levels of different barriers are determined. The barriers for which the reachability and the intersection sets are the same occupy the top level in the ISM hierarchy. The top-level barriers are those barriers that will not lead the other barriers above their own level in the hierarchy. Once the top-level barrier is identified, it is removed from consideration. Then, the same process is repeated to find out the barriers in the next level. This process is continued until the level of each barrier is found. These levels help in building the diagraph and the ISM model. In the present case, the 10 barriers, along with their reachability set, antecedent set, intersection set and levels, are presented in Tables 7, 8, 9, 10, 11, 12, 13.

Table 4 Structural self-interactive matrix (SSIM)

Barrier (B_i)	B_{10}	B_9	B_8	B_7	B_6	B_5	B_4	B_3	B_2
B_1	V	X	V	O	V	V	V	V	V
B_2	X	A	V	A	O	V	V	O	
B_3	V	A	O	V	O	V	V		
B_4	A	A	A	O	V	X			
B_5	O	O	O	A	O				
B_6	A	A	A	A					
B_7	O	O	V						
B_8	V	O							
B_9	O								

Table 5 Initial reachability matrix

Barrier (B_i)	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}
B_1	1	1	1	1	1	1	0	1	1	1
B_2	0	1	0	1	1	0	0	1	0	1
B_3	0	0	1	1	1	0	1	0	0	1
B_4	0	0	0	1	1	1	0	0	0	0
B_5	0	0	0	1	1	0	0	0	0	0
B_6	0	0	0	0	0	1	0	0	0	0
B_7	0	1	0	0	1	1	1	1	0	0
B_8	0	0	0	1	0	1	0	1	0	1
B_9	1	1	1	1	0	1	0	0	1	0
B_{10}	0	1	0	1	0	1	0	0	0	1

Table 6 Final reachability matrix

Barrier (B_i)	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}
B_1	1	1	1	1	1	1	1*	1	1	1
B_2	0	1	0	1	1	1*	0	1	0	1
B_3	0	0	1	1	1	1*	1	0	0	1
B_4	0	0	0	1	1	1	0	0	0	0
B_5	0	0	0	1	1	0	0	0	0	0
B_6	0	0	0	0	0	1	0	0	0	0
B_7	0	1	0	1*	1	1	1	1	0	1*
B_8	0	1*	0	1	1*	1	0	1	0	1
B_9	1	1	1	1	1*	1	1*	1*	1	1*
B_{10}	0	1	0	1	1*	1	1*	0	0	1

* Entries are included to incorporate transitivity

Table 7 Iteration 1

Barriers (B_i)	Reachability set R (B_i)	Antecedent set A (B_i)	Intersection set R (B_i) ∩ A (B_i)	Level
B_1	B_1, B_2, B_3, B_4, B_5, B_6, B_7, B_8, B_9, B_{10}	B_1, B_9	B_1, B_9	
B_2	B_2,B_4, B_5, B_6, B_8, B_{10}	B_1, B_2, B_7, B_8, B_9, B_{10}	B_2, B_8, B_{10}	
B_3	B_3, B_4, B_5, B_6, B_7, B_{10}	B_1, B_3, B_9	B_3	
B_4	B_4, B_5, B_6	B_1, B_2, B_3, B_4, B_7, B_8, B_9, B_{10}	B_4	
B_5	B_5, B_6	B_1, B_2, B_3, B_4, B_5, B_7, B_8, B_9, B_{10}	B_5	
B_6	B_6	B_1, B_2, B_3, B_4, B_5, B_6, B_7, B_8, B_9, B_{10}	B_6	**I**
B_7	B_2, B_4, B_5, B_6, B_7, B_8, B_{10}	B_1, B_3, B_7, B_9, B_{10}	B_7, B_{10}	
B_8	B_2, B_4, B_5, B_6, B_8, B_{10}	B_1, B_2, B_7, B_8, B_9	B_2, B_8	
B_9	B_1, B_2, B_3, B_4, B_5, B_6, B_7, B_8, B_9, B_{10}	B_1, B_9	B_1, B_9	
B_{10}	B_2, B_4, B_5, B_6, B_7, B_{10}	B_1, B_2, B_3, B_7, B_8, B_9, B_{10}	B_2, B_{10}	

3.2.4 Conical matrix

A conical matrix is developed by clustering barriers in the same level across the rows and columns of the final reachability matrix, as shown in Table 14. The drive power of a factor (barrier in this case) is derived by summing up the number of ones in the rows and its dependence power by summing up the number of ones in the columns (Raj et al. 2007, 2012; Attri et al. 2012; Raj and Attri 2011). Next, drive power and dependence power ranks are calculated by giving highest ranks to the barriers that have the maximum number of ones in the rows and columns, respectively.

3.2.5 Digraph

From the conical form of reachability matrix (Table 14), the initial digraph including transitive links is obtained. It is generated by nodes and lines of edges (Raj et al. 2007, 2012; Attri et al. 2012; Raj and Attri 2011). After removing the indirect links, a final digraph is developed (Fig. 1). A digraph is used to represent the elements (barriers)

Table 8 Iteration 2

Barriers (B_i)	Reachability set R (B_i)	Antecedent set A (B_i)	Intersection set R (B_i) ∩ A (B_i)	Level
B_1	B_1, B_2, B_3, B_4, B_5, B_7, B_8, B_9, B_{10}	B_1, B_9	B_1, B_9	
B_2	B_2,B_4, B_5, B_8, B_{10}	B_1, B_2, B_7, B_8, B_9, B_{10}	B_2, B_8, B_{10}	
B_3	B_3, B_4, B_5, B_7, B_{10}	B_1, B_3, B_9	B_3	
B_4	B_4, B_5,	B_1, B_2, B_3, B_4, B_7, B_8, B_9, B_{10}	B_4	
B_5	B_5	B_1, B_2, B_3, B_4, B_5, B_7, B_8, B_9, B_{10}	B_5	**II**
B_7	B_2, B_4, B_5, B_7, B_8, B_{10}	B_1, B_3, B_7, B_9, B_{10}	B_7, B_{10}	
B_8	B_2, B_4, B_5, B_8, B_{10}	B_1, B_2, B_7, B_8, B_9	B_2, B_8	
B_9	B_1, B_2, B_3, B_4, B_5, B_7, B_8, B_9, B_{10}	B_1, B_9	B_1, B_9	
B_{10}	B_2, B_4, B_5, B_7, B_{10}	B_1, B_2, B_3, B_7, B_8, B_9, B_{10}	B_2, B_{10}	

Table 9 Iteration 3

Barriers (B_i)	Reachability set R (B_i)	Antecedent set A (B_i)	Intersection set R (B_i) ∩ A (B_i)	Level
B_1	B_1, B_2, B_3, B_4, B_7, B_8, B_9, B_{10}	B_1, B_9	B_1, B_9	
B_2	B_2,B_4, B_8, B_{10}	B_1, B_2, B_7, B_8, B_9, B_{10}	B_2, B_8, B_{10}	
B_3	B_3, B_4, B_7, B_{10}	B_1, B_3, B_9	B_3	
B_4	B_4	B_1, B_2, B_3, B_4, B_7, B_8, B_9, B_{10}	B_4	III
B_7	B_2, B_4, B_7, B_8, B_{10}	B_1, B_3, B_7, B_9, B_{10}	B_7, B_{10}	
B_8	B_2, B_4, B_8, B_{10}	B_1, B_2, B_7, B_8, B_9	B_2, B_8	
B_9	B_1, B_2, B_3, B_4, B_7, B_8, B_9, B_{10}	B_1, B_9	B_1, B_9	
B_{10}	B_2, B_4, B_7, B_{10}	B_1, B_2, B_3, B_7, B_8, B_9, B_{10}	B_2, B_{10}	

Table 10 Iteration 4

Barriers (B_i)	Reachability set R (B_i)	Antecedent set A (B_i)	Intersection set R (B_i) ∩ A (B_i)	Level
$\mathbf{B_1}$	B_1, B_2, B_3, B_7, B_8, B_9, B_{10}	B_1, B_9	B_1, B_9	
$\mathbf{B_2}$	B_2,B_8, B_{10}	B_1, B_2, B_7, B_8, B_9, B_{10}	B_2, B_8, B_{10}	**IV**
$\mathbf{B_3}$	B_3, B_7, B_{10}	B_1, B_3, B_9	B_3	
$\mathbf{B_7}$	B_2, B_7, B_8, B_{10}	B_1, B_3, B_7, B_9, B_{10}	B_7, B_{10}	
$\mathbf{B_8}$	B_2, B_8, B_{10}	B_1, B_2, B_7, B_8, B_9	B_2, B_8	
$\mathbf{B_9}$	B_1, B_2, B_3, B_7, B_8, B_9, B_{10}	B_1, B_9	B_1, B_9	
$\mathbf{B_{10}}$	B_2, B_7, B_{10}	B_1, B_2, B_3, B_7, B_8, B_9, B_{10}	B_2, B_{10}	

Table 11 Iteration 5

Barriers (B_i)	Reachability set R (B_i)	Antecedent set A (B_i)	Intersection set R (B_i) ∩ A (B_i)	Level
$\mathbf{B_1}$	B_1, B_3, B_7, B_9	B_1, B_9	B_1, B_9	
$\mathbf{B_3}$	B_3, B_7	B_1, B_3, B_9	B_3	
$\mathbf{B_7}$	B_7	B_1, B_3, B_7, B_9	B_7	**V**
$\mathbf{B_9}$	B_1, B_3, B_7, B_9	B_1, B_9	B_1, B_9	

and their interdependencies in terms of nodes and edges or in other words digraph is the visual representation of the elements (barriers) and their interdependence (Raj and Attri 2010). In this development, the top level enabler is positioned at the top of the digraph and second level enabler is placed at second position and so on, until the bottom level is placed at the lowest position in the digraph.

3.2.6 *ISM model*

Digraph is converted into an ISM model by replacing nodes of the barriers with statements as shown in Fig. 2. From the model developed with the identified barriers in this paper, it is clear that the most important barrier that hampers TPM implementation in Indian manufacturing industries is lack of top management commitment and support (B_1) and financial constraints (B_9), which comes as the base of ISM hierarchy.

3.2.7 *Classification of barriers*

Based on their drive power and dependence power, the barriers, in the present case, have been classified into four categories as follows:

Table 12 Iteration 6

Barriers (B_i)	Reachability set R (B_i)	Antecedent set A (B_i)	Intersection set R (B_i) ∩ A (B_i)	Level
B_1	B_1, B_3, B_9	B_1, B_9	B_1, B_9	
B_3	B_3	B_1, B_3, B_9	B_3	**VI**
B_9	B_1, B_3, B_9	B_1, B_9	B_1, B_9	

Table 13 Iteration 7

Barriers (B_i)	Reachability set R (B_i)	Antecedent set A (B_i)	Intersection set R (B_i) ∩ A (B_i)	Level
B_1	B_1, B_9	B_1, B_9	B_1, B_9	**VII**
B_9	B_1, B_9	B_1, B_9	B_1, B_9	**VII**

- *Autonomous barriers*: These barriers have weak drive power and weak dependence. They are relatively disconnected from the system, with which they have few links, which may be very strong.
- *Linkage barriers*: These have strong drive power as well as strong dependence. They are also unstable. Any action on them will have an effect on others and also a feedback effect on themselves.
- *Dependent barriers*: This category includes those barriers which have weak drive power but strong dependence power.
- *Independent barriers*: These have strong drive power but weak dependence power. It is generally observed that a barrier with a very strong drive power, called the 'key barrier', falls into the category of independent or linkage barriers.

This classification is similar to that by Mandal and Deshmukh (1994). The drive power and dependence power of barriers are shown in Table 14. Thereafter, the drive power-dependence power diagram is drawn as shown in Fig. 3. This figure has been divided into four clusters. First cluster includes 'autonomous barriers', second cluster includes 'dependent barriers', third cluster includes 'linkage barriers' and fourth cluster contains 'independent barriers'. In the further illustration of this Fig. 3, it is observed from Table 14 that barrier 9 (B_9) has drive power of 10 and dependence power of 2, hence in Fig. 3; it is positioned at a place which corresponds to drive power of 10 and dependence of 2, i.e. in the fourth cluster. Now, its position in the fourth cluster shows that it is an independent barrier. Similarly, all the barriers are positioned at places corresponding to their driving power and dependence power.

4 Discussion and conclusion

TPM is increasingly implemented by many organizations to improve their equipment efficiency and to obtain the competitive advantage in the global market in terms of cost and quality. The barriers hindering the successful implementation of TPM pose considerable challenges for manufacturing/maintenance managers. In this research, ISM approach has been applied to analyse the barriers to TPM implementation. It used literature review as the research basis and utilized experts to guide model building and analysis. The barriers were partitioned into a multilevel hierarchy to allow clear visualization of their relationships. The relationships hierarchy served as a useful reference for company strategic decision making. The driver-dependence diagram gives some valuable insights about the relative importance and interdependencies among the barriers. The important implications emerging from this study are as follows:

- The driver-dependence matrix (Fig. 3) shows that there is no autonomous barrier. Autonomous barrier is weak driver and dependent and does not have much influence on the system. The absence of autonomous barriers in this study indicates that all the considered barriers play

Table 14 Conical Matrix

Barriers (B_i)	B_6	B_5	B_4	B_2	B_8	B_{10}	B_7	B_3	B_1	B_9	Driver power
B_6	1	0	0	0	0	0	0	0	0	0	**1**
B_5	1	1	0	0	0	0	0	0	0	0	**2**
B_4	1	1	1	0	0	0	0	0	0	0	**3**
B_2	1	1	1	1	1	1	0	0	0	0	**6**
B_8	1	1	1	1	1	1	0	0	0	0	**6**
B_{10}	1	1	1	1	0	1	1	0	0	0	**6**
B_7	1	1	1	1	1	1	1	0	0	0	**7**
B_3	1	1	1	0	0	1	1	1	0	0	**6**
B_1	1	1	1	1	1	1	1	1	1	1	**10**
B_9	1	1	1	1	1	1	1	1	1	1	**10**
Dependence power	**10**	**9**	**8**	**6**	**5**	**7**	**5**	**3**	**2**	**2**	

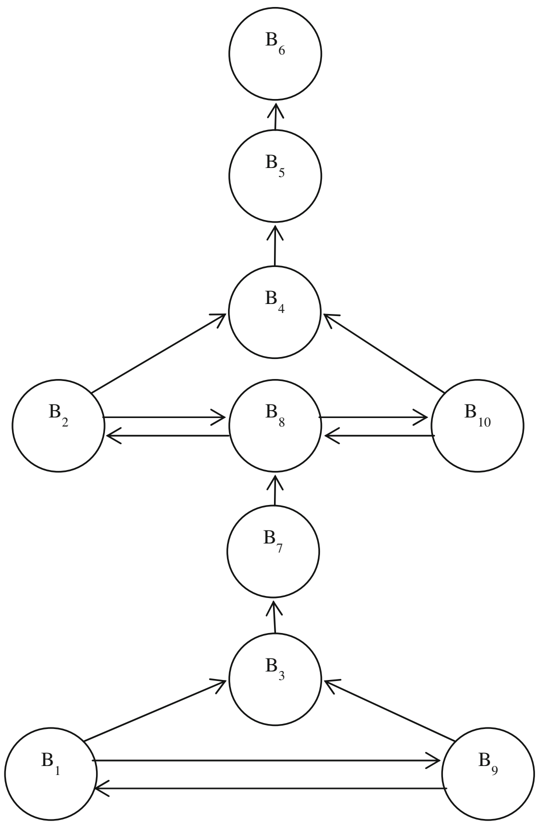

Fig. 1 Digraph showing levels of TPM barriers

a significant role in TPM implementation. The management, therefore, should pay attention to all the considered barriers.

- Dependent barriers are ‘Employee resistance’ (B_4), ‘Cultural resistance’ (B_5), and ‘Failure to allow sufficient time for the evolution’ (B_6). These barriers are weak drivers and strongly depend on the other barriers. The management should, therefore, accord high priority in tackling the root cause of these barriers. In this process, management should understand the dependence of these barriers on other level barriers in the ISM.
- Barriers ‘Lack of training and education’ (B_2) and ‘Lack of understanding and knowledge of TPM’ (B_{10}) are linkage barriers. They have strong driving power as well as high dependence. These are the ones that are influenced by lower-level barriers and in turn impact on other barriers in the model. For tackling these barriers, management should conduct orientation and training programs for all the employees.
- Barriers such as ‘Lack of top management commitment and support’ (B_1), ‘Lack of motivation’ (B_3), ‘Poor relation between production and maintenance department’ (B_7), ‘Lack of communication’ (B_8) and ‘Financial constraints’ (B_9) are independent barriers. These barriers have strong driving power and weak dependency on other barriers. They may be treated as the key barriers for the successful implementation of TPM. It can also be inferred that these barriers may be treated as the root cause of remaining barriers. To manage these barriers, a comprehensive strategic plan for TPM implementation should be formulated to achieve success.

Furthermore, from ISM model (Fig. 2) it is observed that the barriers, employee resistance, cultural resistance and failure to allow sufficient time for the evolution are among the top-level barriers. These are the ones which are being affected by the lower-level barriers. Lack of training and education, Lack of understanding and knowledge of TPM, Lack of communication, Lack of motivation and Poor relation between production and maintenance department are the middle-level barriers. Lack of top management commitment and support and Financial constraints have highest driving power and lowest dependence power, hence they appear at the bottom of ISM hierarchy.

The results of this study can help in strategic and tactical decisions for the organizations to tackle the barriers of TPM implementation. The main strategic decision relies on top management commitment for adoption of TPM. Once top management commits itself, it will help the company to tackle various barriers effectively. This is important as generally management focuses on one or two barriers, which it thinks as significant without taking into consideration those barriers that may be the real barriers to effective implementation of TPM. The hierarchy-based model further demarcates those barriers that are most important and need more attention and are the root cause of the problem. Lack of top management commitment and financial constraints which are at the bottom of the ISM-based model, are the most important barriers that inhibit strategic planning, hampering adoption of TPM. Thus, the ISM-based model proposed in this paper for identification of barriers of TPM can provide the managers and decision makers a more realistic representation of the problem in course of implementing Total Productive Maintenance.

Moreover, ISM model will vary according to the type of barriers present in a particular company. Large size companies may have different types of barriers than small size companies. For example, in large companies, management is in different levels i.e. top, middle, low but in small sized companies, management is not in such levels. In case of large companies barriers may exist in terms of lack of support and commitment from top, middle and low level managers whereas in small sized industry barrier will exist in term of lack of support and commitment from top management only as the management is not at different levels. Barriers such as union resistance will normally exist in large sized company only.

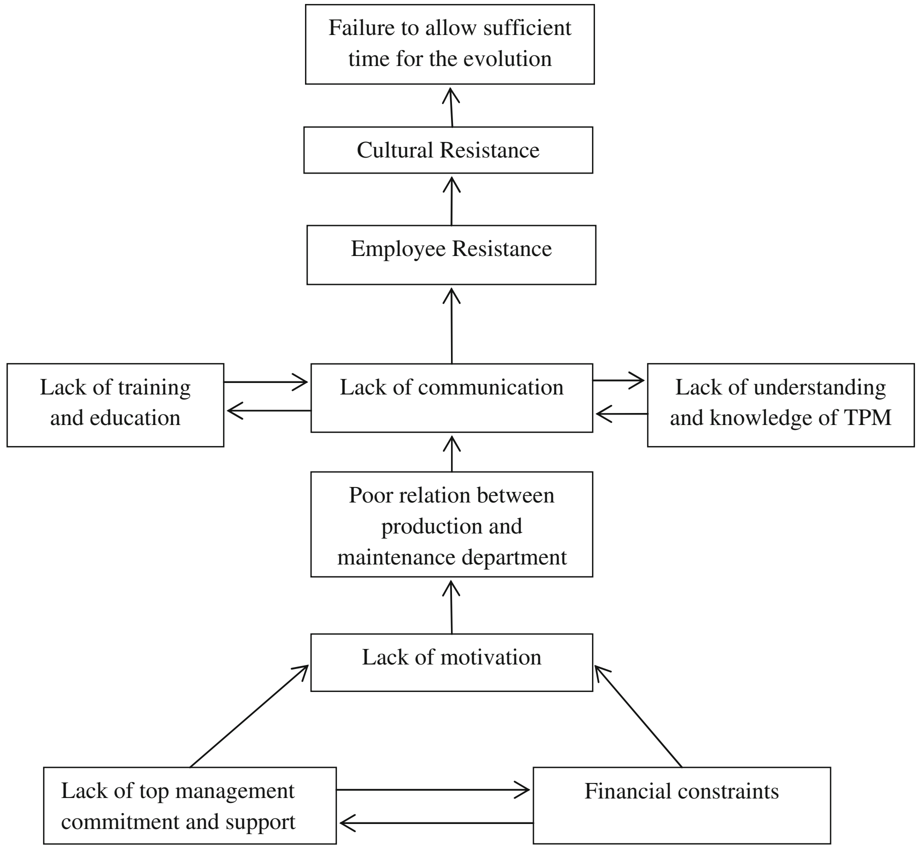

Fig. 2 Interpretive structural model showing levels of TPM Barriers

Fig. 3 Clusters of barriers in the implementation of TPM

Driving Power

10		B_1,B_9								
9										
8			**IV**					**III**		
7					B_7					
6			B_3		B_8	B_2	B_{10}			
5										
4										
3			**I**				**II**	B_4		
2									B_5	
1										B_6
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Dependence power

5 Limitations and scope of future work

In the present work, 10 barriers are identified for modelling the barriers of TPM. The expert's help have been sought to analyse driving and dependence power of the barriers of TPM. Here, the framework developed depends upon the survey and opinion of maintenance/manufacturing experts, which may has some element of bias. Through ISM, a relationship model among barriers of TPM has been developed. This model has not been statistically validated. The present model can be statistically tested with use of structural equation modelling (SEM) which has the ability to test the validity of such models. It is, therefore, very interesting to compare ISM and SEM techniques. SEM can statistically validate an already developed model but cannot prepare an initial model, whereas ISM has the capability to provide such an initial model. Hence due to the complementary nature of both the techniques, future research may be directed to test the validity of the proposed ISM model by using the SEM technique. LISREL software can also be used to examine the relationships derived from this model.

Appendix

See Tables 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14.

References

Adam EE, Corbett LM, Flores BE, Harrison NJ, Lee TS, Rho BH, Ribera J, Samson D, Westbrook R (1997) An international study of quality improvement approach and firm performance. Int J Oper Prod Manag 17(9):842–873

Agarwal A, Shankar R, Tiwari MK (2006) Modeling agility of supply chain. Ind Mark Manag 36:443–457

Ahuja IPS, Khamba JS (2008a) Strategies and success factors for overcoming challenges in TPM implementation in Indian manufacturing industry. J Qual Maint Eng 14(2):123–147

Ahuja IPS, Khamba JS (2008b) Total productive maintenance: literature review and directions. Int J Qual Reliab Manag 25(7):709–756

Ahuja IPS, Khamba JS (2008c) An evaluation of TPM initiatives in Indian industry for enhanced manufacturing performance. Int J Qual Reliab Manag 25(2):144–172

Ahuja IPS, Kumar P (2009) A case study of total productive maintenance implementation at precision tube mills. J Qual in Maint Eng 15(3):241–258

Attri R, Grover S, Dev N, Kumar D (2012) An ISM approach for modelling the enablers in the implementation of Total Productive Maintenance (TPM). Int J Syst Ass Eng Manage. doi:10.1007/s13198-012-0088-7

Baglee D (2008) Maintenance strategy development within SME's: The development of an integrated approach. International conference on maintenance IMC-2008

Bakerjan R (1994) Tool and manufacturing engineers handbook, vol 7, Continuous improvement, 4th edn. An ASME Publication, New York, Chap 15

Bamber CJ, Sharp JM, Hides M (1999) Factors affecting successful implementation of total productive maintenance: a UK manufacturing case study perspective. J Qual Maint Eng 5(3):162–181

Banwet DK, Arora R (1999) Enablers and inhibitors of e-commerce implementation in India-an interpretive structural modelling (ISM) approach. In: Kanda A et al (eds) Operations management for global economy challenges and prospects. Phoenix, New Delhi, pp 332–341

Barve A, Kanda A, Shankar R (2007) Analysis of interaction among the barriers of third party logistics. Int J Agile Syst Manag 2(1):109–129

Becker SW (1993) TQM does work: ten reasons why misguided efforts fail. Manag Rev 82(5):30–34

Blanchard BS (1997) An enhanced approach for implementing total productive maintenance in the manufacturing environment. J Qual Maint Eng 3(2):69–80

Bolanos R, Fontela E, Nenclares A, Paster P (2005) Using interpretive structural modeling in strategic decision making groups. Manag Dec 43(6):877–895

Borade AB and Bansod SV (2011) Interpretive structural modelling-based framework for VMI adoption in Indian industries. Int J Adv Manuf Technol. doi:10.1007/s00170-011-3458-4

Chan FTS, Lau HCW, Ip RWL, Chan HK, Kong S (2005) Implementation of total productive maintenance: a case study. Int J Prod Econ 95:71–94

Chidambaranathan S, Muralidharan C, Deshmukh SG (2009) Analyzing the interaction of critical factors of supplier development using interpretive structural modeling—an empirical study. Int J Adv Manuf Technol 43:1081–1093

Cigolini R, Turco F (1997) Total productive maintenance practices: a survey in Italy. J Qual Maint Eng 3:259–272

Co HC, Patuwo BE, Hu MY (1998) The human factor in advanced manufacturing technology adoption: an empirical analysis. Int J Oper Prod Manag 18(1):87–106

Cooke FL (2000) Implementing TPM in plant maintenance: some organizational barriers. Int J Qual Reliab Manag 17(9):1003–1016

Crawford KM, Blackstone JH Jr, Cox JF (1988) A study of JIT implementation and operating problems. Int J Prod Res 26(9):1561–1568

Davis R (1997) Making TPM a part of factory life. TPM Exp (Project EU 1190, sponsored by DTI), Findlay

Faisal MN, Banwat DK, Shankar R (2006) Supply chain risk mitigation: modeling the enablers. Buss Proc Manag J 12(4):532–552

Faisal MN, Banwat DK, Shankar R (2007a) Supply chain agility: analysing the enablers. Int J Agile Syst Manag 2(1):76–91

Faisal MN, Banwat DK, Shankar R (2007b) Information risks management in supply chain: an assessment and mitigation framework. J Enterp Info Manag 20(6):677–699

Fredendall LD, Patterson JW, Kennedy WJ, Griffin T (1997) Maintenance modeling, its strategic impact. J Manag Issue 9(4):440–453

Georgakopoulos A (2009) Teacher effectiveness examined as a system: interpretive modelling and facilitation sessions with U.S. and Japanese Students. Int Edu Stud 2(3):60–76

Hartmann EH (1992) Successfully installing TPM in a non-Japanese plant. TPM Press, Allison Park

Hartmann E (2000) Prescription for total TPM success. Maint Tech Mag. Available at http://www.mtonline.com/2000/april. Accessed 17 April 2011

Hasan MA, Shankar R, Sarkis J (2007) A study of barriers to agile manufacturing. Int J Agile Syst Manag 2(1):1–22

Huang JJ, Tzeng GH, Ong CS (2005) Multidimensional data in multidimensional scaling using the analytic network process. Pattern Recognit Lett 26(6):755–767

Ireland F, Dale BG (2001) A study of total productive maintenance implementation. J Qual Maint Eng 7(3):183–191

Jeszenka RJ (1993) Breaking through the resistance: achieving TQM in maintenance. Plant Eng 14:30–32

Jharkharia S, Shankar R (2004) IT-Enablement of supply chains: modelling the enablers. Int J Prod Perform Manag 53(8):700–712

Jharkharia S, Shankar R (2005) IT-Enablement of supply chains: understanding the barriers. J Enterp Info Mana 18(1):11–27

Joeng K-Y, Phillips DT (2001) Operational efficiency and effectiveness measurement. Int J Oper Prod Manag 21(11):1404–1416

Jostes RS, Helms MM (1994) Total productive maintenance and its link to total quality management. Work Stud 43(7):18–20

Kaizen K (1997) Focused equipment improvement for TPM Teams. Productivity Press, Portland

Kuo TC, Ma H, Huang SH, Hu AH, Ching CS (2010) Barrier analysis for product service system using interpretive structured model. Int J Adv Manuf Technol 49:407–417

Lawrence JJ (1999) Use mathematical modelling to give your TPM implementation effort an extra boost. J Qual Maint Eng 5(1): 62–69

Lee AHI, Lin C (2011) An integrated fuzzy QFD framework for new product development. Flex Serv Manuf. doi:10.1007/s10696-011-9076-5

Li WL, Humphreys P, Chan LY, Kumaraswamy M (2003) Predicting purchasing performance: the role of supplier development programs. J Mater Process Technol 138(1–3):243–249

Ljungberg O (1998) Measurement of overall equipment effectiveness as a basis for TPM activities. Int J Oper Prod Manag 18(5): 495–507

Maggard BN, Rhyne DM (1992) Total productive maintenance: a timely integration of production and maintenance. Prod Inv Manag J 33(4):6–10

Malhotra MK, Grover V (1998) An assessment of survey research in POM: from constructs to theory. J Oper Manag 16(4):407–425

Mandal A, Deshmukh SG (1994) Vendor selection using interpretive structural modeling (ISM). Int J Oper Prod Manag 14(6):52–59

McAdam R, Duffner AM (1996) Implementation of total productive maintenance in support of an established total quality programme. Total Qual Manag Bus Excell 7(6):613–630

McCarthy D (1997) To benefit, change the way you manage. TPM Exp (Proj EU 1190, Sponsored by DTI), Findlay

Moore R (1997) Combining TPM and reliability-focused maintenance. Plant Eng 51(6):88–90

Mora E (2002) The right ingredients for a successful TPM or lean implementation available at www.tpmonline.com. Accessed 30 March 2011

Nakajima S (1988) Total productive maintenance. Productivity Press, London

Pandey VC, Suresh G, Ravi S (2005) An interpretive structural modelimg of enabler variables for integration in supply chain management. Productivity 46(1):93–108

Park KS, Han SW (2001) TPM—Total Productive Maintenance: impact on competitiveness and a Framework for Successful Implementation. Hum Fact Ergo Manuf 11(4):321–338

Patterson JW, Kennedy WJ, Fredendall LD (1995) Total productive maintenance is not for this company. Prod Inv Manag J 36(2): 61–64

Patterson JW, Fredendall LD, Kennedy WJ, McGee A (1996) Adapting total productive maintenance to Asten. Inc Prod Inventory Manag J 37(4):32–36

Pramod VR, Banwet DK (2010) ISM for the inhibitors of service supply chain: a case study in a safety health environment and risk consultancy health centre. Int J Logic Eco Glob 2(2):151–175

Qureshi MN, Kumar D, Kumar P (2007) Modeling the logistics outsourcing relationships variables to enhance shippers productivity and competitiveness in logistics supply chain. Int J Prod Perform Manag 56(8):689–714

Raj T, Attri R (2010) Quantifying barriers to implementing total quality management (TQM). Euro J Ind Eng 4(3):308–335

Raj T, Attri R (2011) Identification and modelling of barriers in the implementation of TQM. Int J Product Qual Manag 28(2):153–179

Raj T, Shankar R, Suhaib M (2007) An ISM approach for modeling the enablers of flexible manufacturing system: The case for India. Int J Prod Res 1–30

Raj T, Attri R, Jain V (2012) Modelling the factors affecting flexibility in FMS. Int J Ind Syst Eng 11(4):350–374

Rajesh KS, Suresh KG, Deshmukh SG (2007) Interpretive structural modelling of factors for improving competitiveness of SMEs. Int J Prod Qual Manag 2(4):423–440

Ravi V, Shankar R (2005) Analysis of interactions among the barriers of reverse logistics. Techno Forecast Soc Change 72:1011–1029

Ravi V, Shankar R, Tiwari MK (2005) Productivity improvement of a computer hardware supply chain. Int J Prod Perform Meas 54(4):239–255

Rhyne DM (1990) Total plant performance advantages through total productive maintenance. Conference Proceedings APICS, Birmingham pp 683–686

Riis J, Luxhoj J, Thorsteinsson U (1997) A situational maintenance model. Int J Qual Reliab Manag 14(4):349–366

Rodrigues M, Hatakeyama K (2006) Analysis of the fall of TPM in companies. J Mater Process Technol 179:276–279

Sage AP (1977) Interpretive structural modeling: methodology for large scale systems. McGraw-Hill, New York

Sahney S (2008) Critical success factors in online retail-an application of quality function deployment and interpretive structural modelling approach. Int J Bus Inf 3(1):144–163

Saxena JP, Sushil, Vrat P (1990) The impact of indirect relationships in classification of variables: a MICMAC analysis for energy conservation. Syst Res 7(4):245–253

Saxena JP, Sushil, Vrat P (1992) Scenario building: a critical study of energy conservation in the Indian cement industry. Technol Forecast Soc Change 41(2):121–146

Sharma HD, Gupta AD, Sushil (1995) The objectives of waste management in India: a future inquiry. Technol Forecast Soc Change 48:285–309

Sharma RK, Kumar D, Kumar P (2006) Manufacturing excellence through TPM implementation: a practical analysis. Ind Manag Data Syst 106(2):256–280

Singh MD, Kant R (2008) Knowledge management barriers: an interpretive structural modelling approach. Int J Manag Sci Eng Manag 3(2):141–150

Singh MD, Shankar R, Narain R, Agarwal A (2003) An interpretive structural modeling of knowledge management in engineering industries. J Adv Manag Res 1(1):28–40

Singh RK, Garg SK, Deshmukh SG, Kumar M (2007) Modeling of critical success factors for implementation of AMTs. J Model Manag 2(3):232–250

Suzuki T (1992) New directions for TPM. Productivity Press, Cambridge

Swanson L (1997) An empirical study of the relationship between production technology and maintenance management. Int J Prod Econ 53(2):191–207

Talib F, Rahman Z, Qureshi MN (2011) Analysis of interaction among the barriers to total quality management implementation using interpretive structural modelling approach. Bench An Int J 18(4):563–587

Thakkar J, Deshmukh SG, Gupta AD, Shankar R (2007) Development of Score card: an integrated approach of ISM and ANP. Int J Prod Perform Manag 56(1):25–59

Thakkar J, Kanda A, Deshmukh SG (2008) Evaluation of buyer-supplier relationships using an integrated mathematical approach of interpretive structural modeling (ISM) and graph theoretic approach. J Manuf Technol Manag 19(1):92–124

Tsang AHC, Chan PK (2000) TPM Implementation in China: a case study. Int J Qual Reliab Manag 17(2):144–157

Turbide DA (1995) Japan's new advantage: total productive maintenance. Qual Prog 28(3):121–123

Wang F-K (2006) Evaluating the efficiency of implementing total productive maintenance. Total Qual Manag 17(5):655–667

Warfield JW (1974a) Developing interconnected matrices in structural modelling. IEEE Trans Syst Men Cybern 4(1):51–81

Warfield JW (1974b) Toward interpretation of complex structural modelling. IEEE Trans Syst Men Cybern 4(5):405–417

Yu J, Cooper H (1983) A quantitative review of research design effects on response rates to questionnaires. J Mark Res 36:36–44